2015 Annual 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

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Executive Summary:

In response to interest among canola growers and equipment manufacturers, a project was initiated in 2012 at Indian Head, Saskatchewan. The objectives were to evaluate canola performance at row spacing levels exceeding the conventional 25-30 cm commonly used in Saskatchewan and to investigate potential implications of growing canola at up to 61 cm row spacing. Three separate field trials were designed to evaluate row spacing implications for side-banded nitrogen (N) and seeding rate recommendations along with potential impacts on crop competition with weeds. The treatments included five row spacing levels (25, 30, 36, 41 and 61 cm) combined with side-banded N fertilizer rates (0, 50, 100 and 150 kg N ha^{-1}), seeding rates (30, 60, 90 and 120 seeds m^{-2}) or herbicide treatments (no in-crop herbicide, in-crop herbicide applied).

Broadly speaking, canola plant densities declined as row spacing was increased due to higher competition amongst seedlings within each row; however, the reductions were normally too small to be of major agronomic concern and statistically significant differences amongst 25-41 cm row spacing treatments were relatively rare. Increasing row spacing resulted in slight but significant delays in maturity; however, the delays caused by row spacing were usually much smaller than those caused by N fertilizer or seeding rate. Averaged across other factors, row spacing effects on seed yield were small or non-significant but there were cases where higher yields were achieved at the 25 cm row spacing, particularly in 2013. In this case, there were no further declines from 30-61 cm and the observed advantage to 25 cm may have been due to bias introduced while harvesting the plots. In 2014, yields were equal at all row spacing levels and in 2015 the highest mean yields were typically achieved at 61 cm. Row spacing effects on seed size were small and somewhat inconsistent with a slight reduction in seed size with increasing spacing in 2013 but a trend towards the opposite (i.e. larger seeds at wider spacing) in 2014 and 2015. Percent green seed increased slightly with increasing row spacing in 2013 and 2015, particularly when row spacing was increased to 61 cm, but was always still below 1%. In 2014 there was no effect of row spacing on green seed; however, seeding rate had a large impact on this variable under the wet, cool conditions encountered in this year.

Focussing on implications for side-banded N recommendations, there was a reduction in emergence with 100-150 kg ha^{-1} of side-banded N in all three years and a significant interaction between row spacing and N rate in 2014 but not 2013 or 2015. The significant RS × NR interaction in 2014 was due to reduced emergence with increasing N rate at the 25 and 61 cm row spacing levels but not at 30-41 cm spacing; thus, did not suggest that potential for seedling toxicity was worse at wider row spacing especially when considered with the results from other seasons. Despite the effects on emergence, canola responded well to side-banded N overall with sequentially increasing yields right up to 150 kg N ha^{-1} in all three years and maximum yield increases of 40%, 370% and 127% in 2013, 2014 and 2015, respectively. In 2/3 years, significant RS × NR interactions appeared to be due to higher yields at 61 cm relative to the narrower row spacing treatments in the 0N control but not in the fertilized plots. This may have partly been due to a maturity effect (i.e. higher shattering losses with low fertility combined with narrow row spacing) and also contributed to the overall yield bump observed at the widest row spacing during these years. Increasing N rate had small and inconsistent effects on seed size. An interaction in 2013 suggested that the negative impact of N rate on seed size was most prominent at 36-61 cm row spacing where banded N was more concentrated; however row spacing had no effect on seed size in 2014 and a positive effect in 2015. Percent seed N was not affected by row spacing in 2013 but increased slightly with increasing row spacing in 2014, possibly due to more concentrated N bands combined with the strong yield response to N. Agronomic nitrogen use-efficiency, on the other hand, was affected by row spacing in 2013 but was lowest at 61 cm, largely a result of higher yields in the control plots at this spacing combined with a relatively strong yield response to N fertilization at the narrowest spacing. ANUE was unaffected by N rate in 2013 but increased with increasing N rate in 2014, which was a reflection of the extremely strong overall yield response to N combined with higher seed N concentrations as the N rate was increased. Seed N concentration and ANUE data for 2015 are not available at this time. Overall,

results to date suggest that N requirements of canola are likely similar regardless of row spacing, particular for the range of 25-41 cm; however, very high rates of side-banded N combined with wide row spacing may increase the risk of seedling injury.

The seeding rates of 1.5, 3.0, 4.5 and 6.0 kg ha^{-1} corresponded to approximately 30-120 seeds m^{-2}. Averaged across row spacing levels, the respective plant densities were 20-71 plants m^{-2} in 2013, 24-72 plants m^{-2} in 2014 and 35-105 seeds m^{-2} in 2015. Interactions with row spacing were detected all three years years whereby plant populations were not reduced with increasing row spacing (or were affected to a lesser extent) at the lowest seeding rate while, at the widest row spacing, there were no further increases in plant density when seeding rates were increased beyond 4.5 kg ha^{-1}. Under the conditions encountered to date, only the lowest seeding rate has resulted in plant populations below the minimum threshold of 40 plants m^{-2} except at 61 cm row spacing where 3.0-4.5 kg ha^{-1} has been required to reach this commonly recommended minimum threshold. Seeding rate had a greater and more consistent impact on flowering and maturity than row spacing, especially in 2014 where maturity was delayed by nearly two weeks at the lowest seeding rate. Similar yields were achieved with seeding rates from 3.0-6.0 kg seed ha^{-1} in all three years; however, yields were reduced by 3-9% at the 1.5 kg ha^{-1} seeding rate. Seeding rate effects on seed size were inconsistent but percent green seed was consistently reduced as seeding rate was increased, regardless of row spacing and especially in 2014. Based on these results, it would not be recommended to reduce canola seeding rates while implementing wider row spacing, especially considering that emergence was reduced as row spacing increased for all but the lowest seeding rate and, at the widest spacing, higher seeding rates were required to achieve final populations of $\geq$ 40 plants m^{-2}. That being said, there was no advantage to increasing seeding rates past 4.5 kg ha^{-1} at 61 cm row spacing as plant populations appeared to have been maximized at this point; thus increasing seeding rates beyond approximately 90 seeds m^{-2} was not beneficial at this row spacing despite the lower overall plant populations. It is important to note that overall emergence and seedling survival has been excellent over the duration of this study and moisture availability was, for the most part, not limiting. Under these conditions yield penalties or major agronomic issues did not occur at seeding rates as low as 60 seeds m^{-2}; however, these results would not be expected under less favourable conditions and such low seeding rates should be considered high risk.

