Final Project Report

for the

SASKATCHEWAN CANOLA DEVELOPMENT COMMISSION (SASKCANOLA)

PROJECT TITLE: INVESTIGATING WIDER ROW SPACING IN NO-TILL CANOLA: IMPLICATIONS FOR WEED COMPETITION, RESPONSE TO NITROGEN FERTILIZER, AND SEEDING RATE RECOMMENDATIONS (2013-2016)

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Executive Summary:

A project was initiated in 2013 with funding from SaskCanola to evaluate the feasibility of growing canola at row spacing exceeding 25 cm while exploring potential implications for side-banded N, varying seeding rates and competitiveness with weeds. Three separate field trials were conducted where row spacing levels of 25, 30, 36, 41 and 61 cm were combined with varying side-banded urea rates, seeding rates and in-crop herbicide treatments. In general, canola plant populations declined as row spacing was increased, presumably due to higher intraspecific competition amongst seedlings. When averaged across all years and treatments, plant populations declined by 28%, from 85 to 62 plants m^{-2}, when row spacing was increased from 25 cm to 61 cm. Increasing row spacing also resulted in slight but significant delays in flowering and maturity. Broadly speaking, row spacing effects on seed yield were small and, in some cases, non-significant. Seed yields ranged from approximately 2800-3000 kg/ha with the highest yields at 61 cm followed by 25 cm, and row spacing effects on yield were always considerably less than environment or other management effects. Row spacing effects on seed size were small and somewhat inconsistent but there was an overall increase in percent green seed with increasing row spacing in 1/4 years. Focussing on potential implications for side-banded N recommendations, there was a significant reduction in plant densities with increasing side-banded N in all three years. While this occurred at all row spacing levels, there was evidence that plant populations started to decline at lower N rates at the widest row spacing compared to the other levels. Despite the effects on emergence, canola responded well to side-banded N with sequentially increasing yields right up to 150 kg N ha^{-1} in all three years and maximum yield increases of 40%, 370%, 127% and 139% in 2013, 2014, 2015 and 2016, respectively. Even canola at 61 cm spacing benefited from the highest N rates, despite the observed stand reductions. Overall, the results of this study suggest that N requirements of canola are likely similar regardless of row spacing; however, extremely high rates of side-banded N combined with wide row spacing can increase risk of seedling injury. Another key objective was to investigate potential implications of wider row spacing on seeding rate recommendations. Depending on the seeding rate, actual mean plant densities ranged from 30-91 plants m^{-2}; however, interactions with row spacing were detected. The interactions appeared to be due to the negative effect of wider row spacing on emergence being less prominent at the lowest seeding rate and also diminishing benefits to the highest seeding rates when combined with the widest row spacing. Despite the higher mortality, reasonably high seeding rates were required to ensure adequate plant populations at the widest row spacing – only the 120 seeds m^{-2} rate resulted in established populations greater than 40 plants m^{-2} in all four years. These results suggest that seeding rates should not likely be reduced below typically recommended rates as row spacing is increased; however, at the same time, there was little benefit to using seeding rates exceeding 90 seeds m^{-2} when planting canola at 61 cm row spacing. Canola was grown at each row spacing level with and without herbicide to assess potential impacts on crop competition with weeds. While there was a consistent overall linear decline in above-ground crop biomass with increasing row spacing in all three years (28% on average), weed biomass only ever increased with row spacing in the absence of in-crop herbicide and this did not occur in all years. A single in-crop application of glufosinate ammonium kept weed competition acceptably low at all row spacing levels, with reductions of weed biomass ranging from 98-99.5%. It is generally accepted that the ability of crops to compete with weeds may be compromised at wide row spacing; however, this study did not show any practical, short-term effects of row spacing in this regard that could not be managed with well-timed herbicide applications. Failure to control weeds resulted in an overall average yield losses of 21% on average with similar yield loss observed regardless of row spacing. In conclusion, canola is relatively insensitive to increasing row spacing and there are many factors to consider in determining the optimal row spacing for individual farms. Pros and cons exist for both narrow and wide row spacing – this is a complex issue that can affect entire production systems and, therefore, there is no likely single optimal row spacing for all farm operations.

Background / Introduction:

There is a relatively rich history of row spacing research for canola (*Brassica napus*) with an appreciable number of studies completed in western Canada. Early work in central Alberta found that Argentine canola yields were highest at 15 cm row spacing and tended to decline as spacing was increased to 61 cm (Kondra 1975). Averaged across four sites (and three seeding rates), the observed yields were 2988, 2441, 2166 and 1704 kg ha^{-1} for 15, 23, 31 and 61 cm row spacing, respectively. Later studies in northwest Alberta (Beaverlodge 1982-1983) focussed on narrower spacing (7.5-23 cm) and again showed significantly higher yields with 7.5 cm spacing than for either 15 or 23 cm, although yields for the two wider row spacing levels were comparable (Christensen and Drabble 1984). Similarly, Morrison et al. (1990) observed an 18% yield reduction over a two year period in Manitoba when row spacing was increased from 15 to 30 cm. Research in the 1990's in central Saskatchewan showed similar yields for 15-31 cm row spacing, but further increases to 41 cm resulted in a yield reduction 78% of the time (PAMI 1995). Field trials in Vegreville, Alberta showed no yield difference for Polish canola grown at 10 versus 20 cm row spacing (O'Donovan 1994). Under irrigation at Outlook, row spacing from 8-20 cm showed no impact on canola seed yield, even though plant populations tended to decline at wider row spacing (Irvine 1992). Again under irrigation, Irvine and Duncan (1993) found that, with the exception of lower yields at the widest (64 cm) spacing at one of three years, canola yields were generally not affected by row spacing ranging from 8-64 cm. Under dryland conditions in the Brown soil zone of Saskatchewan, Hu et al. (2015) saw mixed results with canola grown at either 30 cm or 60 cm row spacing. There was little effect on yield but higher soil moisture (30 cm depth) with 60 cm spacing at Swift Current compared to higher yields with 30 cm spacing at Central Butte and no impact on soil moisture.

While the conclusions of the past research discussed thus far are varied, one factor that each of these studies shared in common was that fertilizer was always broadcast and incorporated. This would potentially bias results towards narrow row spacing in two ways which, with current equipment, no longer apply on most modern commercial farms. First, incorporating the fertilizer prior to seeding would have equalized soil disturbance across the treatments and eliminated potential moisture conservation benefits to wider row spacing when seeding directly into standing stubble. This is supported by the fact that yields under irrigation appeared to be less sensitive to changes in row spacing than for dryland canola. Second, the fact that N was broadcast rather than banded would result in a larger proportion of the fertilizer being applied farther away from the canola plants as row spacing increased. While NO_3-N is highly mobile, NH_3 movement under dry, cool conditions can be slow and managing N in this manner could potentially favour the narrower row spacing in some environments. When N fertilizer was side-banded under no-till management, grain yields were not affected going from 25 to 38 cm row spacing in Manitoba and there was actually a slight tendency for higher yields at 38 cm (Xie et al. 1998). Row spacing research with canola where N was side-banded has been limited with very few studies found in the literature. With side-banded N, provided that the plants can adequately compensate for the extra canopy space, N-use efficiency could conceivably be increased with wider row spacing because the fertilizer becomes more concentrated; thereby less susceptible to immobilization and available to weeds, but still accessible to the canola. On the other hand, banded fertilizer becomes more concentrated as row spacing increases which could also increase the potential for seedling injury under some soil conditions or in cases where seed-fertilizer separation is inadequate.

Another factor that may be affected by row spacing is seedling mortality and, as a result, optimal seeding rates. Considering the high price of canola seed inputs, growers may be inclined to reduce seeding rates when moving towards wider row spacing in order to compensate for the higher plant numbers within individual rows at any given seeding rate. Kondra (1975) rarely observed significant seeding rate by row spacing interactions, indicating that similar rates should be used regardless of row spacing. Evaluating rates of 7 or 14 kg ha^{-1} and row spacing levels of 7.5, 15 or 23 cm, Christensen and Drabble (1984) found no effect of seeding rates or interactions with row spacing; however, interactions in this case may have been unlikely considering the relatively high rates that were evaluated. In Manitoba, Morrison et al.

(1994) detected a row spacing by seeding rate interaction at one of three sites; however, the specific nature of this interaction was not discussed. At any given seeding rate, overall declines in plant populations with increasing row spacing are frequently detected and considered to be a result of increased seedling competition within the rows. It is conceivable that this effect would be less prominent at lower seeding rates, resulting in lower overall mortality; hence the interest from farmers in using lower seeding rates at wide row-spacing. While recent research at Indian Head, Scott, Swift Current and Melfort, Saskatchewan showed that modern hybrids compensate well at low plant populations, grain quality and maturity are adversely affected when plant densities fall below 20 plants m^{-2} (Kirk et al. 2013).

From a weed management perspective, it is generally quite well accepted that the ability of crops to compete with weeds declines as row spacing is increased, especially early in the growing season. However, O'Donovan (1994) did not observe any effect of canola row spacing on tartary buckwheat densities or dry mass, even though both of these tended to increase with decreasing seeding rates. Nonetheless it is possible that, at least in certain cases, some of the early documented cases of negative effects of wider row spacing on canola yield may have been attributable to increased weed pressure. While weed control in canola was a major challenge from 1970 through the 1990's, with herbicide tolerant hybrids, canola producers today are much better equipped to deal with weed competition than they were 20 years ago. Furthermore, with direct-seeding equipment, there is less soil disturbance with wider row spacing which could result in reduced germination of weed seeds between crops rows, thereby negating the potential negative impacts of wider spacing to some extent. That being said, crop competition is an important component to integrated weed management and there are risks associated with relying too heavily on individual technologies such as herbicides. Therefore, if canola at wider row spacing takes substantially longer to achieve canopy closure control of certain weed species may negatively impacted and the risk of herbicide resistance developing may be increased.

With the combined improvements in genetics, seeding/fertilizing equipment and weed control options over the past twenty years, revisiting the topic of row spacing in canola is well justified. To be most relevant, new work on row spacing should be conducted under zero- or minimum-tillage continuous cropping systems and utilize seeding equipment with side-banding capabilities along with modern, herbicide tolerant hybrids. While it is, at best, questionable whether lower seed or N fertilizer rates should be recommended at wider row spacing, with large drills producers are be able to increase the timeliness of seeding and reduce fuel use and tractor hours on a per acre basis. Drills with wider row spacing utilize fewer openers at any given width and, therefore, significantly reduce the draft and subsequent horsepower requirements for seeding. Furthermore, wider row spacing makes it easier to seed through heavy residues in the spring and, combined with RTK Auto-Steer systems, would increase the ease of seeding between stubble rows and allow growers in semi-arid environments to better capture to the benefits of taller stubble. A multi-year study was initiated at Indian Head to evaluate the impacts of wider row spacing on canola performance and investigate implications for seeding rate, N fertilizer and weed management recommendations.

Objectives:

The specific objectives of the study were to:

1) Evaluate the overall agronomic feasibility of growing canola at 25-61 cm row spacing

2) Evaluate the potential for seedling damage and/or improved NUE when wider row spacing is combined with varying rates of side-banded nitrogen

3) Investigate potential interactions between row spacing and seeding rate to determine whether lower seeding rates can be recommended for canola grown at wider row spacing

4) Evaluate the implications of wide row spacing on the ability of canola to compete with weeds under both normal (sprayed) and weedy conditions.

Materials & Methods:

Three separate field trials were conducted over the period from 2013-16 near Indian Head, Saskatchewan (50˚33'N 103˚39'W). While the trial was initiated in 2012, the data from the first season was considered unreliable and was excluded because of a combination of severe sclerotinia pressure, inadequately controlled plot edge effects and extensive wind damage. Indian Head is located in the thin Black soil zone and the soil is classified as an Indian Head heavy clay (Ih3) which is a mainly calcareous, black soil formed in clayey lacustrine materials and with clay and silty clay surface materials. The average (1981-2010) annual precipitation is 428 mm and the mean frost free period is 113 days (Environment Canada 2017). The specific fields where the trials were located have been managed in long-term (> 10 yr) no-till, continuous cropping systems and the previous crop was always a cereal with a minimum of three years since the most recent canola crop. The trials were established adjacent to each other in all years and all aspects were managed similarly wherever possible. The treatments for each experiment were arranged in a split plot design with row spacing treatments as the main plots and four replicates. The specific treatments evaluated with each of the three field experiments were:

<u>Experiment #1: Row Spacing by Nitrogen Rates (20 treatments)</u>

A. *Row Spacing (main plots)*	B. *N Fertilizer Rate (sub-plots)*
1) 25 cm (10")	1) 6 kg ha^{-1} N (from 11-52-0)
2) 30 cm (12")	2) 50 kg ha^{-1} N
3) 36 cm (14")	3) 100 kg ha^{-1} N
4) 41 cm (16")	4) 150 kg ha^{-1} N
5) 61 cm (24")	

<u>Experiment #2: Row Spacing by Seeding Rate (20 treatments)</u>

A. *Row Spacing (main plots)*	B. *Seeding rate (sub-plots)*
1) 25 cm (10")	1) 30 seeds m^{-2} (~1.5 kg ha^{-1})
2) 30 cm (12")	2) 60 seeds m^{-2} (~3.0 kg ha^{-1})
3) 36 cm (14")	3) 90 seeds m^{-2} (~4.5 kg ha^{-1})
4) 41 cm (16")	4) 120 seeds m^{-2} (~6.0 kg ha^{-1})
5) 61 cm (24")	

<u>Experiment #3: Row Spacing by Herbicide (10 treatments)</u>

A. *Row Spacing (main plots)*	B. *Herbicide Treatment (sub-plots)*
1) 25 cm (10")	1) No in-crop herbicide
2) 30 cm (12")	2) In-crop herbicide applied
3) 36 cm (14")	
4) 41 cm (16")	
5) 61 cm (24")	

For all trials, a glufosinate ammonium tolerant (Liberty-Link™) canola hybrid was seeded using a SeedMaster plot drill with eight openers which can be repositioned along the frame to achieve row spacing treatments of 25, 30, 36 and 41 cm. The 61.0 cm row spacing was achieved by configuring the drill for 30 cm row spacing, lifting every second opener and subsequently diverting all seed/fertilizer away from the unutilized openers. Therefore, each plot on 61 cm spacing only consisted of four crop rows. Except in experiment #2 where seeding rate was a factor, canola was seeded at a target rate of 115-120 seeds m^{-2}. Prior to seeding in all years, potassium sulphate was broadcast across the entire site at a uniform rate to supply 18-20 kg S ha^{-1}. Urea and monoammonium phosphate were side-banded at rates considered sufficient to ensure that nutrients were not limited, unless dictated otherwise by protocol (i.e. Experiment #1). Weeds were controlled using registered herbicides at label recommended rates and included pre-emergent glyphosate and in-crop applications of glufosinate ammonium plus clethodim. The exception was in Experiment 3 where the sub-plots were herbicide treatments and therefore half of the plots did not receive any in-crop herbicides. When the canola had finished flowering and pods/seeds had started to change colour, the outside rows from all plots except the 61 cm row spacing treatments were removed by hand. The purpose of this was to manage edge effects caused by the variable spacing between the outer rows of adjacent plots. Each plot was straight-combined with a Wintersteiger plot combine when the plants were mature and dry enough to harvest. Separate harvest dates were utilized when considered necessary and practical to do so in order to accommodate treatment effects on maturity. Two passes of the plot combine were required to harvest the six remaining rows in the 30-61 cm row spacing treatments; however the 25 cm treatments were harvested in a single pass in 2013. From 2014 onwards, harvest methods were revised so that all plots were combined in two separate passes, regardless of the row spacing treatment. Selected agronomic information and dates of all relevant field operations and data collection activities are provided for Experiments 1, 2 and 3 in Tables A-1, B-1 and C-1, respectively.