To assess potential impacts on crop competition with weeds, canola was grown with and without herbicide at each row spacing level. While there was a consistent overall linear decline in above-ground crop biomass with increasing row spacing, weed biomass yield was not affected in either 2013 or 2014 (under heavy pressure). In 2015, while overall weed competition was much lower, significantly higher weed biomass was detected at 61 cm row spacing relative to any of the narrower treatments. There was, however, a significant interaction detected whereby this only occurred when no in-crop herbicides were applied. Despite extremely high weed pressure in 2/3 years, a single in-crop herbicide application kept weed competition acceptably low at all row spacing levels. It is generally accepted that the ability of crops to compete with weeds may be compromised at wide row spacing; however, this study has not shown 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 with similar losses regardless of row spacing.

This research is in progress with a final year of field trials continuing in 2016.

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 similar (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.

While the conclusions of the past research discussed thus far are varied, one factor that each of these studies shared in common was that nitrogen (N) fertilizer was always broadcast and incorporated. This would potentially favour narrow row spacing in two ways which, with current equipment, typically no longer apply on 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 under some conditions. 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, agronomic N-use efficiency (ANUE) could conceivably be increased with wider row spacing because the fertilizer becomes more concentrated and thereby less susceptible to immobilization and available to weeds, but still in close proximity to the canola plants. On the other hand, banded fertilizer becomes more concentrated as row spacing increases which could also increase the potential for seedling injury in cases where seed-fertilizer separation is inadequate.

Another factor that may be affected by row spacing is crop establishment and 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. In Manitoba, Morrison et al. (1994) detected row spacing by seeding rate interactions 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 observed and due to increased 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 cultivars can compensate well at low plant populations, grain quality and days to maturity were often adversely affected when plant densities fell below 20 plants m^{-2} (Kirk et al. 2013).

From a weed management perspective, it is generally accepted that the ability of crops to compete with weeds is reduced 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.

With all of the improvements in canola varieties, fertilizer management and seeding equipment over the past twenty years, revisiting the topic of row spacing in this crop is well justified. To be 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. If growing canola at wider row spacing proves viable, the economic benefits to growers in Saskatchewan will be substantial. While it is, at best, questionable whether lower seed or N fertilizer rates could 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 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 are 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) Evaluate potential interactions between row spacing and seeding rate to determine whether lower seeding rates can be safely 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 in 2013, 2014 and 2015 near Indian Head, Saskatchewan (50˚33'N 103˚39'W). While the trial was initiated in 2012, the data from this season was considered unreliable and was excluded because 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. The average (1981-2010) annual precipitation is 428 mm and the mean frost free period is 113 days (Environment Canada 2016). The specific fields where the trials were located have been managed in long-term (greater than 10 years) 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 three trials were established adjacent to each other in all years and all aspects of the trials 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:

Experiment #1: Row Spacing by Nitrogen Rates (20 treatments)

A. *Row Spacing (main plots)*	B. *N Fertilizer Rate (sub-plots)*
1) 25 cm (10”)	1) 0 kg ha^{-1} N
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”)	

Experiment #2: Row Spacing by Seeding Rate (20 treatments)

A. *Row Spacing (main plots)*	B. *Seeding rate (sub-plots)*
1) 25 cm (10”)	1) 1.5 kg ha^{-1} (29 seeds m^{-2})
2) 30 cm (12”)	2) 3.0 kg ha^{-1} (58 seeds m^{-2})
3) 36 cm (14”)	3) 4.5 kg ha^{-1} (87 seeds m^{-2})
4) 41 cm (16”)	4) 6.0 kg ha^{-1} (116 seeds m^{-2})
5) 61 cm (24”)	

Experiment #3: Row Spacing by Herbicide (10 treatments)

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(s) 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 (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 half of the plots did not receive any in-crop herbicides. When the canola had finished flowering and the pods and 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 in many cases 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 the agronomic nitrogen use efficiency (ANUE) of the applied fertilizer (fertilized plots only). The formula for ANUE is provided below where *GNfert* is kg N ha^{-1} removed in the fertilized plot, *GNcheck* is kg N ha^{-1} removed in the unfertilized check and *Napplied* is kg N ha^{-1} of applied fertilizer N.

$$ANUE = \left(\frac{(GNfert - GNcheck)}{Napplied}\right) \times 100$$

For each of the three experiments, response data were analysed separately for each year using a mixed model (Proc Mixed) for a split plot design in SAS 9. 3. The effects of row spacing (RS) and either N rate (NR), seeding rate (SR) or herbicide treatment (HERB) along with their interactions were considered fixed while the effect of replicate was considered random. 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. To help facilitate closer inspection of significant treatment interactions, separate orthogonal contrasts to describe the response to N and seed rates were conducted at each row spacing level. All treatment effects, differences between means and orthogonal contrast results were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION:

<u>*Weather conditions*</u>

Mean monthly temperatures and precipitation amounts for the 2013, 2014 and 2015 growing seasons (May-August) are provided in Table 1. Over the 4-month growing season, temperatures were slightly below the long-term average in all three years, particularly in 2014 which was nearly a full degree Celsius cooler on average and especially cool in June and July. The timing and quantity of precipitation varied widely but, in general, canola yields were not limited by lack of moisture during this three 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.

Table 1. Mean monthly temperatures and precipitation amounts for the 2013-15 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
Long-term	10.8	15.8	18.2	17.4	15.6
	------------------------------------ Precipitation (mm) ------------------------------------				
2013	17.1	103.8	50.4	6.1	160
2014	36.0	199.2	7.8	142.2	385
2015	15.6	38.3	94.6	58.8	207
Long-term	51.8	77.4	63.8	51.2	244

[Z] Environment Canada 2016

Experiment #1: Row Spacing × Nitrogen Fertilizer Rates

In experiment #1, plant densities were affected by both row spacing (*P* < 0.001-0.05) and N rate (*P* < 0.001) in each of the three years (Table A-2). While a significant RS × NR interaction was not detected for plant density in 2013 or 2015 (*P* = 0.10-0.11), in 2014 the interaction was significant (*P* = 0.016). Overall, canola plant densities were reduced with both increasing row spacing and with increasing side-banded N rates (Table 2). On average, plant densities declined by 11-31% when row spacing was increased from 25-61 cm and by 12-23% when the N rate was increased from 0-150 kg N ha^{-1}. The largest declines with N fertilizer were observed in 2013, possibly due to drier overall soil conditions during seeding and emergence. The significant RS × NR interaction in 2014 was due to reduced emergence with increasing N rate at the 25 and 61 cm row spacing levels but not at 30-41 cm spacing (Tables 4 and A-3); thus, did not suggest that the potential for NH_3 injury was worse at wider row spacing.

Effects on days to maturity were significant for both RS and NR in all years (*P* < 0.001-0.04) and the interaction was significant in 2013 and 2015 (*P* < 0.001-0.02) but not 2014 (*P* = 0.80). There was a slight increase in maturity with increasing row spacing (~2 days from 25 cm to 61 cm row spacing); however, by comparison, increasing the N fertilizer rate from 0-150 kg N ha^{-1} increased days to maturity by roughly 4-5 days on average (Table 2). While the RS × NR interaction was significant for days to maturity in 2013 and 2015, N rate effects were relatively consistent across row spacing levels and vice versa (Tables 4 and A-3).

Seed yield was affected by RS in 2013 and 2015 (*P* = 0.01-0.02) but not in 2014 (*P* = 0.20) and by NR in all years (*P* < 0.001). Furthermore, a significant RS × NR interaction was detected in 2013 and 2015 (*P* < 0.001) but not in 2014 (*P* = 0.391). In 2013, while the RS effect on yield was significant, the results were somewhat inconsistent in that yields were highest in the 25 cm and 61 cm treatments but tended to be lower at 30-36 cm spacing (Table 2). Such a response is difficult to explain biologically but may have been partly due to biases introduced during harvest where the 25 cm treatments were combined in a single pass while the remaining RS treatments were harvested in two passes (therefore there was potential for higher harvest losses). Again, starting in 2014, all treatments were harvested in two separate passes. In 2015, seed yields were similar for RS ranging from 25-41 cm but significantly higher at 61 cm spacing. The significant interaction in both 2013 and 2015 appeared to be at least partly due in part to higher yields at 61 cm in the 0N control but similar yields across row spacing treatments in the treatments where N fertilizer was applied (Table 4). In 2013, there was also an advantage to the narrowest row spacing (25 cm) at the 150 kg N ha^{-1} rate but not at 50-100 kg N ha^{-1}. Again, in 2014 RS did not have a significant effect on yield and there was no RS × NR interaction detected for this variable. While not the specific focus of this study in itself, it is noteworthy that there was always a strong response to N rate with yields continuing to increase with increasing N right up the highest rate. At 150 kg N ha^{-1}, mean yields were 40%, 370% and 127% higher than the check in 2013, 2014 and 2015, respectively.

Row spacing affected canola seed weight in 2014 and 2015 ($P < 0.001$-0.01) but not in 2013 ($P = 0.13$); however, the RS × NR was significant in 2013 ($P < 0.01$). Where only the main effect of RS was significant, seed weight was generally highest at the widest row spacing. In 2013, the interaction appeared to be due to an overall linear decline in seed weight with increasing NR at the 36-61 cm RS levels but not at 25 or 30 cm row spacing (Table 5 and A-4). Nitrogen rate effects on seed size were always significant ($P < 0.001$) but the specific nature of the response varied between years. In 2013 and 2014 seed size tended to be highest in the 0N control and declined with increasing N rates while, in 2015, seed weight was highest at the 150 kg N ha^{-1} rate.

While NR affected seed N concentrations in both 2013 and 2014 ($P < 0.001$), this variable was not affected by RS in 2013 ($P = 0.15$) but was in 2014 ($P < 0.001$; Table A-2); however, the RS × NR interaction was significant in 2013 ($P < 0.001$). Seed N concentrations in 2013 tended to increase with row spacing without fertilizer but, when 150 kg N ha^{-1} was applied, percent seed N was highest at the narrowest spacing. Because seed yields also increased with row spacing in the absence of N were highest in the 25 cm treatment at the highest N rate, the observed effects on grain N cannot readily be attributed to yield differences. In 2014, there was no RS × NR interaction but there was an overall increase in seed N with increasing RS when averaged across NR (Table 3). As expected, increasing NR always resulted in strong increases in seed N concentrations. Seed N data for 2015 are not yet available.

Agronomic N use-efficiency (ANUE) is a relative measure of crop utilization of applied fertilizer N and was calculated for all of the fertilizer plots in Experiment #1. ANUE was affected by RS ($P = 0.03$) but not NR ($P = 0.28$) in 2013 and by NR ($P < 0.001$) but not RS ($P = 0.07$) in 2014. The RS × NR interaction was not significant in either year ($P = 0.28$-0.46). Due to the comparatively strong response to fertilizer, ANUE at 25 cm row spacing (51%) was significantly higher than for any of the wider row spacing treatments where ANUE was in the range of 34-40% in 2013 (Table 3). In 2014, ANUE was not affected by RS, averaging 49% overall (Table 3). ANUE was not affected by N rate in 2013 and, due to the extremely strong response to N fertilizer in 2014, increased from 44% at 50 kg N ha^{-1} to 53% at 150 kg N ha^{-1}. Results for this variable in 2015 are not yet available.

Table 2. Least squares means and orthogonal contrasts for main effects of row spacing and nitrogen rate effects on plant density, days to maturity and seed yield at Indian Head (2013-15).

Treatment	Plant Density			Days to Maturity			Seed Yield		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Row Spacing	plants m^{-2}			days from planting			%		
25 cm	78 ab	82 a	115 a	93.7 c	99.8 b	95.6 d	3291 ab	2078 a	2473 b
30 cm	82 a	83 a	106 b	93.8 c	99.9 b	95.7 cd	3145 bc	2190 a	2555 b
36 cm	72 b	79 ab	103 b	94.3 b	99.9 b	96.0 c	3083 c	2081 a	2522 b
41 cm	—	78 ab	105 b	—	100.2 ab	96.4 b	—	2091 a	2503 b
61 cm	60 c	73 b	79 c	95.4 a	100.5 a	97.9 a	3366 a	2309 a	2780 a
S.E.M.	2.5	2.2	3.6	0.15	0.20	0.13	83.0	121.8	73.9
Nitrogen Rate									
0 kg N ha^{-1}	83 a	82 a	109 a	91.8 d	98.5 c	93.5 d	2597 d	730 d	1493 d
50 kg N ha^{-1}	77 a	83 a	109 a	93.1 c	98.7 c	95.3 c	3142 c	1734 c	2323 c
100 kg N ha^{-1}	70 b	78 a	100 b	95.4 b	100.6 b	97.4 b	3520 b	2708 b	3054 b
150 kg N ha^{-1}	64 b	72 b	87 c	97.0 a	102.4 a	99.1 a	3626 a	3428 a	3395 a
S.E.M.	2.5	2.0	3.2	0.15	0.19	0.11	69.9	102.8	61.2
Orthogonal Contrasts	*p-values*								
Spacing – linear	<0.001	0.004	< 0.001	<0.001	0.003	< 0.001	0.061	0.063	0.001
Spacing – quadratic	0.832	0.983	0.475	0.954	0.931	0.108	<0.010	0.348	0.169
N rate – linear	<0.001	<0.001	< 0.001	<0.001	<0.001	< 0.001	<0.001	<0.001	< 0.001
N rate – quadratic	0.991	0.094	0.016	0.212	<0.001	0.250	<0.001	<0.001	< 0.001

Table 3. Least squares means and orthogonal contrasts for main effects of row spacing and N rate effects on seed weight, seed nitrogen concentration and agronomic nitrogen use-efficiency (ANUE) at Indian Head (2013-15).