The specific response data collected in each field trial varied depending on the objectives of the experiment. Growing season weather parameters were estimated using data from the nearest Environment Canada station (Environment Canada 2016) which was located within 5 km of the site in all cases. Plant densities were measured in experiments #1 and #2 by counting the number of plants emerged in 2-4 separate 1 m lengths of crop row per plot. Notes on days to the end of flowering (95% of plants finished flowering) and to maturity (60% seed color change) were completed for each plot in experiments #1 and #2. In experiment #3, crop and weed biomass yields were measured at approximately 30-40% seed colour change by hand harvesting 2 x 0.5 m lengths of crop row along with any weeds present between the harvested row and each of the adjacent crop rows. Both the crop and weed biomass samples were air dried, weighed and converted to kg dry matter ha^{-1}. Canola seed yields are expressed in kg ha^{-1} and are corrected for dockage and to a uniform moisture content of 10%. Seed weights were determined for each plot in experiments #1 and #2 by weighing and mechanically counting approximately 5-7.5 g of cleaned seed (>1000 seeds) and calculating g 1000 $seeds^{-1}$ for each plot. Percent green seed was determined for each plot in experiment #2 by crushing 500 seeds and counting the number of distinctly green seeds. For Experiment #1, grain N concentrations were determined for each plot using a Kjeldahl digest and these data were used to calculate total N exports in the harvested grain.

For all experiments, data from each year was combined prior and analyzed using a Mixed model where the effects of year (Y), row spacing (RS) and either N rate (NR), seeding rate (SR) or herbicide treatment (HERB) along with their interactions were considered fixed. Replicate effects were always considered random. However, due to missing treatments in the RS × NR experiment in 2013, treatments means within each year were separated based on results from individual site analyses. Individual treatment means were separated using Fisher's protected LSD test. Orthogonal contrasts were used to test for linear and quadratic responses to row spacing, N fertilizer rate and seeding rate, depending on the experiment. Additional orthogonal contrasts were used to describe the response to N and seed rates at each row spacing level, and vice versa. All treatment effects, differences between means and orthogonal contrast results were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION:

Weather conditions

Mean monthly temperatures and total precipitation amounts for the 2013-16 growing seasons (May-August) are provided in Table 1. Over the 4-month growing season, temperatures were slightly below the long-term average the first three years, particularly in 2014 which was nearly a full degree Celsius below normal on average and especially cool in June and July. The 2016 season was considerably warmer than average, particularly in May and June. The timing and quantity of precipitation varied widely but, in general, canola yields were not limited by lack of moisture during this four year period. In 2014, excess precipitation in June resulted in variable damage due to flooding and certain response data from affected plots was removed prior to any statistical analyses. In 2015, the season was initially dry with no significant precipitation until late in June; however, soil moisture carried the crop well to this point and conditions improved dramatically for the remainder of the season. Both 2013 and 2016 were considered near optimal with adequate but generally not excessive moisture throughout the season and no major environmental challenges.

Table 1. Mean monthly temperatures and precipitation amounts for the 2013-16 growing seasons at Indian Head, Saskatchewan along with long-term averages (1981-2010[Z]).

Year	May	June	July	August	Avg. / Total
	---------- Mean Temperature (°C) ----------				
2013	11.9	15.3	16.3	17.1	15.2
2014	10.2	14.4	17.3	17.4	14.8
2015	10.3	16.2	18.1	17.0	15.4
2016	14.0	17.5	18.5	17.2	16.8
Long-term	10.8	15.8	18.2	17.4	15.6
	---------- Precipitation (mm) ----------				
2013	17	104	50	6	160
2014	36	199	8	142	385
2015	16	38	95	59	208
2016	73	63	113	30	279
Long-term	51.8	77.4	63.8	51.2	244

[Z] Environment Canada 2017

Soil Characteristics

Again, the soil at all sites was classified as an Indian Head Heavy Clay, a fine textured calcareous soil – soil test results for each of the four years are presented in Table 2. Residual NO_3-N for the 60 cm depth ranged from 17-43 kg ha^{-1}; therefore the probability for an N response in Experiment 1 was always highly probable. Soil pH was typical for the region ranging from 7.7-8.1 and organic matter ranged from 3.1-4.3%. Phosphorus was consistently low while K levels were high and residual S was 16-23 kg ha^{-1}; however, these nutrients were applied at rates intended to be non-limiting in all trials.

Table 2. Basic soil test results for canola row spacing evaluation sites at Indian Head (2013-16).

Variable	Year			
	2013	2014	2015	2016
pH (0-15 cm)	7.7	7.9	8.1	7.8
% Organic Matter (0-15 cm)	3.6	3.3	3.1	4.3
kg NO_3-N ha^{-1} (0-60 cm)	34	17	43	16
ppm Olsen-P (0-15 cm)	9	5	7	6
ppm K (0-15 cm)	>375	>340	>340	555
kg SO_4-S ha^{-1} (0-60 cm)	18	19	16	23

Experiment #1: Row Spacing × Nitrogen Fertilizer Rates

Experiment #1 focussed on potential interactions between row spacing and side-banded N fertilizer rate. One of the concerns when banding high rates of N at wide row spacing is that the increasingly concentrated fertilizer bands will potentially have a negative impact on emergence and adequate seed-fertilizer separate cannot be maintained. Effects on emergence, or plant density, are presented in Tables 3, 4 and A-2. Results from the combined analyses (Table 3) showed that emergence was affected by both row spacing (RS) and nitrogen rate (NR) with a significant RS × NR interaction (P = 0.02) and a significant year (Y)×RS interaction (P < 0.01) but no Y × NR interaction (P = 0.40). This indicated that while both main factors were important, the responses to NR varied with RS and the response to RS varied from year-to-year; however, the NR response was consistent across years. Overall, plant populations declined with both increasing RS (23% from 25-61 cm) and increasing NR (21% from 6-150 kg N ha^{-1}); however the RS×NR interaction showed that lower rates of N could impact emergence at very wide RS levels. At 25-41 cm RS, reduced emergence was not observed until rates of 100 kg N ha^{-1} or higher were applied, while at 61 cm RS plant densities were significantly reduced with as little as 50 kg N ha^{-1}. Despite the Y×RS interaction, plant densities were affected by RS in all years; however, in some years, reductions occurred with increases from the lowest RS levels (i.e. 2015) while in others differences in plant density were not significant until RS approached the widest levels evaluated (i.e. 2016). That said, in all individual years the RS response for plant density was always linear (P < 0.01) and never quadratic (P – 0.25-0.98) indicating that it was occurring to some extent at all absolute RS levels (Table 4). Despite the significant treatment effects, plant densities never fell below 40 established plants m^{-2}, regardless of year and even with the combination of 150 kg N ha^{-1} at 61 cm RS (Table A-2).

Table 3. Tests of fixed effects for row spacing and nitrogen rate effects on canola plant density (plants/m^2) at Indian Head (2013-16).

Variable	**Year**				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	------------ Pr > *F* ------------				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)[Y]	**< 0.001**	**0.046**	**< 0.001**	**0.002**	**< 0.001**
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × NR	0.095	**0.016**	0.106	0.880	**0.017**
Y × RS	–	–	–	–	**< 0.001**
Y × NR	–	–	–	–	0.404
Y × RS × NR	–	–	–	–	0.276

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 4. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on canola plant density at Indian Head (2013-16).

Treatment			**Plant Density**		
	2013 [Z]	2014	2015	2016	Mean
Row Spacing			plants/m^2		
25 cm	78 ab	82 a	115 a	120 a	99 A
30 cm	82 a	83 a	106 b	111 a	96 AB
36 cm	72 b	79 ab	103 b	113 a	92 B
41 cm [Z]	—	78 ab	105 b	112 a	92 B
61 cm	60 c	73 b	79 c	93 b	76 C
S.E.M.	2.5	2.2	3.6	4.5	1.6
Nitrogen Rate					
6 kg N ha^{-1}	83 a	82 a	109 a	118 a	98.0 A
50 kg N ha^{-1}	77 a	83 a	109 a	114 ab	95.9 A
100 kg N ha^{-1}	70 b	78 a	100 b	107 bc	89.0 B
150 kg N ha^{-1}	64 b	72 b	87 c	100 c	80.6 C
S.E.M.	2.5	2.0	3.2	3.9	1.47
Orthogonal Contrasts			*p-values*		
Spacing – linear	**< 0.001**	**0.004**	**< 0.001**	**< 0.001**	**< 0.001**
Spacing – quadratic	0.832	0.983	0.475	0.516	0.253
N rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
N rate – quadratic	0.991	0.094	**0.016**	0.516	**0.015**

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Days to both the start and end of flowering were measured in all years; however, most of the variation was observed at the end of flowering and therefore these measurements were used to calculate the total number of days in bloom. Results for RS and NR effects on canola flowering period are presented in Tables 5, 6 and A-3. The length of time for which canola flowered was affected by RS and NR with significant RS×NR, Y×RS and Y×NR interactions (Table 5; $P < 0.01$-0.02). Overall, the length of flowering was extended by 1.1 days (4%) going from 25-61 cm RS while increasing NR from 6-150 kg N ha^{-1} increased the flowering period by 2.5 days or 9% (Table 5). The RS × NR interaction appeared to be due to the RS effects being more prominent at higher NR levels and to flowering being significantly extended at lower NR at the widest RS relative to the narrowest. At 61 cm RS and 150 kg N ha^{-1}, flowering was extended by an average of approximately 4 days relative to 10 cm RS combined with 6 kg N ha^{-1}. The Y×RS interaction was due to the increase in flowering period with RS occurring in all years except 2014. The Y×NR interaction was due the response being linear in all years except 2016 where differences amongst treatments were small and slightly longer flowering periods were observed with both the lowest and highest NR relative to the intermediate rates. Somewhat of a shift in flowering was noted whereby flowering often initiated slightly earlier at low NR (data not shown).

Table 5. Tests of fixed effects for row spacing and nitrogen rate effects on canola flowering period (days in bloom) at Indian Head (2013-16).

Variable	Year				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	------ Pr > *F* ------				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)[Y]	**< 0.001**	0.103	**< 0.001**	**0.025**	**< 0.001**
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × NR	**0.009**	0.333	0.275	**0.001**	**0.018**
Y × RS	–	–	–	–	**< 0.001**
Y × NR	–	–	–	–	**< 0.001**
Y × RS × NR	–	–	–	–	0.091

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 6. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on canola flowering period at Indian Head (2013-16).

Treatment	Flowering Period				
	2013[Z]	2014	2015	2016	Mean
Row Spacing	------ days in bloom ------				
25 cm	34.7 b	27.7 a	24.0 b	24.1 b	27.6 B
30 cm	34.4 b	27.0 b	24.2 b	24.2 b	27.5 B
36 cm	34.5 b	27.0 b	24.2 b	24.2 b	27.5 B
41 cm[Z]	–	27.5 a	24.4 b	24.2 b	27.8 B
61 cm	36.4 a	28.1	25.5 a	24.6 a	28.7 A
S.E.M.	------ 0.39 ------				0.20
Nitrogen Rate					
6 kg N ha^{-1}	33.3 d	24.9 d	23.6 c	24.6 a	26.7 D
50 kg N ha^{-1}	33.9 c	26.6 c	24.0 c	24.0 b	27.1 C
100 kg N ha^{-1}	35.8 b	28.6 b	24.7 b	24.1 b	28.2 B
150 kg N ha^{-1}	37.0 a	29.8 a	25.6 a	24.5 a	29.2 A
S.E.M.	0.38				0.19
Orthogonal Contrasts	------ *p-values* ------				
Spacing – linear	**< 0.001**	0.066	**< 0.001**	**< 0.001**	**< 0.001**
Spacing – quadratic	**0.006**	0.100	**0.022**	0.401	**0.036**
N rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	0.652	**< 0.001**
N rate – quadratic	**< 0.001**	0.289	**0.002**	**< 0.001**	**0.045**

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Maturity was defined as days from planting to 60% seed colour change and was affected by RS and NR with highly significant Y×RS, Y×NR and Y×RS×NR interactions (Table 7; $P < 0.01$). Overall, increasing RS from 25-61 cm delayed maturity by 1.5 days, approximately 2%, while increasing NR from 6-150 kg N ha^{-1} delayed maturity by approximately 5 days, or 5% (Table 8). Despite the Y×RS interaction, RS effects were quite consistent for individual years with significant linear ($P < 0.01$) but not quadratic (P = 0.11-0.95) orthogonal contrasts in all years. For the Y×NR interaction, the NR effect on maturity was strictly linear in three of four years with significant gains in maturity of every NR level increase but quadratic in 2014 with no difference in maturity observed for 6-50 kg N ha^{-1}. Three-way interactions (i.e. Y×RS×NR) can be complex to interpret; however, individual site analyses results revealed that the RS×NR interaction for maturity was significant in 2013/2015 but not 2014/2016 (Tables 7 and A-4).

Table 7. Tests of fixed effects for row spacing and nitrogen rate effects on canola maturity (days from planting) at Indian Head (2013-16).

Variable	Year				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	------------------ Pr > *F* ------------------				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)[Y]	**< 0.001**	**0.040**	**< 0.001**	**0.001**	**< 0.001**
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × NR	**0.021**	0.800	**< 0.001**	0.520	0.576
Y × RS	–	–	–	–	**< 0.001**
Y × NR	–	–	–	–	**< 0.001**
Y × RS × NR	–	–	–	–	**0.021**

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 8. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen

rate effects on canola maturity at Indian Head (2013-16).

Treatment	**Maturity**				
	2013 [Z]	2014	2015	2016	Mean
Row Spacing	days from planting				
25 cm	93.7 c	99.8 b	95.6 d	93.1 c	95.5 D
30 cm	93.8 c	99.9 b	95.7 cd	93.3 c	95.6 CD
36 cm	94.3 b	99.9 b	96.0 c	93.3 bc	95.9 C
41 cm [Z]	—	100.2 ab	96.4 b	93.8 b	96.2 B
61 cm	95.4 a	100.5 a	97.9 a	94.3 a	97.0 A
S.E.M.	0.15				0.07
Nitrogen Rate					
6 kg N ha^{-1}	91.8 d	98.5 c	93.5 d	91.6 d	93.8 D
50 kg N ha^{-1}	93.1 c	98.7 c	95.3 c	92.8 c	95.0 C
100 kg N ha^{-1}	95.4 b	100.6 b	97.4 b	94.3 b	96.9 B
150 kg N ha^{-1}	97.0 a	102.4 a	99.1 a	95.5 a	98.5 A
S.E.M.	0.14				0.07
Orthogonal Contrasts	*p-values*				
Spacing – linear	**< 0.001**	**0.003**	**< 0.001**	**< 0.001**	**< 0.001**
Spacing – quadratic	0.954	0.931	0.108	0.940	0.918
N rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
N rate – quadratic	0.212	**< 0.001**	0.250	1.000	**0.004**

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Results for treatment effects on canola seed yield are presented in Tables 9, 10 and A-5. Both RS and NR affected yield when averaged across sites and RS×NR, Y×RS and Y×NR interactions were all highly significant ($P < 0.01$). Averaged across years and NR, seed yields were highest at 61 cm, intermediate at 25-30 cm and slightly but significantly lower at 36-41 cm RS (Table 9). The response to N was strong with significant yield increases detected at each incremental NR increase and a maximum yield increase of 1929 kg ha^{-1}, or 123%, over the control where only 6 kg N ha^{-1} was provided with the monoammonium phosphate. While the observed higher yields at the widest RS were unexpected, the higher yields at 61 cm may be partly attributable to edge effects that favoured these treatments, but interaction also showed that canola as low NR (6-50 kg N ha^{-1}) in particular fared better at wider row spacing (Table 10). At high NR levels, the tendency was for the highest yields at narrower RS. At the more intermediate 100 kg N ha^{-1} NR level, yields were numerically and statistically similar regardless of RS. The Y×RS interaction reflected the lack of any RS effect in 2014 but responses that were consistent with the main effects in the remaining years. The NR effects were generally quite consistent across years; however the significant interaction was likely due to differences in the overall slope of the response. Yields at the highest NR level were relatively consistent at 3395-3626 kg ha^{-1} while, at 6 kg N ha^{-1}, yields ranged widely from 730-2597 kg ha^{-1} when averaged across RS levels.