Treatment	**Seed Weight**			**Seed Nitrogen**			**ANUE**		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Row Spacing	------------------ plants m^{-2} ------------------			------------- days from planting -------------			----------------------- % -----------------------		
25 cm	3.04 a	3.41 bc	2.84 b	2.78 a	2.67 bc	—	51.2 a	49.0 a	—
30 cm	3.08 a	3.44 b	2.82 b	2.69 a	2.69 bc	—	40.0 b	50.3 a	—
36 cm	3.03 a	3.34 c	2.83 b	2.68 a	2.61 c	—	39.1 b	43.6 a	—
41 cm	—	3.45 b	2.82 b	—	2.71 b	—	—	38.3 a	—
61 cm	3.01 a	3.53 a	2.95 a	2.79 a	2.85 a	—	34.0 b	52.1 a	—
S.E.M.	0.019	0.034	0.030	0.059	0.056	—	3.27	2.57	—
Nitrogen Rate									
0 kg N ha^{-1}	3.10 a	3.86 a	2.84 b	2.26 d	2.83 b	—	—	—	—
50 kg N ha^{-1}	3.03 b	3.35 b	2.74 c	2.50 c	2.48 d	—	39.6 a	44.0 c	—
100 kg N ha^{-1}	3.02 b	3.30 b	2.85 b	2.89 b	2.60 c	—	42.9 a	49.2 b	—
150 kg N ha^{-1}	3.01 b	3.23 c	2.98 a	3.29 a	2.92 a	—	40.5 a	52.6 a	—
S.E.M.	0.013	0.032	0.028	0.052	0.054	—	2.01	2.23	—
Orthogonal Contrasts	--- *p-values* ---								
Spacing – linear	0.116	0.004	< 0.001	< 0.255	< 0.001	—	0.013	0.115	—
Spacing – quadratic	0.768	0.118	0.005	0.055	0.034	—	0.078	0.072	—
N rate – linear	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	—	0.689	< 0.001	—
N rate – quadratic	< 0.001	< 0.001	< 0.001	0.001	<0.001	—	0.129	0.525	—

Table 4. Least squares means for row spacing by nitrogen rate interactions on plant density, days to maturity and seed yield at Indian Head (2013-15).

Nitrogen Rate	Plant Density			Days to Maturity			Seed Yield		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	----------- plants m^{-2} -----------			------ days from seeding ------			------------- kg ha^{-1} -------------		
25 cm row spacing									
0 kg N ha^{-1}	89 ab	87 ab	117 ab	91.3 h	98.3 e	93.0 i	2515 h	623 f	1366 h
50 kg N ha^{-1}	82 a-d	93 a	126 a	92.3 fg	98.6 e	94.8 gh	3167 ef	1629 e	2175 f
100 kg N ha^{-1}	80 a-d	68 cde	108 bc	94.4 e	100.3 cd	96.6 f	3625 b	2637 bc	2942 d
150 kg N ha^{-1}	62 ef	79 bcd	110 bc	97.0 b	102.1 b	97.9 e	3860 a	3424 a	3408 a
30 cm row spacing									
0 kg N ha^{-1}	87 abc	81 abc	111 abc	91.4 h	98.3 e	93.0 i	2504 h	725 f	1352 h
50 kg N ha^{-1}	94 a	88 ab	110 abc	92.6 f	98.4 e	94.6 h	3053 fg	1820 de	2241 f
100 kg N ha^{-1}	76 b-e	86 ab	106 bc	95.0 de	100.6 cd	96.6 f	3469 bcd	2806 bc	3205 bc
150 kg N ha^{-1}	73 cde	78 bcd	97 cde	96.1 c	102.3 b	98.5 d	3553 bc	3411 a	3421 a
36 cm row spacing									
0 kg N ha^{-1}	77 bcd	80 bcd	111 abc	91.8 gh	98.8 e	93.1 i	2483 h	732 f	1415 h
50 kg N ha^{-1}	71 de	86 ab	108 bc	92.9 f	98.6 e	95.0 gh	3015 fg	1637 e	2280 f
100 kg N ha^{-1}	70 de	78 bcd	109 bc	95.4 d	100.1 d	96.9 f	3362 cde	2586 c	3031 cd
150 kg N ha^{-1}	72 de	71 cde	83 ef	97.0 b	102.3 b	98.9 cd	3471 bcd	3369 a	3362 ab
41 cm row spacing [z]									
0 kg N ha^{-1}	—	80 bcd	110 bc	—	98.4 e	93.3 i	—	718 f	1396 h
50 kg N ha^{-1}	—	80 abc	111 abc	—	99.0 e	95.0 gh	—	1643 e	2279 f
100 kg N ha^{-1}	—	80 abc	102 bcd	—	100.9 cd	98.0 e	—	2615 c	2976 d
150 kg N ha^{-1}	—	72 cd	95 cde	—	102.4 ab	99.5 b	—	3389 a	3362 ab
61 cm row spacing									
0 kg N ha^{-1}	79 a-d	86 ab	97 cde	92.6 f	98.9 e	95.1 g	2885 g	850 f	1938 g
50 kg N ha^{-1}	62 ef	67 de	89 def	94.5 e	99.0 e	97.0 f	3334 de	1944 d	2642 e
100 kg N ha^{-1}	52 f	78 bcd	77 f	96.8 bc	101.0 c	99.0 c	3623 b	2894 b	3115 cd
150 kg N ha^{-1}	48 f	59 e	52 g	97.8 a	103.1 a	100.5 a	3622 b	3547 a	3424 a
S.E.M.	5.0	4.5	6.0	0.25	0.32	0.18	93.0	130.3	87.6

[z] The 41 cm row spacing treatments were absent in 2013 due to an error at seeding

Table 5. Least squares means for row spacing by nitrogen rate interactions on seed weight, grain nitrogen concentrations, and agronomic nitrogen use-efficiency (ANUE) at Indian Head (2013-15).