Table 9. Tests of fixed effects for row spacing and nitrogen rate effects on canola seed yield (kg ha^{-1}) at Indian Head (2013-16).

Variable	Year				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	Pr > *F*				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)[Y]	**0.024**	0.195	**0.009**	**< 0.001**	**< 0.001**
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × NR	**< 0.001**	0.391	**< 0.001**	**< 0.001**	**< 0.001**
Y × RS	–	–	–	–	**< 0.001**
Y × NR	–	–	–	–	**< 0.001**
Y × RS × NR	–	–	–	–	0.107

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 10. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on canola seed yield at Indian Head (2013-16).

Treatment	Seed Yield				
	2013[Z]	2014	2015	2016	Mean
Row Spacing	kg ha^{-1}				
25 cm	3291 ab	2078 a	2473 b	2770 a	2666 B
30 cm	3145 bc	2190 a	2555 b	2612 b	2635 BC
36 cm	3083 c	2081 a	2522 b	2493 c	2550 C
41 cm[Z]	—	2091 a	2503 b	2595 bc	2520 C
61 cm	3366 a	2309 a	2780 a	2865 a	2830 A
S.E.M.	74.8				39.4
Nitrogen Rate					
6 kg N ha^{-1}	2597 d	730 d	1493 d	1499 d	1562 D
50 kg N ha^{-1}	3142 c	1734 c	2323 c	2371 c	2380 C
100 kg N ha^{-1}	3520 b	2708 b	3054 b	3209 b	3128 B
150 kg N ha^{-1}	3626 a	3428 a	3395 a	3589 a	3491 A
S.E.M.	72.1				36.4
Orthogonal Contrasts	*p-values*				
Spacing – linear	0.061	0.063	**0.001**	**0.001**	**0.002**
Spacing – quadratic	**0.010**	0.348	0.169	**< 0.001**	**< 0.001**
N rate – linear	**<0.001**	**<0.001**	**< 0.001**	**< 0.001**	**< 0.001**
N rate – quadratic	**<0.001**	**<0.001**	**< 0.001**	**< 0.001**	**< 0.001**

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Results for RS and NR effects on canola thousand seed weight (TKW) are presented in Tables 11, 12 and A-6. Effects of RN, NR, Y×RS and Y×NR were all highly significant ($P < 0.01$) for this variable while the RS×NR and Y×RN×NR interactions were not ($P = 0.08-0.83$). The overall RS effect was such that TKW increased slightly as RS increased with an overall average increase of 1.5% going from 25-61 cm. In contrast, TKW decreased with N fertilization with consistently lower values with side-banded urea and the lowest TKW at 50-100 kg N ha^{-1} where the observed values were approximately 7% lower than the control. The Y×RS interaction was a result of the observed RS effect on TKW being linear in 2014, quadratic in 2015 and not significant in 2013 and 2016. Nitrogen rate effects on TKW were inconsistent from year-to-year with the highest TKW values observed at the lowest NR levels in 3/4 years but the opposite occurring in 2016. In general, environmental conditions had a much greater impact on TKW than either of the factors being evaluated (Tables 12 and A-6).

Table 11. Tests of fixed effects for row spacing and nitrogen rate effects on canola thousand kernel weight (g/1000 seeds) at Indian Head (2013-16).

Variable	**Year**				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	Pr > *F*				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)[Y]	0.129	**0.008**	**< 0.001**	0.674	**0.003**
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × NR	**0.002**	0.666	0.089	0.614	0.826
Y × RS	–	–	–	–	**< 0.001**
Y × NR	–	–	–	–	**< 0.001**
Y × RS × NR	–	–	–	–	0.075

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 12. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on canola thousand kernel weight at Indian Head (2013-16).

Treatment	**Thousand Kernel Weight**				
	2013 [Z]	2014	2015	2016	Mean
Row Spacing	g/1000 seeds				
25 cm	3.04 a	3.41 bc	2.84 b	3.25 a	3.13 AB
30 cm	3.08 a	3.44 b	2.82 b	3.27 a	3.15 AB
36 cm	3.03 a	3.34 c	2.83 b	3.26 a	3.12 B
41 cm [Z]	—	3.45 b	2.82 b	3.26 a	3.14 AB
61 cm	3.01 a	3.53 a	2.95 a	3.24 a	3.18 A
S.E.M.	0.029				0.015
Nitrogen Rate					
6 kg N ha^{-1}	3.10 a	3.86 a	2.84 b	3.40 a	3.30 A
50 kg N ha^{-1}	3.03 b	3.35 b	2.74 c	3.22 b	3.08 C
100 kg N ha^{-1}	3.02 b	3.30 b	2.85 b	3.16 b	3.07 C
150 kg N ha^{-1}	3.01 b	3.23 c	2.98 a	3.24 c	3.14 B
S.E.M.	0.028				0.014
Orthogonal Contrasts	*p-values*				
Spacing – linear	0.116	**0.004**	**< 0.001**	0.411	**0.050**
Spacing – quadratic	0.768	0.118	0.005	0.299	0.318
N rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
N rate – quadratic	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

At the time of writing, seed N concentrations from the 2016 growing season are not yet available therefore detailed statistical analyses and interpretation of results for this variable have not yet been completed. Results available to date are provided in Tables 13, 14 and A-7.

Table 13. Tests of fixed effects for row spacing and nitrogen rate effects on canola seed nitrogen concentrations (g 100 g^{-1}) at Indian Head (2013-16).

Variable	**Year**				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	------------------------------------ Pr > *F* ------------------------------------				
Year (Y)	–	–	–	–	–
Row Spacing (RS)[Y]	0.149	**< 0.001**	**< 0.001**	–	–
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	–	–
RS × NR	**< 0.001**	0.132	0.800	–	–
Y × RS	–	–	–	–	–
Y × NR	–	–	–	–	–
Y × RS × NR	–	–	–	–	–

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 14. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on canola seed nitrogen concentrations at Indian Head (2013-16).

Treatment	**Seed Nitrogen Concentrations**				
	2013[Z]	2014	2015	2016	Mean
Row Spacing	------------------------------------- g 100 g^{-1} -------------------------------------				
25 cm	2.78 a	2.67 bc	2.97 c	–	–
30 cm	2.69 a	2.69 bc	2.99 bc	–	–
36 cm	2.68 a	2.61 c	2.98 bc	–	–
41 cm[Z]	—	2.71 b	3.05 b	–	–
61 cm	2.79 a	2.85 a	3.18 a	–	–
S.E.M.		–			–
Nitrogen Rate					
6 kg N ha^{-1}	2.26 d	2.83 b	2.83 c	–	–
50 kg N ha^{-1}	2.50 c	2.48 d	2.81 c	–	–
100 kg N ha^{-1}	2.89 b	2.60 c	3.10 b	–	–
150 kg N ha^{-1}	3.29 a	2.92 a	3.41 a	–	–
S.E.M.		–			–
Orthogonal Contrasts	------------------------------------- *p-values* -------------------------------------				
Spacing – linear	0.255	**< 0.001**	**< 0.001**	–	–
Spacing – quadratic	0.055	**0.034**	0.373	–	–
N rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	–	–
N rate – quadratic	**0.001**	**< 0.001**	**< 0.001**	–	–

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

At the time of writing, seed N concentrations from the 2016 growing season are not yet available. This data is required to calculate total seed N removed; therefore detailed statistical analyses and interpretation of results for this variable have not yet been completed. Results available to date are provided in Tables 15, 16 and A-8.

Table 15. Tests of fixed effects for row spacing and nitrogen rate effects on canola seed N exports (kg N ha^{-1}) at Indian Head (2013-16).

Variable	Year				
	2013[ZY]	2014[Z]	2015[Z]	2016[Z]	Mean
	-------------------	-------------------	Pr > *F*	-------------------	-------------------
Year (Y)	–	–	–	–	–
Row Spacing (RS)[Y]	**0.031**	**0.017**	**< 0.001**	–	–
Nitrogen Rate (NR)	**< 0.001**	**< 0.001**	**< 0.001**	–	–
RS × NR	**< 0.001**	**< 0.001**	**0.018**	–	–
Y × RS	–	–	–	–	–
Y × NR	–	–	–	–	–
Y × RS × NR	–	–	–	–	–

[Z] Overall F-test results for individual years are based on single site mixed model analyses
[Y] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Table 16. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on canola agronomic N use-efficiency at Indian Head (2013-16).

Treatment	**Seed Nitrogen Exports**				
	2013 [Z]	2014	2015	2016	Mean
Row Spacing			$kg\ N\ ha^{-1}$		
25 cm	94.0 ab	56.0 b	75.0 b	–	–
30 cm	86.0 bc	59.2 b	78.0 b	–	–
36 cm	84.1 c	54.8 b	76.9 b	–	–
41 cm [Z]	–	57.4 b	78.1 b	–	–
61 cm	95.0 a	65.9 a	89.9 a	–	–
S.E.M.		–			–
Nitrogen Rate					
$6\ kg\ N\ ha^{-1}$	59.0 d	20.9 d	42.4 d	–	–
$50\ kg\ N\ ha^{-1}$	78.8 c	43.1 c	65.5 c	–	–
$100\ kg\ N\ ha^{-1}$	101.8 b	70.5 b	94.6 b	–	–
$150\ kg\ N\ ha^{-1}$	119.6 a	100.2 a	115.9 a	–	–
S.E.M.		–			–
Orthogonal Contrasts			*p-values*		
Spacing – linear	0.153	**0.004**	**< 0.001**	–	–
Spacing – quadratic	**0.009**	0.138	0.215	–	–
N rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	–	–
N rate – quadratic	**0.314**	**< 0.001**	**< 0.001**	–	–

[Z] 41 cm row spacing treatments excluded in 2013 due to a seeding error

Experiment #2: Row Spacing × Seeding Rates

Experiment #2 focussed on row spacing (RS) interactions with seeding rates (SR) in canola and is discussed in the following section. Treatment effects on canola emergence, or plant densities, are presented in Tables 17, 18 and B-2. Again, RS affected plant populations in all four years ($P < 0.01$-0.02) and, as expected, so did SR ($P < 0.01$). In the combined analyses, the effects of RS, SR along with the RS×SR, Y×RS, Y×SR and Y×RS×SR interactions were all significant (Table 17; $P < 0.01$-0.04). Focussing on RS effects, when averaged across years (Y) and SR final plant densities declined from 71 to 47 plants m^{-2} (34% reduction) when RS was increased from 25-61 cm. With seeding rates increasing from a targeted 30-120 viable seeds m^{-2} the actual observed populations increased from 30-91 plants m^{-2} and there was a clear tendency for higher seedling mortality at higher SR. According to the orthogonal contrasts, responses to both RS and SR were linear ($P < 0.01$) but not quadratic ($P = 0.08$-0.89). The significant RS×SR interaction appeared to be due to diminishing returns to increasing seeding rates beyond 90 seeds m^{-2} at the widest RS. For example, at 25 cm RS plant populations were increased from 80 to 102 plants m^{-2} when SR was increased from 90-120 seeds m^{-2} while, at 61 cm spacing, densities only increased from 57 to 64 seeds m^{-2} for the same SR levels. The Y×RS interaction was due to subtle variation in the effects of RS at narrower (i.e. 25-41 cm) levels; however, the same overall trend of declined populations as RS increased was consistent across years. The Y×SR interaction was due to differences in the slope of the response (which was linear in all years) whereby in most years mortality was noticeably higher with increasing SR but in 2016 mortality was low and largely unaffected by SR (i.e. closer to a 1:1 slope). This also contributed to the Y×RS×SR interaction with significant RS×SR interactions detected in all individual years except 2016.

Table 17. Tests of fixed effects for row spacing and seeding rate effects on canola plant density (plants/m²) at Indian Head (2013-16).

Variable	Year				
	2013[Z]	2014[Z]	2015[Z]	2016[Z]	Mean
	------------------	------------------	Pr > *F*	------------------	------------------
Year (Y)	–	–	–	–	
Row Spacing (RS)	**< 0.001**	**0.020**	**< 0.001**	**0.002**	**< 0.001**
Seeding Rate (SR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × SR	**< 0.001**	**0.027**	**< 0.001**	0.257	**< 0.001**
Y × RS	–	–	–	–	**< 0.001**
Y × SR	–	–	–	–	**< 0.001**
Y × RS × SR	–	–	–	–	**0.043**

[Z] Overall F-test results for individual years are based on single site mixed model analyses

Table 18. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on canola plant density at Indian Head (2013-16).

Treatment	Plant Density				
	2013	2014	2015	2016	Mean
<u>Row Spacing</u>	plants/m^2				
25 cm	56 a	50 bc	88 a	90 a	71 A
30 cm	54 ab	57 a	75 b	84 ab	68 A
36 cm	49 b	54 ab	72 b	77 c	63 B
41 cm	45 bc	49 bc	73 b	76 bc	61 B
61 cm	28 c	44 c	50 c	64 d	47 C
S.E.M.	2.9				2.0
<u>Seeding Rate</u>					
30 seeds m^{-2}	20 d	26 d	35 d	40 d	30 D
60 seeds m^{-2}	39 c	46 c	63 c	68 c	54 C
90 seeds m^{-2}	56 b	58 b	83 b	88 b	71 B
120 seeds m^{-2}	71 a	72 a	105 a	117 a	91 A
S.E.M.	3.9				1.9
<u>*Orthogonal Contrasts*</u>	*p-values*				
Spacing – linear	**< 0.001**	**0.003**	**< 0.001**	**< 0.001**	**< 0.001**
Spacing – quadratic	0.676	0.148	0.783	0.201	0.886
Seed rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Seed rate – quadratic	0.381	0.181	0.134	0.833	0.080

Results for RS and SR effects on length of the flowering period in canola are presented in Tables 19, 20 and B-3. All main effects and possible interactions for this variable were highly significant (Table 19; $P < 0.01$). Similar to Experiment #1, there was a small but significant increase in the length of flowering with increasing RS but a significant Y×RS interaction whereby this did not occur in 2014. Averaged across years flowering was extended by 1.2 days when RS was increased from 25 cm to 61 cm (Table 20). Seeding rate had a greater effect on flowering period with higher SR significantly shortening flower periods relative to the lower levels. Averaged over the four year period, the length of the flowering period was reduced by 4.4 days (13%) when SR was increased from 30 seeds m^{-2} to 120 seeds m^{-2}. This occurred in all years; however, there was still a Y×SR interaction due to there being no further effect on flowering period going from 90-120 seeds m^{-2} in 2016 but significant differences between these two SR levels in each of the previous three years. This was likely due to the higher overall plant populations in 2016. The RS×SR interaction appeared to be due to there being no effect on flower period when SR was increased from 90-120 seeds m-2 at the 61 cm RS but further reductions at all of the narrower RS levels (Table B-3). This was only statistically significant in 2/4 years though, hence the significant Y×RS×SR interaction.

Table 19. Tests of fixed effects for row spacing and seeding rate effects on canola flowering period (days in bloom) at Indian Head (2013-16).

Variable	Year				
	2013[Z]	2014[Z]	2015[Z]	2016[Z]	Mean
	---------- Pr > *F* ----------				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)	**< 0.001**	0.291	**< 0.001**	**< 0.001**	**< 0.001**
Seeding Rate (SR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × SR	**0.038**	0.149	**0.014**	0.277	**0.001**
Y × RS	–	–	–	–	**< 0.001**
Y × SR	–	–	–	–	**< 0.001**
Y × RS × SR	–	–	–	–	**0.008**

[Z] Overall F-test results for individual years are based on single site mixed model analyses

Table 20. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on canola flowering period at Indian Head (2013-16).

Treatment	Flowering Period				
	2013	2014	2015	2016	Mean
Row Spacing	---------- days in bloom ----------				
25 cm	36.7 d	35.9 a	26.4 c	25.1 c	31.0 C
30 cm	37.1 cd	35.7 a	26.6 bc	25.3 c	31.2 BC
36 cm	37.5 bc	35.9 a	26.8 bc	25.5 bc	31.4 B
41 cm	38.0 b	34.8 b	27.1 b	25.8 b	31.4 B
61 cm	39.3 a	34.4 b	28.5 a	26.6 a	32.2 A
S.E.M.	---------- 0.44 ----------				0.23
Seeding Rate					
30 seeds m^{-2}	39.7 a	40.8 a	28.5 a	26.8 a	33.9 A
60 seeds m^{-2}	38.0 b	35.8 b	27.4 b	25.8 b	31.7 B
90 seeds m^{-2}	36.9 c	33.7 c	26.6 c	25.2 c	30.6 C
120 seeds m^{-2}	36.3 d	31.1 d	25.9 d	24.9 c	29.5 D
S.E.M.	---------- 0.21 ----------				0.21
Orthogonal Contrasts	---------- *p-values* ----------				
Spacing – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Spacing – quadratic	0.586	0.773	0.337	0.893	0.793
Seed rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Seed rate – quadratic	**0.003**	**< 0.001**	0.225	**0.016**	**< 0.001**

Results for RS and SR effects on canola maturity (days to 60% seed colour change) are presented in Tables 21, 22 and B-4. Maturity was affected by RS and SR with significant Y×RS and Y×SR interactions ($P < 0.01$). Similar to flowering period, maturity was delay slightly (1.1 days on average) when RS was increased from 25-61 cm and, to a greater extent (5.1 days on average) when SR was reduced from 120 to 30 seeds m^{-2}. The Y×RS interaction was due primarily to an unusual response in 2014 where maturity not affected by RS while, in the other three years, a spread of 1-2 days across RS levels was observed. The Y×SR interaction was also mostly due to the response in 2014 where the range in maturity across SR was extremely large (13 days) compared to the other three years where a comparatively minor spread of 2-3 days was observed.

Table 21. Tests of fixed effects for row spacing and seeding rate effects on canola maturity (days from planting) at Indian Head (2013-16).

Variable			**Year**		
	2013[Z]	2014[Z]	2015[Z]	2016[Z]	Mean
	----------	----------	Pr > *F*	----------	----------
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)	**< 0.001**	0.948	**< 0.001**	**< 0.001**	**0.004**
Seeding Rate (SR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × SR	0.547	0.567	0.222	0.277	0.138
Y × RS	–	–	–	–	**0.002**
Y × SR	–	–	–	–	**< 0.001**
Y × RS × SR	–	–	–	–	0.315

[Z] Overall F-test results for individual years are based on single site mixed model analyses

Table 22. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on canola maturity at Indian Head (2013-16).

Treatment	**Maturity**				
	2013	2014	2015	2016	Mean
Row Spacing	days from planting				
25 cm	97.0 b	109.2 a	98.4 c	96.2 c	100.2 B
30 cm	97.3 b	108.9 ab	98.6 c	96.4 bc	100.2 B
36 cm	97.7 b	108.6 ab	99.0 bc	96.9 bc	100.6 B
41 cm	97.7 b	108.3 b	99.5 b	97.0 ab	100.6 B
61 cm	98.6 a	108.0 ab	100.6 a	97.5 a	101.3 A
S.E.M.	0.56				0.29
Seeding Rate					
30 seeds m^{-2}	99.2 a	116.2 a	100.6 a	97.8 a	103.4 A
60 seeds m^{-2}	97.8 b	109.7 b	99.6 b	96.9 b	101.0 B
90 seeds m^{-2}	97.2 b	106.1 c	98.7 c	96.5 bc	99.6 C
120 seeds m^{-2}	96.5 c	102.8 d	98.1 d	95.9 c	98.3 D
S.E.M.	0.53				0.27
Orthogonal Contrasts	*p-values*				
Spacing – linear	**< 0.001**	0.307	0.183	**< 0.001**	**< 0.001**
Spacing – quadratic	0.772	0.183	**< 0.001**	0.285	0.993
Seed rate – linear	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Seed rate – quadratic	0.130	**< 0.001**	0.340	0.537	**< 0.001**

Results for RS and SR effects on canola seed yield at Indian Head are presented in Tables 23, 24 and B-5. Yield was affected by RS and SR with significant interactions for Y×RS and Y×SR (P < 0.01) but not RS×SR or Y×RS×SR (P = 0.32-0.69). Averaged across years, the RS effects on yield were similar to those in Experiment #1 with the highest yields at 61 cm and 25 cm row spacing but slightly lower yields at the intermediate RS levels. While the Y×RS interaction showed subtle variation in means separations over the years, the overall trends were generally similar with significant quadratic responses in 3/4 years. The exception was 2014 where the lowest yields occurred at 25 cm spacing (with the highest at 61 cm RS); therefore linear response was significant (P < 0.01) but quadratic response was not (P = 0.88). Across the four-year period, seed yield was lowest at the 30 seeds m^{-2} SR and then leveled off for the 60-120 seeds m^{-2} rates. The yield loss at the lowest SR was quite small over the 4 year period averaging only 114 kg ha^{-1} or 3.4%. As for the Y×SR interaction, results were consistent from 2013-15 where yield losses of 3-9% occurred at the lowest SR; however, the response differed in 2016 which, notably, was the year where the highest overall plant populations were achieved. In 2016 the highest yields occurred at the two lowest rates (30-60 seeds m^{-2}), with a slight but significant reduction at 90 seeds m^{-2} and the lowest yield at the highest SR of 120 seeds m^{-2}. This response was atypical and presumably due to the exceptionally low seedling mortality combined with wet conditions later in the season that contributed to relatively high disease pressure and a strong ability for the canola to compensate for lower plant populations.

Table 23. Tests of fixed effects for row spacing and seeding rate effects on canola seed yield (kg/ha) at Indian Head (2013-16).					
Variable	**Year**				
	2013[Z]	2014[Z]	2015[Z]	2016[Z]	Mean
	Pr > *F*				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)	**0.002**	0.216	**< 0.001**	**< 0.001**	**< 0.001**
Seeding Rate (SR)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × SR	0.748	0.807	0.072	0.063	0.320
Y × RS	–	–	–	–	**< 0.001**
Y × SR	–	–	–	–	**< 0.001**
Y × RS × SR	–	–	–	–	0.690

[Z] Overall F-test results for individual years are based on single site mixed model analyses

Table 24. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on canola seed yield at Indian Head (2013-16).					
Treatment	**Seed Yield**				
	2013	2014	2015	2016	Mean
<u>*Row Spacing*</u>	kg/ha				
25 cm	3444 a	2793 b	3232 b	3899 a	3342 B
30 cm	3182 c	2848 b	3182 b	3756 b	3242 C
36 cm	3187 c	2901 ab	3163 b	3660 c	3228 CD
41 cm	3152 c	2828 b	3163 b	3602 c	3186 D
61 cm	3306 b	2977 a	3384 a	3984 a	3413 A
S.E.M.	91.3				45.9
<u>*Seeding Rate*</u>					
30 seeds m^{-2}	3065 b	2670 b	3153 b	3899 a	3197 B
60 seeds m^{-2}	3318 a	2910 a	3256 a	3836 a	3330 A
90 seeds m^{-2}	3284 a	2913 a	3230 ab	3740 b	3292 A
120 seeds m^{-2}	3351 a	2985 a	3260 a	3645 c	3310 A
S.E.M.	89.8				45.0
<u>*Orthogonal Contrasts*</u>	*p-values*				
Spacing – linear	0.371	**0.002**	**< 0.001**	**< 0.001**	**< 0.001**
Spacing – quadratic	**< 0.001**	0.879	**< 0.001**	**< 0.001**	**< 0.001**
Seed rate – linear	**< 0.001**	**< 0.001**	**0.019**	**< 0.001**	**< 0.001**
Seed rate – quadratic	**0.001**	**0.014**	0.195	0.558	**< 0.001**

Effects of RS and SR along with the potential interactions on canola thousand kernel weight (TKW) are presented in Tables 25, 26 and B-6. Thousand kernel weight was affected by RS ($P < 0.01$) but not SR ($P = 0.33$); however, interactions between both of these main effects and year (Y) were significant ($P < 0.01$). Neither the RS×SR or Y×RS×SR were significant ($P = 0.38$-0.61). Averaged across years, RS had a quadratic effect TKW with no differences amongst RS ranging from 25-41 cm but significantly higher TKW at 61 cm; however, the RS effects were inconsistent over the years. In 2013 TKW declined with increasing RS while in the following three years it increased, quadratically in 2014 and 2015 but linearly in 2016. While TKW was similar across SR across years, responses were observed in 3/4 years individually, the exception being 2013; however, similar to RS, these responses were inconsistent from year-to-year. In 2014, TKW was lowest at 30 seeds m^{-2} while in 2015 and 2016 the opposite occurred with slightly larger seeds observed at lower plant populations. Conceivably, seed size could be increased by either low populations or high populations; therefore these results are not entirely inexplicable. At low populations, once crops have filled the canopy to the best of their ability through increased branching, additional resources can bet put towards larger seeds. This response would generally require both adequate moisture and also a longer growing season as maturity is inevitably delayed. In contrast, at high populations, canopy closure typically occurs earlier, thereby again potentially allowing more time and resources to be put towards larger seeds, particularly if water is not limiting.

Table 25. Tests of fixed effects for row spacing and seeding rate effects on canola thousand kernel weight (g/1000 seeds) at Indian Head (2013-16).

Variable	**Year**				
	2013[Z]	2014[Z]	2015[Z]	2016[Z]	Mean
	---------- Pr > *F* ----------				
Year (Y)	–	–	–	–	**< 0.001**
Row Spacing (RS)	**0.003**	0.115	**< 0.001**	**0.014**	**0.001**
Seeding Rate (SR)	0.160	**0.002**	**< 0.001**	**0.002**	0.333
RS × SR	0.856	0.947	**0.020**	0.121	0.378
Y × RS	–	–	–	–	**< 0.001**
Y × SR	–	–	–	–	**< 0.001**
Y × RS × SR	–	–	–	–	0.609

[Z] Overall F-test results for individual years are based on single site mixed model analyses

Table 26. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on canola thousand kernel weight at Indian Head (2013-16).

Treatment	**Thousand Kernel Weight**				
	2013	2014	2015	2016	Mean
Row Spacing	------------ g/1000 seeds ------------				
25 cm	2.94 bc	3.19 b	2.96 b	3.14 c	3.06 B
30 cm	3.00 a	3.18 b	2.96 b	3.19 b	3.08 B
36 cm	2.96 ab	3.16 b	2.95 b	3.16 bc	3.06 B
41 cm	2.91 cd	3.19 b	2.98 b	3.17 b	3.06 B
61 cm	2.89 d	3.29 a	3.08 a	3.23 a	3.12 A
S.E.M.	------------ 0.033 ------------				0.016
Seeding Rate					
30 seeds m^{-2}	2.92 a	3.11 b	3.03 a	3.23 a	3.07 A
60 seeds m^{-2}	2.93 a	3.23 a	3.00 ab	3.16 b	3.08 A
90 seeds m^{-2}	2.94 a	3.25 a	2.96 bc	3.17 b	3.08 A
120 seeds m^{-2}	2.96 a	3.22 a	2.94 c	3.15 b	3.07 A
S.E.M.	------------ 0.032 ------------				0.016
Orthogonal Contrasts	------------ *p-values* ------------				
Spacing – linear	**< 0.001**	**< 0.001**	**< 0.001**	**0.001**	**< 0.001**
Spacing – quadratic	0.689	**0.021**	**0.041**	0.650	**0.038**
Seed rate – linear	0.073	**< 0.001**	**< 0.001**	**0.001**	0.604
Seed rate – quadratic	0.818	**< 0.001**	0.670	0.190	0.084

One of the downsides to the increased branching and delayed maturity associated with low plant population is increased green seed; however, percent green seed is also largely a function of basic management (i.e. timing of operations). Green seed is an important grading factor with a minimum of 2% distinctly green seed permitted for top grade canola in Canada and, overall, values were well below this level in all years except 2014. Results for RS and SR effects on this variable are presented in Tables 27, 28 and B-7. Green seed was not affected by RS ($P = 0.28$) and there were no interactions between RS and either Y or SR ($P = 0.19$-0.32). In contrast, both the overall SR effect and the Y×SR interaction were highly significant ($P < 0.01$). Averaged across years and RS level, percent green seed was markedly higher at the 30 seeds m^{-2} SR (1.5%) and continued to gradually decline to a minimum of 0.2% as SR was increased from 60-120 seeds m^{-2}. The Y×SR interaction and inspection of SR effects for individual years revealed that this effect was largely due to the response observed in 2014 where distinctly green seed ranged from 0.1% at 120 seeds m^{-2} to 4.8% at the lowest SR of 30 seeds m^{-2}. In the remaining years, orthogonal contrast results for SR effects on percent green seed were not significant for either the linear or quadratic responses ($P = 0.45$-1.00).