Nitrogen Rate	Seed Weight			Seed N Concentration			Agronomic N-Use Efficiency (ANUE)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	-------- g 1000 seeds^{-1} --------			----------------- % ------------------			--------------- kg ha^{-1} ---------------		
25 cm row spacing									
0 kg N ha^{-1}	3.08 a-d	3.87 a	2.82 cd	2.17 f	2.77 cde	—	—	—	—
50 kg N ha^{-1}	3.01 e-h	3.32 cde	2.72 ef	2.47 de	2.46 ijk	—	47.7 bc	44.5 cde	—
100 kg N ha^{-1}	3.01 e-h	3.18 ef	2.84 bcd	2.87 c	2.53 g-j	—	49.5 ab	48.4 a-d	—
150 kg N ha^{-1}	3.06 b-f	3.27 def	2.99 a	3.61 a	2.91 bc	—	56.5 a	54.1 ab	—
30 cm row spacing									
0 kg N ha^{-1}	3.09 a-d	3.91 a	2.79 de	2.24 f	2.79 cde	—	—	—	—
50 kg N ha^{-1}	3.08 a-e	3.30 cde	2.68 f	2.49 de	2.45 jk	—	39.5 bcd	47.0 bcd	—
100 kg N ha^{-1}	3.07 a-e	3.30 cde	2.80 cde	2.86 c	2.68 d-g	—	42.8 bcd	53.8 ab	—
150 kg N ha^{-1}	3.10 abc	3.26 ef	3.01 a	3.15 b	2.82 cd	—	37.0 cd	49.9 abc	—
36 cm row spacing									
0 kg N ha^{-1}	3.11 ab	3.70 b	2.80 cde	2.22 f	2.76 cde	—	—	—	—
50 kg N ha^{-1}	3.03 c-g	3.29 cde	2.72 ef	2.46 de	2.37 k	—	38.2 bcd	37.1 e	—
100 kg N ha^{-1}	2.99 fgh	3.11 f	2.80 cde	2.90 c	2.49 h-k	—	42.5 bcd	43.9 cde	—
150 kg N ha^{-1}	3.01 e-h	3.28 cde	2.98 a	3.15 b	2.82 cd	—	36.5 cd	49.7 a-d	—
41 cm row spacing [z]									
0 kg N ha^{-1}	—	3.87 a	2.80 cde	—	2.75 de	—	—	—	—
50 kg N ha^{-1}	—	3.41 cd	2.70 f	—	2.52 hij	—	—	42.5 de	—
100 kg N ha^{-1}	—	3.25 ef	2.88 bc	—	2.61 fgh	—	—	48.5 a-d	—
150 kg N ha^{-1}	—	3.28 de	2.93 ab	—	2.98 ab	—	—	54.0 ab	—
61 cm row spacing									
0 kg N ha^{-1}	3.13 a	3.97 a	2.99 a	2.40 e	2.06 a	—	—	—	—
50 kg N ha^{-1}	3.02 d-g	3.43 c	2.87 bcd	2.59 d	2.60 f-i	—	33.1 d	49.1 a-d	—
100 kg N ha^{-1}	2.97 gh	3.32 cde	2.92 ab	2.94 c	2.68 ef	—	36.8 cd	51.6 abc	—
150 kg N ha^{-1}	2.94 h	3.43 cd	3.01 a	3.25 b	3.09 a	—	32.0 d	55.5 a	—
S.E.M.	0.026	0.058	0.040	0.070	0.070	—	4.02	3.29	—

[z] The 41 cm row spacing treatments were absent in 2013 due to an error at seeding

Experiment #2: Row Spacing × Seeding Rates

Canola emergence in Experiment #2 was affected by RS (P < 0.001-0.002) and SR (P < 0.001) with a significant RS × SR interaction (P < 0.001-0.27) detected in all three years (Table B-2). Similar to the previous experiment, mean plant densities declined with increasing row spacing. Averaged across seeding rates, plant densities declined from 56 plants m^{-2} at 25 cm to 28 plants m^{-2} at 61 cm in 2013, from 50 to 44 plants m^{-2} in 2014 and from 88 to 50 plants m^{-2} in 2015. Across row spacing levels, overall average plant densities ranged from 20-35 plants m^{-2} at the lowest seeding rate to 71-105 plants m^{-2} at the highest rate (Table 6). The RS × SR interaction appeared to be due to the observed decline in plant densities with increasing row spacing becoming more prominent at the higher seed rates (Table 8). For example, with the exception of more plants at 25 cm in 2015, no significant differences in emergence were detected amongst row spacing levels at the 1.5 kg ha^{-1} seeding rate while such reductions always occurred at the higher seeding rates (Table 8). Where they did occur, significant differences in plant densities at any given seeding rate were small and unlikely to impact yield for row spacing levels ranging from 25-41 cm.

Canola responds to lower plant populations with extended flowering and branching, in many cases with little or no impact on yield, and it is possible that row spacing may affect flowering in a similar manner. Days to last flower was affected by RS in 2013 and 2015 (P < 0.001) but not 2014 (P = 0.29) and by SR in all three years (P < 0.001) (Table B-2). The RS **×** SR interaction was also significant in 2013 and 2015 (P = 0.01-0.03) but not in 2014 (P = 0.149). In the years where the effect was significant, increasing row spacing from 25-61 cm prolonged flowering by 2.5 days while the spread between the lowest and highest seeding rates ranged from approximately 3-10 days (Table 6). The interactions appeared to be due to subtle differences in the response to seeding rate at different row spacing levels; however, the trends were consistent and the interactions, while significant, are of little agronomic importance (Table 8).

In general, days to maturity was affected by the treatments in a similar manner but to a lesser extent than days to flowering (Tables B-2, 6 and 8). Similar to flowering, maturity was affected by RS in 2013 and 2015 (P < 0.001) and by SR in all three years (P < 0.001); however, there were no significant interactions for this variable (P = 0.22-0.57). Increasing row spacing from 25-61 cm resulted in a 1.2-2.2 delay in maturity while the spread between the lowest and highest seeding rates was approximately 2.5 days in 2013 and 2015 but over 13 days in 2014. The longer delay in 2014 was also observed at flowering and was attributed to extended cool/wet conditions and variability caused by excess moisture in June (despite having removed the worst affected plots).