Table 27. Tests of fixed effects for row spacing and seeding rate effects on percent green canola seed (%) at Indian Head (2013-16).					
Variable	**Year**				
	2013[Z]	2014[Z]	2015[Z]	2016[Z]	Mean
	---------- Pr > *F* ----------				
Year (Y)	–	–	–	–	**0.025**
Row Spacing (RS)	**0.015**	0.554	0.253	0.810	0.278
Seeding Rate (SR)	**0.049**	**< 0.001**	0.093	0.364	**< 0.001**
RS × SR	0.616	0.756	0.610	0.259	0.323
Y × RS	–	–	–	–	0.185
Y × SR	–	–	–	–	**< 0.001**
Y × RS × SR	–	–	–	–	0.397

[Z] Overall F-test results for individual years are based on single site mixed model analyses

ble 28. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on percent green canola seed at Indian Head (2013-16).					
Treatment	**Green Seed**				
	2013	2014	2015	2016	Mean
<u>*Row Spacing*</u>	---------- % ----------				
25 cm	0.39 a	2.72 a	0.30 a	0.05 a	0.86 A
30 cm	0.26 a	1.08 a	0.34 a	0.09 a	0.44 A
36 cm	0.38 a	2.04 a	0.26 a	0.09 a	0.69 A
41 cm	0.25 a	1.66 a	0.40 a	0.11 a	0.61 A
61 cm	0.65 a	1.37 a	0.48 a	0.14 a	0.66 A
S.E.M.	---------- 0.408 ----------				0.209
<u>*Seeding Rate*</u>					
30 seeds m^{-2}	0.46 a	4.82 a	0.47 a	0.11 a	1.47 A
60 seeds m^{-2}	0.23 a	1.61 b	0.37 a	0.14 a	0.59 B
90 seeds m^{-2}	0.47 a	0.55 c	0.33 a	0.06 a	0.35 BC
120 seeds m^{-2}	0.38 a	0.12 c	0.25 a	0.07 a	0.21 C
S.E.M.	---------- 0.032 ----------				0.201
<u>*Orthogonal Contrasts*</u>	---------- *p-values* ----------				
Spacing – linear	0.300	**0.034**	0.540	0.795	0.744
Spacing – quadratic	0.439	0.194	0.936	0.934	0.286
Seed rate – linear	1.000	**< 0.001**	0.453	0.830	**< 0.001**
Seed rate – quadratic	0.737	**< 0.001**	0.962	0.962	**0.001**

Experiment #3: Row Spacing × Herbicide Application

The final field experiment (Experiment #3) focussed on row spacing (RS) effects on the ability of canola to compete with natural weed populations and was conducted over a three-year period, 2013-15. For this experiment, RS was combined with in-crop herbicide (HERB) treatments where the canola either did, or did not receive a single in-crop application of glufosinate ammonium. Data collection as limited to measurements of crop and weed above-ground biomass (when the canola was at 40-60% seed colour change) along with seed yield.

Treatment effects on canola crop biomass are presented in Tables 29, 30 and C-2. Canola above-ground biomass yields were affected by RS and HERB ($P < 0.01$) and significant interactions with year (Y) were detected for each of these factors ($P < 0.01$-0.04). Neither the RS×HERB nor Y×RS×HERB interactions were significant for canola above-ground biomass yields ($P = 0.10$-0.58). Averaged over the three years and across herbicide treatments, canola above-ground biomass yields were reduced from 8412 kg ha^{-1} to 6098 kg ha^{-1} as RS was increased from 25 cm to 61 cm. Despite the Y×RS interaction, this was observed in all three years; however, the specific groupings of treatments means varied and in 2013 the decline was linear while in 2014 and 2015 the response was more quadratic. Removal of weeds with an in-crop herbicide application resulted in an increase in crop biomass of 1576 kg ha^{-1}, or 24% relative to the unsprayed plots when averaged over the three-year period. While the general trend of higher crop biomass when weeds were removed occurred in all years, the Y×HERB interaction was a result of the difference not being statistically significant in 2015 (in the combined analyses) when naturally occurring weed populations were much lower. In 2013 and 2014, the gains were 1305-2794 kg ha^{-1} (32-45%) over the unsprayed plots (Table 30).

Table 29. Tests of fixed effects for row spacing and in-crop herbicide effects on canola above-ground crop biomass (kg ha^{-1}) at Indian Head (2013-15).

Variable	**Year**			
	2013^{Z}	2014^{Z}	2015^{Z}	Mean
	------------------------------------ Pr > *F* ------------------------------------			
Year (Y)	–	–	–	**< 0.001**
Row Spacing (RS)	**0.007**	0.064	**< 0.001**	**< 0.001**
Herbicide (HERB)	**< 0.001**	**0.002**	**0.017**	**< 0.001**
RS × HERB	0.129	0.989	0.101	0.097
Y × RS	–	–	–	**0.041**
Y × HERB	–	–	–	**< 0.001**
Y × RS × HERB	–	–	–	0.582

^{Z} Overall F-test results for individual years are based on single site mixed model analyses

Table 30. Least squares means and orthogonal contrasts for main effects of row spacing and in-crop herbicide effects on canola above-ground biomass at Indian Head (2013-15).

Treatment	Above-Ground Crop Biomass			
	2013	2014	2015	Mean
Row Spacing	--- kg ha^{-1} ---			
25 cm	8445 a	5694 a	11096 a	8412 A
30 cm	8149 ab	5430 ab	9334 b	7637 B
36 cm	8141 ab	4071 b	9689 b	7300 BC
41 cm	7394 b	4417 b	8732 bc	6848 C
61 cm	6006 c	4282 b	8007 c	6098 D
S.E.M.	--- 418.7 ---			243.2
In-crop Herbicide				
No Herbicide	6230 b	4126 b	9059 a	6471 B
Herbicide Applied	9024 a	5431 a	9684 a	8047 A
S.E.M.	--- 301.8 ---			174.6
Orthogonal Contrasts	--- *p-values* ---			
Spacing – linear	**< 0.001**	**0.010**	**< 0.001**	**< 0.001**
Spacing – quadratic	0.697	**0.023**	**0.036**	**0.038**

Test results and treatment means for RS and HERB effects on weed (above-ground) biomass, along with all possible interactions are presented in Tables 31, 32 and C-3. Overall, weed pressure was highest in 2013 and 2014 where the dominant species were wild oats and volunteer canaryseed, respectively. In 2015, overall weed pressure was lower with sparse populations of miscellaneous broadleaves, wild oats and volunteer wheat. In the combined analyses, weed biomass was only affected by HERB with a significant Y×HERB interaction ($P < 0.01$); however, note that, when site-years were analyzed individually, RS and RS×HERB effects were detected in 2015 (Table 31). While the overall F-tests were not significant, weed biomass increased linearly with RS in 2013 and in 2015 weed biomass at 61 cm RS was notably higher than at the narrower RS levels. In-crop HERB reduced weed biomass to negligible levels in all cases, from 1874 kg ha^{-1} to 35 kg ha^{-1} when averaged across the three-year period. The Y×HERB interaction was due to the HERB effect not being significant in the combined analyses; however, this was partly due to the data being combined and much lower overall weed pressure in 2015. Overall, these results show that if herbicides are effective (i.e. no HT weeds, applied at optimal stages), RS effects on crop competition with weeds are not likely to present immediate agronomic concerns; however, when they were not removed, there was reasonably compelling evidence for increased weed growth with increasing RS.

Table 31. Tests of fixed effects for row spacing and in-crop herbicide effects on weed biomass (kg ha^{-1}) at Indian Head (2013-15).

Variable	**Year**			
	2013[Z]	2014[Z]	2015[Z]	Mean
	------------ Pr > *F* ------------			
Year (Y)	–	–	–	**0.002**
Row Spacing (RS)	0.440	0.546	**0.011**	0.174
Herbicide (HERB)	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
RS × HERB	0.657	0.594	**0.012**	0.226
Y × RS	–	–	–	0.850
Y × HERB	–	–	–	**< 0.001**
Y × RS × HERB	–	–	–	0.962

[Z] Overall F-test results for individual years are based on single site mixed model analyses

Table 32. Least squares means and orthogonal contrasts for main effects of row spacing and in-crop herbicide effects on weed biomass at Indian Head (2013-15).

Treatment	**Weed Biomass**			
	2013	2014	2015	Mean
<u>*Row Spacing*</u>	------------ kg ha^{-1} ------------			
25 cm	1528 ab	1374 a	54 a	985 A
30 cm	1306 b	941 a	53 a	767 A
36 cm	1497 ab	1386 a	94 a	993 A
41 cm	1338 b	1052 a	57 a	816 A
61 cm	2061 a	1336 a	239 a	1212 A
S.E.M.	------------ 279.5 ------------			161.4
<u>*In-crop Herbicide*</u>				
No Herbicide	3031 a	2423 a	169 b	1874 A
Herbicide Applied	61 b	13 b	30 b	35 B
S.E.M.	------------ 301.8 ------------			127.8
<u>*Orthogonal Contrasts*</u>	------------ *p-values* ------------			
Spacing – linear	**0.030**	0.745	0.506	0.088
Spacing – quadratic	0.156	0.450	0.821	0.188

Row spacing (RS) and HERB effects on canola seed yield are presented in Tables 33, 34 and C-4. Across years, canola yields in this experiment were not affected by RS and no Y×RS interaction was detected (Table 33; *P* = 0.11-0.25). Furthermore, there were no RS×HERB or Y×RS×HERB interactions (*P* =

0.42-0.71) which indicated that RS effects on canola yield were consistent regardless of environmental conditions or weed pressure. While the F-tests were not significant, the orthogonal contrasts did show a similar overall quadratic response ($P = 0.02$) to the previous experiments and evidence of higher yields at narrower RS in 2013 (Table 34). Averaged across years, weed removal with an in-crop herbicide application resulted in a yield benefit of 650 kg ha^{-1}, or 27%. With the Y×HERB interaction, the yield benefits were only significant in 2013 and 2014 when weed pressure was much higher. Note that all plots received a non-selective, pre-emergent herbicide application and, with very dry early season conditions in 2015, the crop had a strong head start when the rains finally came which had a major impact on overall weed pressure. In 2013 and 2014 the yield benefit to weed removal was 65% and 27% while in 2015 the observed 2% yield advantage was not statistically significant.

Table 33. Tests of fixed effects for row spacing and in-crop herbicide effects on canola seed yield (kg ha^{-1}) at Indian Head (2013-15).

Variable	Year			
	2013^{Z}	2014^{Z}	2015^{Z}	Mean
	---------- Pr > *F* ----------			
Year (Y)	–	–	–	**0.001**
Row Spacing (RS)	0.237	0.414	**< 0.001**	0.114
Herbicide (HERB)	**< 0.001**	**< 0.001**	**0.019**	**< 0.001**
RS × HERB	0.435	0.818	0.192	0.416
Y × RS	–	–	–	0.247
Y × HERB	–	–	–	**< 0.001**
Y × RS × HERB	–	–	–	0.711

^{Z} Overall F-test results for individual years are based on single site mixed model analyses

Table 34. Least squares means and orthogonal contrasts for main effects of row spacing and in-crop herbicide effects on canola seed yield at Indian Head (2013-15).

Treatment	Seed Yield			
	2013	2014	2015	Mean
<u>Row Spacing</u>	---------- kg ha^{-1} ----------			
25 cm	2891 a	2556 a	3186 a	2878 A
30 cm	2658 ab	2647 a	3115 a	2807 A
36 cm	2500 b	2390 a	3060 a	2650 A
41 cm	2469 b	2595 a	3002 a	2688 A
61 cm	2463 b	2612 a	3254 a	2777 A
S.E.M.	---------- 116.4 ----------			67.2
<u>In-crop Herbicide</u>				
No Herbicide	1960 b	2252 b	3092 a	2435 B
Herbicide Applied	3232 a	2868 a	3155 a	3085 A
S.E.M.	---------- 84.2 ----------			48.6
<u>*Orthogonal Contrasts*</u>	---------- *p-values* ----------			

Spacing – linear	0.012	0.700	0.462	0.418
Spacing – quadratic	0.022	0.550	0.083	0.019

Conclusions and Recommendations:

The broad objectives of this project were to evaluate the feasibility of growing canola at row spacing levels exceeding 25 cm and to explore potential implications on crop response to side-banded N, varying seeding rates and competitiveness with weeds. Western Canadian canola growers have been interested in adopting wider row spacing (30 cm or wider), primarily to facilitate wider drills while reduce overall equipment costs and minimum horsepower requirements for seeding. Furthermore, wider row spacing generally allows for seeding into heavy crop residues or between stubble rows more easily which is important to many growers committed to improving soil quality and (albeit less so in recent years) conserving moisture. More recently, some growers have invested in planters (primarily for corn) with wider row spacing than conventional no-till drills and these growers are interested in planting canola with this equipment to help justify the investment. Additionally, large commercial drills are currently available with row spacing as wide as 38 cm and, with relatively simple modifications to existing equipment, even wider spacing can be readily achieved with traditional no-till seeding equipment. While most growers recognize the many logistic advantages to wider spacing, important questions exist as to whether this spacing is too wide from an agronomic perspective for certain crop types and conditions.

In general, canola plant populations declined as row spacing was increased, presumably due to higher intraspecific competition amongst seedlings. While consistently significant, the observed reductions were typically too small to be of major agronomic concern, particularly amongst row spacing levels ranging from 25-41 cm. When averaged across all years, seeding rates, and N rates, plant populations declined by 28%, from 85 to 62 plants m^{-2}, when row spacing was increased from 25 cm to 61 cm (Figure 1). Increasing row spacing also resulted in slight but significant delays in flowering and maturity; however, the effects were generally much smaller than those caused by either N fertilizer or seeding rate and unlikely to be of agronomic importance provided that adequate seeding rates and other recommended practices are utilized. This delay was presumably due to the need for canola plants at wider spacing to grow larger and branch out more to utilize the extra canopy space. Broadly speaking, row spacing effects on seed yield were small and in some cases non-significant. While there were cases of higher yields at 25 cm row spacing relative to those ranging from 30-41 cm, canola yields at 61 cm row spacing were also consistently amongst the highest. To some extent, yields may have been biased towards higher yields at 61 cm due to edge effects and potentially lower harvest losses in some cases. Interactions, particularly with side-banded N rate, may have also contributed to the observed quadratic response with narrower row spacing generally performing between at high N rates while 61 cm was favoured in the lower input systems. When averaged across all years, N rates and seeding rates, seed yields ranged from approximately 2800-3000 kg/ha with the highest yields at 61 cm followed by 25 cm (Figure 2) and row spacing effects on yield were always much less than environment or other management effects. Row spacing effects on seed size were small and somewhat inconsistent. While there was an overall tendency for slightly smaller seeds with increasing row spacing in 2013, the opposite occurred in remaining years and, when averaged across years and other management factors, row spacing effects on thousand kernel weight were negligible. There was an overall increase in percent green seed with increasing row spacing in 2013 but no measureable effects in the remaining years indicating that other factors such as seeding rate/uniformity and timing of operations are much more important than row spacing for managing green seed in canola.

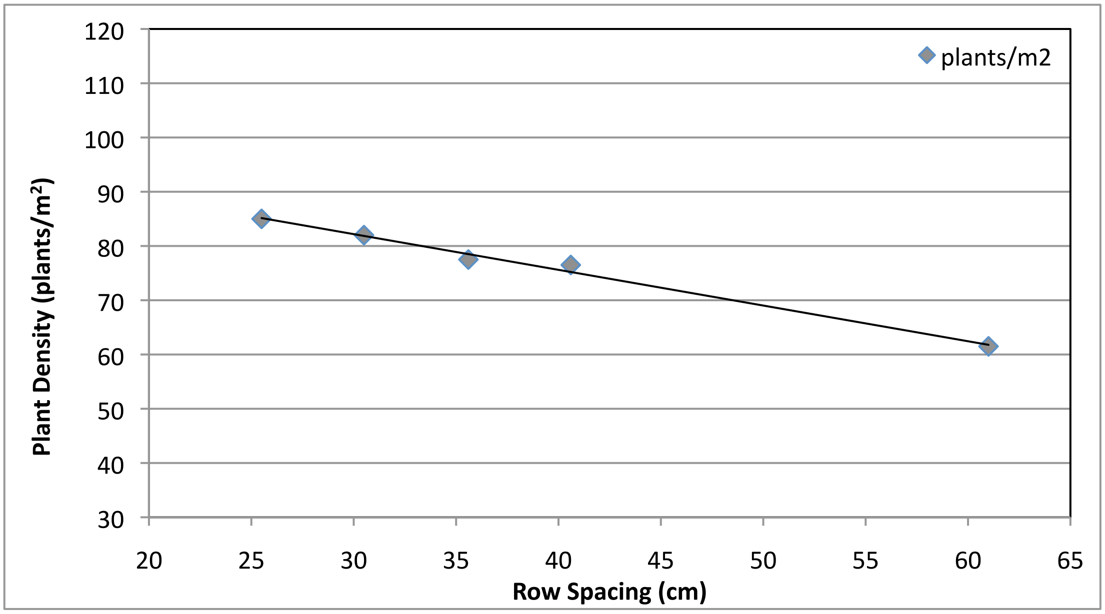

Figure 1. Row spacing effects on canola plant density at Indian Head over a four-year period and averaged across nitrogen fertilizer and seeding rates.