With similar results as observed in experiment #1, seed yield was affected by RS in 2013 and 2015 (P < 0.001-0.002) but not 2014 (P = 0.22). The SR effect on yield was significant in all three years (P < 0.001) but the RS × SR interaction was not significant in any cases (P = 0.07-0.81). In 2013, there was an overall quadratic response to RS (P = 0.001; Table B-4) where yields were highest at 25 cm spacing but relatively stable for levels ranging from 30-61 cm with a slight increase going from 41-61 cm (Table 7). The observed RS effect was consistent with Experiment #1 in 2013; however, again, may have been partly attributable to biases introduced to during harvest that favoured the 25 cm row spacing treatments (lower header losses due to combining entire plot in a single pass where all other RS treatments required 2 passes). In 2014, canola seed yields were similar across the entire range of RS treatments while in 2015 yields were similar for 25-41 cm and slightly but significantly higher at 61 cm row spacing. Higher yields at 61 cm are somewhat difficult to explain and were possibly due in part to differences in edge effects or harvest losses. Again, seed yields were affected by SR in all three years with yields increased from 3065 kg ha^{-1} to 3351 kg ha^{-1} in 2013, from 2677 kg ha^{-1} to 2992 kg ha^{-1} in 2014 and from 3153-3260 kg ha^{-1} in 2015 by increasing the seeding rate from 1.5 kg ha^{-1} to 6.0 kg ha^{-1}. The quadratic contrasts were significant in the majority of cases and yields never significantly differed between seeding rates of 3.0 kg ha^{-1} and 6.0 kg ha^{-1}. Looking back at the emergence data, plant populations were generally 40 plants m^{-2} or higher provided that a seeding rate of at least 3.0 kg ha^{-1} (60 seeds m^{-2}) was used and overall plant populations in 2015 (when the weakest seeding rate response occurred) were substantially higher than in

2013 and 2014. The lack of any interactions between RS and SR for seed yield suggests that the effects of seeding rate on yield were similar across row spacing levels and vice versa; therefore, supporting the recommendation that similar seeding rates should be used regardless of row spacing.

Seed weight was affected by RS ($P = 0.003$) but not SR ($P = 0.16$) in 2013 and by SR ($P = 0.002$) but not RS ($P = 0.12$) in 2014 (Table B-2). There was no RS × SR interaction for seed weight in either of these two years ($P = 0.86$-0.95). In 2015, seed weight was affected by both RS ($P < 0.001$), SR ($P < 0.001$) and the RS × SR interaction was significant ($P = 0.02$). Overall, row spacing effects on seed size were inconsistent resulting in a slight decline (with increasing row spacing) in 2013 but a positive response in 2015 and no effect in 2014 (Table 7). Seeding rate effects on seed weight were also inconsistent with smaller seeds were observed at the lowest seeding rate in 2014 but the opposite effect in 2015 and no response in 2014. The canola in 2014 was much later to mature, particularly at the lowest seeding rate, and a larger percentage of the seeds in this treatment may not have reached full size before being terminated by frost and pre-harvest glyphosate. In 2015, the canola matured earlier overall and plant populations were considerably higher than in previous years. While the overall *F*-test for SR was not significant in 2013, a linear increase in seed weight with seeding rate was detected ($P = 0.03$; Table 7). This was consistent with the results from 2014; however the effect was small with less than a 2% difference between the lowest and highest values.

Percent green seed was affected by RS in 2013 ($P = 0.015$) but not in 2014 or 2015 ($P = 0.25$-0.55) and by SR in 2013 and 2014 ($P < 0.001$-0.05) but not in 2015 ($P = 0.09$). No interactions between RS and SR for percent green seed were detected in any of the three growing seasons ($P = 0.61$-0.76). In 2013, percent green seed was significantly higher at 61 cm than with any of the narrower row spacing treatments but was still only 0.7% (Table 7). In 2015, there was a clear tendency for more green seed at wider row spacing but, again, levels were low in all treatments and the linear response was not significant at the desired probability level ($P = 0.06$). In two of three years (2014 and 2015), percent green seed declined with increasing SR and, in 2014, percent green seed at the lowest seeding rate was nearly 5% and would have resulted in a grade reduction. At seeding rates of 4.5-6 kg ha^{-1}, percent green seed was always below 1% regardless of either row spacing or year.

Table 6. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate effects on plant density, days to last flower and days to maturity at Indian Head (2013-15).

Treatment	Plant Density			Days to Last Flower			Days to Maturity		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Row Spacing	------------------ plants m^{-2} ------------------			------------- days from planting -------------			------------- days from planting -------------		
25 cm	56 a	50 abc	88 a	75.8 c	87.8 a	74.0 d	97.0 c	109.2 a	98.4 d
30 cm	54 ab	57 a	75 b	75.8 c	87.7 a	74.6 cd	97.3 bc	108.9 a	98.6 d
36 cm	49 ab	54 ab	72 b	76.3 c	87.9 a	74.8 bc	97.7 b	108.6 a	99.0 c
41 cm	45 b	49 bc	73 b	77.0 b	86.8 a	75.1 b	97.7 b	108.3 a	99.5 b
61 cm	28 c	44 c	50 c	78.3 a	86.4 a	76.5 a	98.6 a	108.0 a	100.6 a
S.E.M.	3.7	2.8	1.9	0.35	0.92	0.15	0.30	1.26	0.14
Seeding Rate									
1.5 kg ha^{-1}	20 d	26 d	35 d	78.7 a	92.7 a	77.0 a	99.2 a	116.1 a	100.6 a
3.0 kg ha^{-1}	39 c	46 c	63 c	77.0 b	87.8 b	75.4 b	97.8 b	109.6 b	99.6 b
4.5 kg ha^{-1}	56 b	58 b	83 b	75.9 c	85.6 c	74.6 c	97.2 c	106.1 c	98.7 c
6.0 kg ha^{-1}	71 a	72 a	105 a	75.1 d	83.1 d	73.9 d	96.5 d	102.8 d	98.1 d
S.E.M.	2.9	2.5	1.8	0.32	0.84	0.12	0.26	1.12	0.11
Orthogonal Contrasts	-- *p-values* --								
Spacing – linear	<0.001	0.009	< 0.001	<0.001	0.064	< 0.001	<0.001	0.755	< 0.001
Spacing – quadratic	0.729	0.160	0.707	0.896	0.960	0.146	0.667	0.679	0.606
Seed rate – linear	<0.001	<0.001	< 0.001	<0.001	<0.001	< 0.001	<0.001	<0.001	< 0.001
Seed rate – quadratic	0.241	0.155	0.046	<0.001	0.005	0.002	<0.001	0.010	0.010

Table 7. Least squares means and orthogonal contrasts for main effects of row spacing and seeding rate on seed yield, seed weight and percent green seed at Indian Head (2013-15).