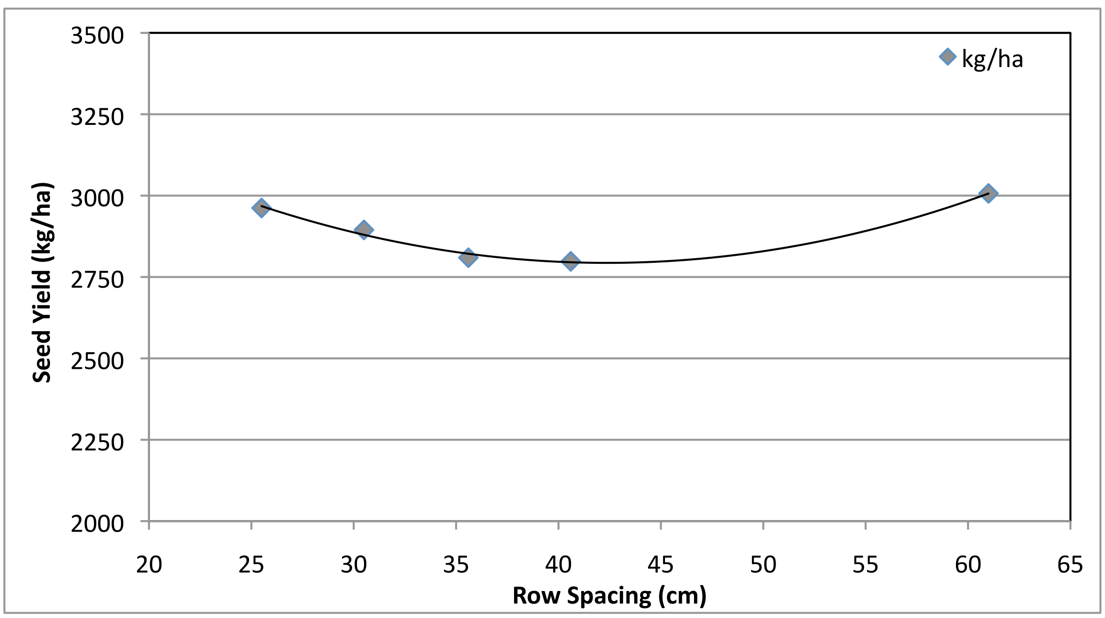

Figure 2. Row spacing effects on canola seed yield at Indian Head over a four-year period and averaged across nitrogen fertilizer rates, seeding rates and herbicide treatments.

Focussing on potential implications for side-banded N recommendations, there was a significant reduction in plant densities with side-banded N in all three years. While this occurred at all row spacing levels, there was evidence that plant populations started to decline at lower N rates at the widest row spacing compared to the other levels. At 61 cm row spacing, significant stand reductions occurred with as little as 50 kg N ha^{-1} while, for all narrow levels, stand reduction was not significant until 100-150 N ha^{-1} rates were applied. Despite the effects on emergence, canola responded well to side-banded N with sequentially increasing yields right up to 150 kg N ha^{-1} in all three years and maximum yield increases of 40%, 370%, 127% and 139% in 2013, 2014, 2015 and 2016, respectively. An interaction was detected that appeared to be due to higher yields at 61 cm in the 0N control but not in the fertilized plots. At the other end of the fertility scale, even canola at 61 cm spacing benefited from the highest N rates, despite the observed stand reductions with the combination and high rates of side-banded N and wide row spacing. Overall, the results of this study suggest that N requirements of canola are likely similar regardless of row spacing; however, extremely high rates of side-banded N combined with wide row spacing may increase the risk of seedling injury.

Another key objective was to investigate potential implications of wider row spacing on seeding rate recommendations. The target seeding rates evaluated were 30, 60, 90 and 120 seeds m^{-2} with the lowest two rates falling below those that would normally recommended and the upper two falling in the range commonly used by Saskatchewan canola growers. Depending on the seeding rate, actual mean plant densities ranged from 20-71 plants m^{-2} in 2013, 26-72 plants m^{-2} in 2014, 35-105 plants m^{-2} in 2015 and 40-117 plants m^{-2} in 2016; however, interactions with row spacing were detected. The interactions appeared to be due to the negative effect of wider row spacing on emergence being less prominent at the lowest seeding rate and also diminishing benefits to the highest seeding rates when combined with the widest row spacing. This suggests that intraspecific competition became increasingly limiting to establishment at when wide row spacing was combined with high seeding rates. Despite the higher mortality, reasonably high seeding rates were required to ensure adequate plant populations at the widest row spacing – only the 120 seeds m^{-2} rate resulted in established populations greater than 40 plants m^{-2} in all four years. These results suggest that seeding rates should not likely be reduced below typically recommended rates as row spacing is increased; however, at the same time, there was little benefit to using seeding rates exceeding 90 seeds m^{-2} when planting canola at 61 cm row spacing. While only speculative, it is conceivable that higher plant populations encourage more lateral growth towards adjacent rows which could lead to earlier and more thorough canopy closure compared to lower plant populations at wide row spacing. Overall, seeding rate had a larger impact on canola development (i.e. flowering period, days to maturity) than row spacing, especially in 2014 where, under cool, wet conditions, maturity was delayed by nearly two weeks at the lowest seeding rate relative to the highest. Similar yields were achieved with seeding rates ranging from 60-120 seeds m^{-2} in all four years; however, yields were reduced by an average of 4% at 30 seeds m^{-2} relative to the higher rates. It should be noted that, over the study period, emergence was generally considered excellent, issues with flea beetles were promptly controlled and canola growth was never limited by drought. Under less favourable conditions for emergence and crop growth, the responses to seeding rate may have varied.

Canola was grown with and without herbicide to assess potential impacts of increasing row spacing on canola`s ability to compete with weeds. While there was a consistent overall linear decline in above-ground crop biomass with increasing row spacing in all three years (28% on average), weed biomass only ever increased in the absence of in-crop herbicide and, even then, this did not occur in all years. Despite extremely high weed pressure in 2013 and 2014, a single in-crop application of glufosinate ammonium kept weed competition acceptably low at all row spacing levels, with reductions of weed biomass ranging from 98-99.5%. In 2015, herbicide reduced weed biomass from 169 kg ha^{-1} to 30 kg ha^{-1} which was not statistically significant; however, overall pressure was much lower and, with the dry start to the season, many weeds did not germinate until relatively late in the season giving the canola a strong head start. It is generally accepted that the ability of crops to compete with weeds may be compromised at wide row spacing; however, this study did not show any practical, short-term effects of row spacing in this regard that could not be managed with well-timed herbicide applications. Failure to control weeds resulted in average yield losses of 43%, 28% and 3% in 2013, 2014 and 2015 (21% on average) with similar yield loss observed regardless of row spacing.

In conclusion, canola is relatively insensitive to increasing row spacing and there are many factors to consider in determining the optimal row spacing for individual farms. Narrower row spacing consistently produced amongst the highest yields, particularly when combined with high rates of side banded;

however, row spacing as wide as 61 cm was always viable under the environmental conditions encountered and when combined with timely, effective weed removal. Canola growing on wider row spacing did take longer to achieve canopy closure which does have drawbacks; however, the effects on maturity were negligible. For growers dealing with or looking to prevent the development of herbicide tolerant weeds, narrow row spacing can be an important component to integrated management strategies. Many of the major drawbacks to narrower row spacing are more logistic than agronomic (i.e. higher equipment operating costs, increased horsepower requirements / fuel use); however, narrow row spacing can also make it considerably more difficult to seed into heavy crop residues. If slightly wider row spacing can lead to better seed placement in heavy residues, increased organic matter retention, more timely seeding, better utilization of existing equipment, lower seed-bed preparation requirements etc., there could be numerous, longer-term benefits not accounted for in this study. All factors considered row spacing is a complex issue that can affect entire production systems; therefore, there is no likely single optimal row spacing for all farm operations.

References:

Christensen J. V. and Drabble, J. C. 1984. Effect of row spacing and seeding rate on rapeseed yield in northwest Alberta. Can. J. Plant Sci. **64**:1011-1013.

Environment Canada. 2015. National Climate Data and Information Archive. Online [Available]: http://climate.weather.gc.ca/historical_data/search_historic_data_e.html (March 9 2017).

Irvine, B. 1992. Saskatchewan Irrigation Development Centre Annual Report.

Irvine, B. and Duncan, D. 1993. Saskatchewan Irrigation Development Centre Annual Report.

Hu, W., Schoenau, J. J., Cutforth, H. W., Bing, C. S. 2015. Effects of row-spacing and stubble height on soil water content and water use by canola and wheat in the dry prairie region of Canada. Ag. Water Manage. **153:** 77-85.

Kirk, A., Davey, B., Phelps, S. Johnson, E., Shirtliffe, S., Vera, C., Holzapfel, C. and Nybo, B. 2013. Response of canola to low plant populations and evaluation of reseeding options. SaskCanola Annual Report. Online [Available]: http://www.saskcanola.com/research/response-of-canola-to-low-plant-populations-and-evaluation-of-reseeding-options (March 9 2017).

Kondra Z. P. 1975. Effects of row spacing and seeding rate on rapeseed. Can. J Plant Sci. **55**:339-341.

Morrison, M. J., McVetty, P. B. E and Scarth, R. 1990. Effect of row spacing and seeding rates on summer rape in southern Manitoba. Can. J. Plant Sci. **70:**127-137.

O'Donovan, J. 1994. Canola (Brassica rapa) Plant Density Influences Tartary Buckwheat (Fagopyrum tataricum), interference, biomass and seed yield. Weed Sci. **42:**385-389.

PAMI. 1995. Row spacing trials 1993-1995. Canola Production Centre Annual Reports.

Xie, H. Rourke, D and Hargrave, A. 1998. Effect of row spacing and seed/fertilizer placement on agronomic performance of wheat and canola in zero tillage systems. Can. J. Plant. Sci. **81:**389-394.

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Appendices:

Table A-1. Dates of selected field operations and data collection activities completed in canola row spacing Experiment #1 (Row Spacing × Nitrogen Rates) at Indian Head (2013-16).

Agronomic Factor / Field Operation	2013	2014	2015	2016
Previous Crop	Spring Wheat	Canaryseed	Spring Wheat	Barley
Soil Nutrient Sampling	May-23	May-13	May-7	May-7
K_2SO_4 broadcast application	May-29	May-13	May-7	May-8
Pre-seed herbicide	May-29 (890 g glyphosate ha^{-1} + 18 g carfentrazone ha^{-1})	May-18 (890 g glyphosate ha^{-1})	May-9 (890 g glyphosate ha^{-1} + 18 g carfentrazone ha^{-1})	May-15 (890 g glyphosate ha^{-1})
Cultivar	InVigor L130	InVigor L130	InVigor L140P	InVigor L140P
Seeding Rate	115 seeds m^{-2}	115 seeds m^{-2}	115 seeds m^{-2}	115 seeds m^{-2}
Seeding Date	May-31	May-13	May-12	May-18
Fertilizer Applied (kg N-P_2O_5-K_2O-S ha^{-1})	N^Z-27-44-20	N^Z-27-48-17	N^Z-27-54-20	N^Z-35-48-17
In-crop herbicide application(s)	Jun-17 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jun-12 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jun-15 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jun-15 (593 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})
	Jul-2 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jul-7 (211 g sethoxydim ha^{-1})	—	—
Plant densities	Jun-27	Jun-6	Jun-5	Jun-6
Foliar insecticide	—	—	May-27 (6.5 g deltamethrin ha^{-1})	—
Foliar fungicide	Jul-12 (246 g boscalid ha^{-1}) Jul-15 (246 g boscalid ha^{-1})	Jul-9 (246 g boscalid ha^{-1})	Jul-3 (246 g boscalid ha^{-1})	Jul-5 (246 g boscalid ha^{-1})
Pre-harvest application	—	Sep-5 (890 g glyphosate ha^{-1}) Sep-11 (415 g diquat ha^{-1})	Aug-27 (890 g glyphosate ha^{-1})	Aug-25 (890 g glyphosate ha^{-1})
Straight-Combined	Sep-16 (6-50 N) Sep-17 (100-150 N)	Sep-14 (0-50 N) Sep-15 (100-150 N)	Sept-3 (all)	Sep-12 (all)

^{Z}N fertilizer rates varied as per protocol

Table A-2. Least squares means for row spacing by nitrogen rate interactions on canola plant density at Indian Head (2013-16).

Seed Rate	Plant Density 2013 [Z]	2014	2015	2016	Mean
	------------------ plants m^{-2} ------------------				
25 cm row spacing					
6 kg N ha^{-1}	89	87	117	127	105 AB
50 kg N ha^{-1}	82	93	126	128	107 A
100 kg N ha^{-1}	80	68	108	114	92 DEF
150 kg N ha^{-1}	62	79	110	110	90 E-H
30 cm row spacing					
6 kg N ha^{-1}	87	81	111	123	100 ABC
50 kg N ha^{-1}	94	88	110	110	100 A-D
100 kg N ha^{-1}	76	86	106	113	95 CDE
150 kg N ha^{-1}	73	78	97	99	86 F-I
36 cm row spacing					
6 kg N ha^{-1}	77	80	111	122	98 B-E
50 kg N ha^{-1}	71	86	108	120	97 CDE
100 kg N ha^{-1}	70	78	109	106	91 EFG
150 kg N ha^{-1}	72	71	83	105	83 HI
41 cm row spacing [Z]					
6 kg N ha^{-1}	—	80	110	114	95 CDE
50 kg N ha^{-1}	—	80	111	116	96 B-E
100 kg N ha^{-1}	—	80	102	114	93 C-F
150 kg N ha^{-1}	—	72	95	105	84 GHI
61 cm row spacing					
6 kg N ha^{-1}	79	86	97	105	92 EFG
50 kg N ha^{-1}	62	67	89	98	79 IJ
100 kg N ha^{-1}	52	78	77	88	74 J
150 kg N ha^{-1}	48	59	52	80	60 K
S.E.M. (LSD)	---------- 5.7 (15.6) ----------				2.8

[Z] 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table A-3. Least squares means for row spacing by nitrogen rate interactions on canola flowering period at Indian Head (2013-16).

Seed Rate	Flowering Period 2013 [Z]	2014	2015	2016	Mean
	------------------ days in bloom ------------------				
			25 cm row spacing		
6 kg N ha^{-1}	32.9	25.5	23.3	24.5	26.6 HI
50 kg N ha^{-1}	33.4	26.7	23.6	24.1	26.9 HI
100 kg N ha^{-1}	35.3	29.2	24.3	23.8	28.0 DEF
150 kg N ha^{-1}	37.1	29.5	25.0	24.0	28.8 BC
			30 cm row spacing		
6 kg N ha^{-1}	32.9	24.8	23.5	24.8	26.6 HI
50 kg N ha^{-1}	33.3	26.3	23.8	24.1	26.8 HI
100 kg N ha^{-1}	35.4	27.8	24.4	23.9	27.8 EFG
150 kg N ha^{-1}	36.1	29.3	25.1	24.1	28.7 BCD
			36 cm row spacing		
6 kg N ha^{-1}	32.9	24.7	23.4	24.4	26.4 I
50 kg N ha^{-1}	33.3	25.4	23.8	24.0	26.6 HI
100 kg N ha^{-1}	35.1	28.2	24.4	24.0	27.9 EFG
150 kg N ha^{-1}	36.6	29.9	25.3	24.3	28.9 BC
			41 cm row spacing [Z]		
6 kg N ha^{-1}	–	24.6	23.3	24.6	26.6 HI
50 kg N ha^{-1}	–	27.0	24.0	23.8	27.3 FGH
100 kg N ha^{-1}	–	28.9	24.8	24.1	28.3 CDE
150 kg N ha^{-1}	–	29.4	25.5	24.4	29.0 BC
			61 cm row spacing		
6 kg N ha^{-1}	34.5	25.0	24.8	24.5	27.2 GH
50 kg N ha^{-1}	35.6	27.5	24.6	23.8	27.9 EFG
100 kg N ha^{-1}	37.4	29.0	25.6	24.6	29.2 B
150 kg N ha^{-1}	38.3	31.0	27.1	25.5	30.5 A
S.E.M. (LSD)	------------ 0.46 (1.17) ------------				0.23

[Z] 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table A-4. Least squares means for row spacing by nitrogen rate interactions on canola maturity at Indian Head (2013-16).

Seed Rate	Maturity 2013 [Z]	2014	2015	2016	Mean
	days from planting				
			25 cm row spacing		
6 kg N ha^{-1}	91.3	98.3	93.0	91.3	93.4 J
50 kg N ha^{-1}	92.3	98.6	94.8	92.3	94.5 H
100 kg N ha^{-1}	94.4	100.3	96.6	94.0	96.3 EF
150 kg N ha^{-1}	97.0	102.1	97.9	95.0	98.0 C
			30 cm row spacing		
6 kg N ha^{-1}	91.4	98.3	93.0	91.3	93.4 J
50 kg N ha^{-1}	92.6	98.4	94.6	92.6	94.6 H
100 kg N ha^{-1}	95.0	100.6	96.6	94.0	96.6 E
150 kg N ha^{-1}	96.1	102.3	98.5	95.1	98.0 C
			36 cm row spacing		
6 kg N ha^{-1}	91.8	98.8	93.1	91.5	93.7 IJ
50 kg N ha^{-1}	92.9	98.6	95.0	92.4	94.7 GH
100 kg N ha^{-1}	95.4	100.1	96.9	94.4	96.7 DE
150 kg N ha^{-1}	97.0	102.3	98.9	95.0	98.3 BC
			41 cm row spacing [Z]		
6 kg N ha^{-1}	—	98.4 e	93.3	91.9	93.9 I
50 kg N ha^{-1}	—	99.0 e	95.0	93.0	95.1 G
100 kg N ha^{-1}	—	100.9 cd	98.0	94.4	97.2 D
150 kg N ha^{-1}	—	102.4 ab	99.5	95.8	98.7 B
			61 cm row spacing		
6 kg N ha^{-1}	92.6 f	98.9 e	95.1	92.3	94.7GH
50 kg N ha^{-1}	94.5 e	99.0 e	97.0	93.6	96.0 F
100 kg N ha^{-1}	96.8 bc	101.0 c	99.0	94.9	97.9 C
150 kg N ha^{-1}	97.8 a	103.1 a	100.5	96.5	99.5 A
S.E.M. (LSD)	0.25 (0.67)				0.13

[Z] 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table A-5. Least squares means for row spacing by nitrogen rate interactions on canola seed yield at Indian Head (2013-16).

Seed Rate	Seed Yield 2013 [Z]	2014	2015	2016	Mean
	----------	----------	kg ha^{-1}	----------	----------
			25 cm row spacing		
6 kg N ha^{-1}	2515	623	1366	1415	1511 I
50 kg N ha^{-1}	3167	1629	2175	2406	2366 G
100 kg N ha^{-1}	3625	2637	2942	3326	3140 DE
150 kg N ha^{-1}	3860	3424	3408	3935	3647 A
			30 cm row spacing		
6 kg N ha^{-1}	2504	725	1352	1423	1535 I
50 kg N ha^{-1}	3053	1820	2241	2268	2345 G
100 kg N ha^{-1}	3469	2806	3205	3122	3156 DE
150 kg N ha^{-1}	3553	3411	3421	3635	3505 AB
			36 cm row spacing		
6 kg N ha^{-1}	2483	732	1415	1344	1511 I
50 kg N ha^{-1}	3015	1637	2280	2205	2294 G
100 kg N ha^{-1}	3362	2586	3031	3094	3014 DE
150 kg N ha^{-1}	3471	3369	3362	3328	3380 BC
			41 cm row spacing [Z]		
6 kg N ha^{-1}	—	718	1396	1535	1389 I
50 kg N ha^{-1}	—	1643	2279	2296	2245 G
100 kg N ha^{-1}	—	2615	2976	3126	3078 DE
150 kg N ha^{-1}	—	3389	3362	3421	3368 BC
			61 cm row spacing		
6 kg N ha^{-1}	2885	850	1938	1780	1863 H
50 kg N ha^{-1}	3334	1944	2642	2680	2650 F
100 kg N ha^{-1}	3623	2894	3115	3376	3252 CD
150 kg N ha^{-1}	3622	3547	3424	3625	3554 AB
S.E.M. (LSD)	----------	----------	95.0 (247.1)	----------	49.1

[Z] 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table A-6. Least squares means for row spacing by nitrogen rate interactions on canola thousand kernel weight at Indian Head (2013-16).

Seed Rate	Thousand Kernel Weight				
	2013 [Z]	2014	2015	2016	Mean
	g/1000 seeds				
			25 cm row spacing		
6 kg N ha^{-1}	3.08	3.87	2.82	3.43	3.28 AB
50 kg N ha^{-1}	3.01	3.32	2.72	3.19	3.06 EF
100 kg N ha^{-1}	3.01	3.18	2.84	3.15	3.05 EF
150 kg N ha^{-1}	3.06	3.27	2.99	3.22	3.14 DE
			30 cm row spacing		
6 kg N ha^{-1}	3.09	3.91	2.79	3.43	3.28 AB
50 kg N ha^{-1}	3.08	3.30	2.68	3.27	3.08 DEF
100 kg N ha^{-1}	3.07	3.30	2.80	3.15	3.08 DEF
150 kg N ha^{-1}	3.10	3.26	3.01	3.23	3.15 DE
			36 cm row spacing		
6 kg N ha^{-1}	3.11	3.70	2.80	3.42	3.25 BC
50 kg N ha^{-1}	3.03	3.29	2.72	3.23	3.07 DEF
100 kg N ha^{-1}	2.99	3.11	2.80	3.19	3.04 F
150 kg N ha^{-1}	3.01	3.28	2.98	3.21	3.13 DEF
			41 cm row spacing [Z]		
6 kg N ha^{-1}	—	3.87	2.80	3.41	3.32 AB
50 kg N ha^{-1}	—	3.41	2.70	3.22	3.07 DEF
100 kg N ha^{-1}	—	3.25	2.88	3.16	3.06 DEF
150 kg N ha^{-1}	—	3.28	2.93	3.27	3.11 DEF
			61 cm row spacing		
6 kg N ha^{-1}	3.13	3.97	2.99	3.33	3.36 A
50 kg N ha^{-1}	3.02	3.43	2.87	3.20	3.13 DEF
100 kg N ha^{-1}	2.97	3.32	2.92	3.17	3.09 DEF
150 kg N ha^{-1}	2.94	3.43	3.01	3.26	3.16 CD
S.E.M. (LSD)	0.043 (0.116)				0.022

[Z] 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table A-7 Least squares means for row spacing by nitrogen rate interactions on canola seed nitrogen concentrations at Indian Head (2013-16).

Seed Rate	Seed Nitrogen Concentration				
	2013 [Z]	2014	2015	2016	Mean
	---------- $g\ 100\ g^{-1}$ ----------				
			25 cm row spacing		
6 kg N ha^{-1}	2.17 f	2.77 cde	2.80 h	–	–
50 kg N ha^{-1}	2.47 de	2.46 ijk	2.76 h	–	–
100 kg N ha^{-1}	2.87 c	2.53 g-j	2.98 f	–	–
150 kg N ha^{-1}	3.61 a	2.91 bc	3.33 bc	–	–
			30 cm row spacing		
6 kg N ha^{-1}	2.24 f	2.79 cde	2.79 h	–	–
50 kg N ha^{-1}	2.49 de	2.45 jk	2.77 h	–	–
100 kg N ha^{-1}	2.86 c	2.68 d-g	3.04 f	–	–
150 kg N ha^{-1}	3.15 b	2.82 cd	3.36 b	–	–
			36 cm row spacing		
6 kg N ha^{-1}	2.22 f	2.76 cde	2.76 h	–	–
50 kg N ha^{-1}	2.46 de	2.37 k	2.74 h	–	–
100 kg N ha^{-1}	2.90 c	2.49 h-k	3.05 ef	–	–
150 kg N ha^{-1}	3.15 b	2.82 cd	3.37 b	–	–
			41 cm row spacing [Z]		
6 kg N ha^{-1}	—	2.75 de	2.84 gh	–	–
50 kg N ha^{-1}	—	2.52 hij	2.81 h	–	–
100 kg N ha^{-1}	—	2.61 fgh	3.16 de	–	–
150 kg N ha^{-1}	—	2.98 ab	3.41 b	–	–
			61 cm row s pacing		
6 kg N ha^{-1}	2.40 e	2.06 a	2.95 fg	–	–
50 kg N ha^{-1}	2.59 d	2.60 f-i	2.96 f	–	–
100 kg N ha^{-1}	2.94 c	2.68 ef	3.24 cd	–	–
150 kg N ha^{-1}	3.25 b	3.09 a	3.59 a	–	–
S.E.M. (LSD)		–			–

[Z] 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table A-8. Least squares means for row spacing by nitrogen rate interactions on canola seed N exports

at Indian Head (2013-16).					
Seed Rate	**Seed Nitrogen Exports**				
	2013 Z	**2014**	**2015**	**2016**	**Mean**
	-- kg N ha^{-1} --				
			25 cm row spacing		
6 kg N ha^{-1}	54.5 h	17.1 h	38.3 i	–	–
50 kg N ha^{-1}	78.4 fg	40.0 f	60.2 gh	–	–
100 kg N ha^{-1}	104.0 cde	66.8 d	87.7 e	–	–
150 kg N ha^{-1}	139.3 a	100.2 b	113.7 b	–	–
			30 cm row spacing		
6 kg N ha^{-1}	56.5 h	20.5 gh	37.7 i	–	–
50 kg N ha^{-1}	76.3 g	44.8 ef	62.2 gh	–	–
100 kg N ha^{-1}	99.3 de	75.6 c	97.4 cd	–	–
150 kg N ha^{-1}	112.0 bc	96.1 b	114.8 b	–	–
			36 cm row spacing		
6 kg N ha^{-1}	55.1 h	21.0 gh	39.1 i	–	–
50 kg N ha^{-1}	74.2 g	39.2 f	62.7 gh	–	–
100 kg N ha^{-1}	97.6 e	64.3 d	92.6 de	–	–
150 kg N ha^{-1}	109.6 bc	94.6 b	113.3 b	–	–
			41 cm row spacing Z		
6 kg N ha^{-1}	–	19.7 gh	39.7 i	–	–
50 kg N ha^{-1}	–	41.0 f	64.0 g	–	–
100 kg N ha^{-1}	–	68.2 d	94.0 de	–	–
150 kg N ha^{-1}	–	100.7 b	114.7 b	–	–
			61 cm row spacing		
6 kg N ha^{-1}	69.7 g	26.1 g	57.2 h	–	–
50 kg N ha^{-1}	86.3 f	50.6 e	78.2 f	–	–
100 kg N ha^{-1}	106.5 cd	77.6 c	101.2 c	–	–
150 kg N ha^{-1}	117.7 b	109.4 a	122.9 a	–	–
S.E.M. (LSD)		–			–

Z 41 cm row spacing treatments excluded in 2014 due to a seeding error

Table B-1. Dates of selected field operations and data collection activities completed in canola row spacing Experiment #2 (Row Spacing × Seeding Rates) at Indian Head (2013-16).				
Operation / Collection	**2013**	**2014**	**2015**	**2016**
Previous Crop	Spring Wheat	Canaryseed	Spring Wheat	Barley
K_2SO_4 broadcast application	May-29	May-13	May-7	May-8
Pre-seed herbicide	May-29 (890 g glyphosate ha^{-1} + 18 g carfentrazone ha^{-1})	May-18 (890 g glyphosate ha^{-1})	May-9 (890 g glyphosate ha^{-1} + 18 g carfentrazone ha^{-1})	May-15 (890 g glyphosate ha^{-1})
Cultivar	InVigor L130	InVigor L130	InVigor L140P	InVigor L140P
Seeding Date	May-31	May-13	May-12	May-18
In-crop herbicide application(s)	Jun-17 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jun-12 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jun-15 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jun-15 (593 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})
	Jul-2 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})	Jul-7 (211 g sethoxydim ha^{-1})	—	—
Plant densities	Jun-27	Jun-6 (Reps 1-2) Jun-9 (Reps 3-4)	Jun-8	Jun-6
Foliar insecticide	—	—	May-27 (6.5 g deltamethrin ha^{-1})	—
Foliar fungicide	Jul-12 (246 g boscalid ha^{-1}) Jul-15 (246 g boscalid ha^{-1})	Jul-9 (246 g boscalid ha^{-1})	Jul-3 (246 g boscalid ha^{-1})	Jul-5 (246 g boscalid ha^{-1})
Pre-harvest application	n/a	Sep-5 (890 g glyphosate ha^{-1}) Sep-11 (415 g diquat ha^{-1})	Aug-26 (890 g glyphosate ha^{-1})	Aug-29 (890 g glyphosate ha^{-1})
Straight-Combined	Sep-16 (90-120 seeds m^{-2}) Sep-21 (30-60 seeds m^{-2})	Sep-16 (all plots)	Sep-4 (all plots)	Sep-14 (all)

[Z] Seeding rates varied as per protocol

Table B-2. Least squares means for row spacing by seed rate interactions on canola plant density at Indian Head (2013-16).

Seed Rate	Plant Density 2013	2014	2015	2016	Mean
	---------- plants m^{-2} ----------				
			25 cm row spacing		
30 seeds m^{-2}	24	32	46	49	38 I
60 seeds m^{-2}	42	45	81	82	63 FG
90 seeds m^{-2}	74	48	105	95	80 C
120 seeds m^{-2}	84	74	118	133	102 A
			30 cm row spacing		
30 seeds m^{-2}	21	26	33	55	34 IJ
60 seeds m^{-2}	49	52	69	72	60 FG
90 seeds m^{-2}	63	70	83	84	75 CD
120 seeds m^{-2}	84	79	113	125	100 AB
			36 cm row spacing		
30 seeds m^{-2}	19	25	35	32	28 JK
60 seeds m^{-2}	45	51	68	63	57 GH
90 seeds m^{-2}	55	60	76	92	70 DE
120 seeds m^{-2}	77	81	108	118	96 AB
			41 cm row spacing		
30 seeds m^{-2}	21	22	33	33	27 JK
60 seeds m^{-2}	36	45	60	63	51 H
90 seeds m^{-2}	54	57	85	97	73 D
120 seeds m^{-2}	71	73	115	116	94 B
			61 cm row spacing		
30 seeds m^{-2}	14	27	26	31	25 K
60 seeds m^{-2}	24	35	39	60	40 I
90 seeds m^{-2}	33	58	64	71	57 GH
120 seeds m^{-2}	42	54	69	92	64 EF
S.E.M. (LSD)	---------- 5.7 (15.4) ----------				2.9

Table B-3. Least squares means for row spacing by seed rate interactions on canola flowering period at Indian Head (2013-16).