Treatment	Seed Yield			Seed Weight			Green Seed		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Row Spacing	kg ha^{-1}			g 1000 $seeds^{-1}$			%		
25 cm	3444 a	2802 a	3232 b	2.94 bc	3.19 a	2.96 b	0.4 b	2.7 a	0.3 a
30 cm	3182 bc	2848 a	3182 b	3.00 a	3.18 a	2.96 b	0.3 b	1.1 a	0.3 a
36 cm	3187 bc	2916 a	3163 b	2.96 ab	3.17 a	2.95 b	0.4 b	2.1 a	0.3 a
41 cm	3152 c	2828 a	3163 b	2.91 cd	3.19 a	2.98 b	0.3 b	1.7 a	0.4 a
61 cm	3306 b	2986 a	3384 a	2.89 d	3.28 a	3.08 a	0.7 a	1.4 a	0.5 a
S.E.M.	156.9	73.8	37.4	0.044	0.042	0.025	0.07	0.96	0.071
Seeding Rate									
1.5 kg ha^{-1}	3065 c	2677 b	3153 b	2.92 a	3.11 b	3.03 a	0.5 a	4.8 a	0.5 a
3.0 kg ha^{-1}	3318 ab	2917 a	3256 a	2.93 a	3.23 a	3.00 b	0.2 b	1.6 b	0.4 a
4.5 kg ha^{-1}	3283 b	2917 a	3230 a	2.94 a	3.25 a	2.96 c	0.5 a	0.6 b	0.3 a
6.0 kg ha^{-1}	3351 a	2992 a	3260 a	2.96 a	3.22 a	2.94 c	0.5 ab	0.1 b	0.3 a
S.E.M.	153.6	66.0	34.0	0.043	0.039	0.023	0.07	0.90	0.06
Orthogonal Contrasts	*p-values*								
Spacing – linear	0.516	0.054	< 0.001	0.001	0.025	< 0.001	0.007	0.385	0.057
Spacing – quadratic	< 0.001	0.884	< 0.001	0.771	0.168	0.053	0.030	0.583	0.787
Seed rate – linear	< 0.001	< 0.001	< 0.001	0.027	0.005	< 0.001	1.000	<0.001	0.013
Seed rate – quadratic	< 0.001	0.067	0.031	0.771	0.004	0.518	0.293	0.024	0.870

Table 8. Least squares means for row spacing by seed rate interactions on canola plant density, days to last flower and days to maturity at Indian Head (2013-15).

Seed Rate	Plant Density			Days to Last Flower			Days to Maturity		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	---------- plants m^{-2} ----------			------------------------ days from seeding ------------------------					
25 cm row spacing									
1.5 kg ha^{-1}	24 kl	32 ghi	46 f	78.1 bc	93.5 a	76.0 d	98.6 b	116 a	99.8 d
3.0 kg ha^{-1}	42 ghi	45 efg	81 c	76.3 fg	88.5 bcd	74.9 fg	97.3 c-f	111 bc	98.9 f
4.5 kg ha^{-1}	74 bcd	48 c-f	105 b	74.8 ij	86.4 cde	73.8 lk	96.5 gh	108 cde	97.6 hi
6.0 kg ha^{-1}	84 a	74 a	118 a	74.1 jk	82.8 g	73.1 l	95.8 i	103 fgh	97.4 i
30 cm row spacing									
1.5 kg ha^{-1}	21 l	26 hi	33 gh	78.3 bc	92.5 a	76.3 cd	98.6 b	115 ab	100.0 cd
3.0 kg ha^{-1}	49 fg	52 cde	69 de	76.3 fg	88.8 c	74.8 fgh	97.5 cde	109 c	99.0 f
4.5 kg ha^{-1}	63 de	70 ab	83 c	75.0 hi	86.0 de	74.0 ij	97.0 efg	107 c-f	98.0 gh
6.0 kg ha^{-1}	84 ab	79 a	113 ab	73.8 k	83.4 fg	73.4 kl	96.0 hi	103 gh	97.5 hi
36 cm row spacing									
1.5 kg ha^{-1}	19 l	25 hi	35 gh	78.6 b	93.1 a	76.3 cd	99.3 b	117 a	100.5 bc
3.0 kg ha^{-1}	45 fgh	51 cde	68 de	76.6 ef	89.1 bc	75.1 ef	97.8 c	110 bc	99.1 ef
4.5 kg ha^{-1}	55 ef	60 bc	76 cd	75.6 gh	87.4 cd	74.4 hi	97.4 de	106 c-g	98.9 f
6.0 kg ha^{-1}	77 abc	81 a	108 ab	74.4 ijk	82.1 g	73.6 jk	96.4 fgh	101 h	97.6 hi
41 cm row spacing [z]									
1.5 kg ha^{-1}	21 l	22 i	33 gh	78.8 b	93.1 a	76.6 bc	99.1 b	117 a	100.8 b
3.0 kg ha^{-1}	36 hij	45 def	60 e	77.3 de	86.9 cd	75.4 e	97.9 c	109 cd	99.8d
4.5 kg ha^{-1}	54 efg	57 b-e	85 c	76.1 fg	84.4 efg	74.6 gh	97.3 de	105 e-h	99.1 ef
6.0 kg ha^{-1}	71 cd	73 a	115 ab	75.8 gh	82.9 g	73.9 j	96.6 fgh	103 gh	98.3 g
61 cm row spacing									
1.5 kg ha^{-1}	14 l	27 hi	26 h	79.8 a	91.4 ab	77.4 a	100.5 a	115 a	102.0 a
3.0 kg ha^{-1}	24 jkl	35 fgh	39 fg	78.5 b	85.7 def	77.0 ab	98.6 b	109 cd	101.0 b
4.5 kg ha^{-1}	33 ijk	58 bcd	64 e	77.8 cd	84.2 efg	76.1 d	97.9 cd	105 d-h	99.9 d
6.0 kg ha^{-1}	42 ghi	54 cde	69 de	77.3 de	84.4 efg	75.5 e	97.5 cde	105 e-h	99.6 de
S.E.M.	4.8	4.8	3.6	0.41	1.18	0.19	0.34	1.68	0.21

Table 9. Least squares means for row spacing by seed rate interactions on canola seed yield, seed weight and percent green seed at Indian Head (2013-15).