Seed Rate	Flowering Period 2013	2014	2015	2016	Mean
	---------- days in bloom ----------				
			25 cm row spacing		
30 seeds m^{-2}	38.9	41.6	28.0	26.5	33.7 AB
60 seeds m^{-2}	37.1	36.6	26.9	25.1	31.4 DEF
90 seeds m^{-2}	35.6	34.4	25.8	24.6	30.1 HI
120 seeds m^{-2}	35.1	30.9	25.1	24.3	28.8 K
			30 cm row spacing		
30 seeds m^{-2}	39.4	40.6	28.3	26.5	33.7 B
60 seeds m^{-2}	37.5	36.8	26.8	25.1	31.5 DE
90 seeds m^{-2}	36.3	34.1	26.0	24.9	30.3 H
120 seeds m^{-2}	35.3	31.4	25.4	24.6	29.2 JK
			36 cm row spacing		
30 seeds m^{-2}	39.6	41.1	28.3	26.8	33.9 AB
60 seeds m^{-2}	37.6	37.1	27.1	25.4	31.8 CD
90 seeds m^{-2}	36.9	35.4	26.4	25.0	30.9 FG
120 seeds m^{-2}	35.8	30.1	25.6	24.9	29.1 JK
			41 cm row spacing		
30 seeds m^{-2}	39.8	41.1	28.6	26.8	34.1 AB
60 seeds m^{-2}	38.3	34.9	27.4	26.3	31.7 D
90 seeds m^{-2}	37.1	32.4	26.6	25.4	30.4 GH
120 seeds m^{-2}	36.8	30.9	25.9	25.0	29.6 IJ
			61 cm row spacing		
30 seeds m^{-2}	40.6	39.4	29.4	27.6	34.2 A
60 seeds m^{-2}	39.5	33.7	29.0	26.9	32.3 C
90 seeds m^{-2}	38.8	32.2	28.1	26.1	31.3 DEF
120 seeds m^{-2}	38.4	32.4	27.5	25.9	31.0 EF
S.E.M. (LSD)	---------- 0.55 (1.43) ----------				0.28

Table B-4. Least squares means for row spacing by seed rate interactions on canola flowering period at Indian Head (2013-16).

Seed Rate	Maturity				
	2013	2014	2015	2016	Mean
	------------------------------------ days from planting ------------------------------------				
25 cm row spacing					
30 seeds m^{-2}	98.6	115.8	99.8	97.1	102.8 B
60 seeds m^{-2}	97.3	110.8	98.9	96.3	100.8 CDE
90 seeds m^{-2}	96.5	107.5	97.6	95.9	99.4 G
120 seeds m^{-2}	95.8	102.8	97.4	95.4	97.8 H
30 cm row spacing					
30 seeds m^{-2}	98.6	114.9	100.0	97.5	102.8 B
60 seeds m^{-2}	97.5	109.3	99.0	96.6	100.6 DEF
90 seeds m^{-2}	97.0	106.7	98.0	96.0	99.4 G
120 seeds m^{-2}	96.0	102.6	97.5	95.5	97.9 H
36 cm row spacing					
30 seeds m^{-2}	99.3	117.4	100.5	98.0	103.8 A
60 seeds m^{-2}	97.8	110.4	99.1	97.1	101.1 D
90 seeds m^{-2}	97.4	106.4	98.9	96.6	99.8 FG
120 seeds m^{-2}	96.4	101.4	97.6	95.9	97.8 H
41 cm row spacing					
30 seeds m^{-2}	99.1	117.3	100.8	98.0	103.8 A
60 seeds m^{-2}	97.9	108.9	99.8	97.1	100.9 CD
90 seeds m^{-2}	97.3	104.5	99.1	96.6	99.4 FG
120 seeds m^{-2}	96.6	102.6	98.3	96.1	98.4 H
61 cm row spacing					
30 seeds m^{-2}	100.5	115.4	102.0	98.4	104.1 A
60 seeds m^{-2}	98.6	108.9	101.0	97.5	101.5 C
90 seeds m^{-2}	97.9	105.4	99.9	97.4	100.1 EFG
120 seeds m^{-2}	97.5	104.6	99.6	96.6	99.6 G
S.E.M. (LSD)	------------------------------ 0.72 (1.88) ------------------------------				0.37

Table B-5 Least squares means for row spacing by seed rate interactions on canola seed yield at Indian Head (2013-16).

Seed Rate	Seed Yield				
	2013	2014	2015	2016	Mean
	kg/ha				
25 cm row spacing					
30 seeds m^{-2}	3251	2519	3238	3955	3241 DEF
60 seeds m^{-2}	3527	2762	3302	4008	3400 AB
90 seeds m^{-2}	3482	2895	3181	3886	3361 BC
120 seeds m^{-2}	3517	2997	3205	3745	3366 BC
30 cm row spacing					
30 seeds m^{-2}	2980	2769	3143	3842	3184 F
60 seeds m^{-2}	3191	2832	3184	3806	3253 DEF
90 seeds m^{-2}	3258	2876	3207	3710	3263 DEF
120 seeds m^{-2}	3298	2915	3194	3664	3268 DEF
36 cm row spacing					
30 seeds m^{-2}	3062	2700	3084	3981	3207 DEF
60 seeds m^{-2}	3227	3072	3190	3664	3288 CDE
90 seeds m^{-2}	3196	2866	3156	3557	3194 EF
120 seeds m^{-2}	3262	2968	3223	3437	3222 DEF
41 cm row spacing					
30 seeds m^{-2}	2920	2577	3035	3689	3055 G
60 seeds m^{-2}	3209	2870	3221	3634	3234 DEF
90 seeds m^{-2}	3189	2938	3178	3614	3230 DEF
120 seeds m^{-2}	3292	2925	3217	3471	3226 DEF
61 cm row spacing					
30 seeds m^{-2}	3111	2787	3265	4028	3298 CD
60 seeds m^{-2}	3435	3015	3381	4068	3475 A
90 seeds m^{-2}	3293	2989	3428	3935	3411 AB
120 seeds m^{-2}	3383	3119	3460	3906	3467 A
S.E.M. (LSD)	107.6 (272.2)				54.0

Table B-6. Least squares means for row spacing by seed rate interactions on canola thousand kernel weight at Indian Head (2013-16).

Seed Rate	Thousand Seed Weight 2013	2014	2015	2016	Mean
	-- g/1000 seeds --				
			25 cm row spacing		
30 seeds m^{-2}	2.95	3.05	3.02	3.08	3.06 C-F
60 seeds m^{-2}	2.91	3.21	2.99	3.07	3.05 DEF
90 seeds m^{-2}	2.94	3.23	2.90	3.07	3.05 EF
120 seeds m^{-2}	2.96	3.27	2.91	3.09	3.07 C-F
			30 cm row spacing		
30 seeds m^{-2}	2.98	3.11	3.04	3.21	3.09 B-E
60 seeds m^{-2}	3.01	3.19	2.96	3.10	3.09 B-E
90 seeds m^{-2}	3.00	3.24	2.95	3.13	3.08 C-F
120 seeds m^{-2}	3.00	3.19	2.89	3.12	3.06 C-F
			36 cm row spacing		
30 seeds m^{-2}	2.95	3.05	3.02	3.23	3.06 C-F
60 seeds m^{-2}	2.95	3.20	2.97	3.20	3.07 C-F
90 seeds m^{-2}	2.96	3.26	2.92	3.13	3.07 C-F
120 seeds m^{-2}	2.97	3.15	2.89	3.18	3.03 F
			41 cm row spacing		
30 seeds m^{-2}	2.89	3.08	3.00	3.22	3.05 EF
60 seeds m^{-2}	2.92	3.26	3.01	3.17	3.09 CDE
90 seeds m^{-2}	2.92	3.24	2.98	3.15	3.07 C-F
120 seeds m^{-2}	2.92	3.19	2.93	3.12	3.04 F
			61 cm row spacing		
30 seeds m^{-2}	2.86	3.25	3.08	3.26	3.10 BC
60 seeds m^{-2}	2.85	3.30	3.07	3.15	3.10 AC
90 seeds m^{-2}	2.91	3.30	3.07	3.16	3.15 A
120 seeds m^{-2}	2.93	3.30	3.09	3.12	3.13 AB
S.E.M. (LSD)	----------------------------- 0.044 (0.115) -----------------------------				0.022

Table B-7. Least squares means for row spacing by seed rate interactions on percent green canola seed at Indian Head (2013-16).

Seed Rate	Green Seed 2013	2014	2015	2016	Mean
	----------	----------	%	----------	----------
			25 cm row spacing		
30 seeds m^{-2}	0.40	7.46	0.40	0.00	2.07 A
60 seeds m^{-2}	0.20	2.56	0.45	0.10	0.83 BC
90 seeds m^{-2}	0.60	0.77	0.20	0.05	0.40 CD
120 seeds m^{-2}	0.35	0.06	0.15	0.05	0.15 CD
			30 cm row spacing		
30 seeds m^{-2}	0.35	2.22	0.35	0.05	0.74 CD
60 seeds m^{-2}	0.20	1.00	0.45	0.25	0.48 CD
90 seeds m^{-2}	0.25	0.95	0.30	0.00	0.38 CD
120 seeds m^{-2}	0.25	0.15	0.25	0.05	0.18 CD
			36 cm row spacing		
30 seeds m^{-2}	0.40	5.06	0.45	0.05	1.49 AB
60 seeds m^{-2}	0.15	3.06	0.10	0.10	0.85 BC
90 seeds m^{-2}	0.60	0.36	0.45	0.10	0.38 CD
120 seeds m^{-2}	0.35	-0.34	0.05	0.10	0.04 D
			41 cm row spacing		
30 seeds m^{-2}	0.25	5.35	0.60	0.10	1.58 A
60 seeds m^{-2}	0.25	0.40	0.30	0.20	0.29 CD
90 seeds m^{-2}	0.35	0.45	0.30	0.05	0.29 CD
120 seeds m^{-2}	0.15	0.45	0.40	0.10	0.28 CD
			61 cm row spacing		
30 seeds m^{-2}	0.90	4.01	0.55	0.35	1.45 AB
60 seeds m^{-2}	0.35	1.01	0.55	0.05	0.49 CD
90 seeds m^{-2}	0.55	0.21	0.40	0.10	0.31 CD
120 seeds m^{-2}	0.80	0.27	0.40	0.05	0.38 CD
S.E.M. (LSD)	----------	----------	0.595 (1.591)	----------	0.298

Table C-1. Dates of selected field operations and data collection activities completed in canola row spacing Experiment #3 (Row Spacing × Herbicide Treatment) at Indian Head (2013-15).			
Operation / Collection	**2013**	**2014**	**2015**
Previous Crop	Spring Wheat	Canaryseed	Spring Wheat
K_2SO_4 broadcast application	May-29	May 13	May 7
Pre-seed herbicide	May-29 (890 g glyphosate ha^{-1} + 18 g carfentrazone-ethyl ha^{-1})	May-18 (890 g glyphosate ha^{-1})	May-9 (890 g glyphosate ha^{-1} + 18 g carfentrazone ha^{-1})
Cultivar	InVigor L130	InVigor L130	InVigor L140P
Seeding Rate	115 seeds m^{-2}	115 seeds m^{-2}	115 seeds m^{-2}
Seeding Date	May-31	May 13	May 12
In-crop herbicide application [Z]	Jun-28 (593 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1}	Jun-25 (593 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1}	Jun-15 (500 g glufonisnate-ammonium ha^{-1} + 30 g clethodim ha^{-1})
Foliar insecticide	—	—	May-27 (6.5 g deltamethrin ha^{-1})
Foliar fungicide	Jul-12 (246 g boscalid ha^{-1}) Jul-15 (246 g boscalid ha^{-1})	Jul-9 (246 g boscalid ha^{-1})	Jul-3 (246 g boscalid ha^{-1})
Crop / Weed Biomass	Aug-13	Aug-5	Aug-18
Pre-harvest application	n/a	Sep-5 (890 g glyphosate ha^{-1}) Sep-11 (415 g diquat ha^{-1})	Aug-27 (890 g glyphosate ha^{-1})
Straight-Combined	Sep-16	Sep-13	Sept-3 (all treatments)

[Z] In-crop herbicides applied as per protocol

Table C-2. Least squares means for row spacing by in-crop herbicide interactions on canola above-ground biomass at Indian Head (2013-15).

Herbicide Treatment	Above-Ground Crop Biomass 2013	2014	2015	Mean
	---------- kg ha^{-1} ----------			
		25 cm row spacing		
Unsprayed	6093	4990	10570	7217 CD
Sprayed	10797	6398	11623	9606 A
		30 cm row spacing		
Unsprayed	6972	4618	8980	6856 D
Sprayed	9326	6242	9688	8418 B
		36 cm row spacing		
Unsprayed	7347	3466	10048	6953 CD
Sprayed	8936	4675	9330	7647 BCD
		41 cm row spacing		
Unsprayed	5918	3863	8044	5942 E
Sprayed	8871	4971	9419	7754 BC
		61 cm row spacing		
Unsprayed	4819	3691	7652	5387 E
Sprayed	7193	4872	8361	6809 D
S.E.M. (LSD)	---------- 560.8 (1553.3) ----------			324.8

Table C-3. Least squares means for row spacing by in-crop herbicide interactions on weed biomass at Indian Head (2013-15).

Herbicide Treatment	Weed Biomass 2013	2014	2015	Mean
	------------------------- kg ha^{-1} -------------------------			
	25 cm row spacing			
Unsprayed	3046	2726	82	1952 AB
Sprayed	10	22	25	19 C
	30 cm row spacing			
Unsprayed	2559	1882	77	1506 B
Sprayed	53	0	29	28 C
	36 cm row spacing			
Unsprayed	2977	2752	162	1964 AB
Sprayed	18	19	26	21 C
	41 cm row spacing			
Unsprayed	2651	2104	84	1613 B
Sprayed	25	0	30	18 C
	61 cm row spacing			
Unsprayed	3921	2648	439	2336 A
Sprayed	201	25	40	88 C
S.E.M. (LSD)	------------- 355.9 (965.2) -------------			205.5

Table C-4. Least squares means for row spacing by in-crop herbicide interactions on canola seed yield at Indian Head (2013-15).

Herbicide Treatment	Seed Yield			
	2013	2014	2015	Mean
	---------- kg ha^{-1} ----------			
	25 cm row spacing			
Unsprayed	2154	2192	3107	2484 CD
Sprayed	3629	2921	3266	3272 A
	30 cm row spacing			
Unsprayed	2044	2418	3099	2521 CD
Sprayed	3271	2875	3131	3092 AB
	36 cm row spacing			
Unsprayed	1751	2052	3054	2286 D
Sprayed	3249	2727	3066	3014 B
	41 cm row spacing			
Unsprayed	1782	2267	3004	2351 CD
Sprayed	3155	2923	3000	3026 B
	61 cm row spacing			
Unsprayed	2069	2330	3194	2531 C
Sprayed	2858	2894	3314	3022 B
S.E.M. (LSD)	---------- 155.9 (431.7) ----------			90.0