Nitrogen Rate	Seed Yield			Seed Weight			Green Seed		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	------------- kg ha^{-1} -------------			-------- g 1000 seeds^{-1} --------			--------------- % ---------------		
25 cm row spacing									
1.5 kg ha^{-1}	3251 cde	2530 d	3238 cde	2.95 a-e	3.06 cd	3.02 a-d	0.4 bcd	7.5 a	0.4 a
3.0 kg ha^{-1}	3527 a	2773 bcd	3302 bc	2.91 d-g	3.22 a-d	2.99 c-f	0.2 cd	2.6 bcd	0.5 a
4.5 kg ha^{-1}	3482 a	2895 abc	3181 def	2.94 a-e	3.23 ab	2.90 hi	0.6 abc	0.8 cd	0.2 a
6.0 kg ha^{-1}	3517 a	3008 abc	3205 cde	2.96 a-d	3.27 ab	2.91 ghi	0.4 cd	0.1 cd	0.2 a
30 cm row spacing									
1.5 kg ha^{-1}	2980 gh	2769 cd	3143 efg	2.98 a-d	3.11 bcd	3.04 abc	0.4 cd	2.2 bcd	0.4 a
3.0 kg ha^{-1}	3191 def	2832 bc	3184 def	3.01 a	3.19 a-d	2.96 d-h	0.2 cd	1.0 cd	0.5 a
4.5 kg ha^{-1}	3258 cde	2875 abc	3207cde	3.00 a-c	3.24 abc	2.95 e-i	0.3 cd	0.9 cd	0.3 a
6.0 kg ha^{-1}	3298 bcd	2915 abc	3194 c-f	3.00 ab	3.19 a-d	2.89 i	0.3 cd	0.2 d	0.3 a
36 cm row spacing									
1.5 kg ha^{-1}	3062 fgh	2715 cd	3084 fg	2.95 a-e	3.05 d	3.02 a-d	0.4 bcd	5.1 ab	0.5 a
3.0 kg ha^{-1}	3227 cde	3087 ab	3190 cde	2.95 a-e	3.20 a-d	2.97 d-g	0.2 d	3.1 a-d	0.1 a
4.5 kg ha^{-1}	3196 def	2880 abc	3156 def	2.96 a-d	3.26 ab	2.92 ghi	0.6 abc	0.4 cd	0.5 a
6.0 kg ha^{-1}	3262 b-e	2983 abc	3223 cde	2.97 a-d	3.15 a-d	2.89 i	0.4 cd	0.0 d	0.1 a
41 cm row spacing ^{z}									
1.5 kg ha^{-1}	2920 h	2577 d	3035 g	2.89 efg	3.08 d	3.00 cde	0.3 cd	5.4 ab	0.6 a
3.0 kg ha^{-1}	3209 c-f	2870 abc	3221 cde	2.92 d-g	3.26 a	3.01 bcd	0.3 cd	0.4 d	0.3 a
4.5 kg ha^{-1}	3189 def	2938 abc	3178 def	2.92 d-g	3.24 ab	2.98 c-g	0.4 cd	0.5 d	0.3 a
6.0 kg ha^{-1}	3292 bcd	2925 abc	3217 cde	2.92 c-g	3.19 a-d	2.93 f-i	0.2 d	0.5 d	0.4 a
61 cm row spacing									
1.5 kg ha^{-1}	3111 efg	2796 bcd	3265 cd	2.86 fg	3.25 ab	3.08 a	0.9 a	4.0 abc	0.6 a
3.0 kg ha^{-1}	3435 ab	3024 abc	3381 ab	2.85 g	3.30 a	3.07 ab	0.4 cd	1.0 cd	0.6 a
4.5 kg ha^{-1}	3293 bcd	2997 abc	3428 a	2.91 d-g	3.30 a	3.07 ab	0.6 a-d	0.2 d	0.4 a
6.0 kg ha^{-1}	3383 abc	3128 a	3460 a	2.93 b-f	3.30 a	3.09 a	0.8 ab	0.3 d	0.4 a
S.E.M.	163.2	111.6	48.9	0.049	0.064	0.031	0.15	1.48	0.065

Experiment #3: Row Spacing × Herbicide Application

Experiment #3, which included both row spacing and in-crop herbicide treatments as factors, was designed to investigate the effects of wider row spacing on the ability of canola to compete with weeds during the growing season. The two herbicide treatments were included to assess whether any potential negative impacts of wide row spacing on the ability of canola to compete with weeds could be negated with typical herbicide applications. The main indicators of treatment performance considered in the trial were above-ground crop biomass, weed biomass yield and canola seed yield.

Crop biomass yield was affected by row spacing in 2013 (P = 0.01) and 2015 (P < 0.001) but not 201 4 (P = 0.06) and by herbicide in all three years (P < 0.001-0.02; Table C-2). There was no interaction between RS and herbicide treatment in any of the three years for this variable (P = 0.10-0.99). While the multiple comparisons groupings varied from year-to-year, the overall row spacing effect was consistent in that total above-ground crop biomass yields were highest at the narrowest spacing and lowest at the widest spacing. In 2014, although the overall F-test was not significant, the orthogonal contrasts did detect a slight linear decline in crop biomass with increasing row spacing in that year as well. Averaged across RS, in-crop herbicide applications resulted in 45%, 31% and 7% more crop biomass relative to the unsprayed plots in 2013, 2014 and 2015, respectively.

Weed biomass was not affected by RS in either 2013 or 2014 (P =0.44-0.55) and none of the orthogonal contrasts significant for row spacing effects on weed biomass during these years (Tables 10 and C-2). Natural weed populations during these two years were high and also reasonably uniform, with mean weed biomass yields of 3031 kg ha^{-1} in 2013 and 2423 kg ha^{-1} in 2014 (no in-crop herbicide applied; Table 10). The predominant weeds present were wild oats (*Avena fatua*) in 2013 and volunteer canaryseed (*Phalaris canariensis*) in 2014. A single in-crop herbicide application reduced weed biomass dramatically, to 61 kg ha^{-1} (98% reduction) in 2013 and to 13 kg ha^{-1} (99.5% reduction) in 2014. In 2015, overall pressure was much lower but RS did have a significant impact on weed biomass (P = 0.01); however, the RS × herbicide interaction was also significant (P = 0.01). Inspection of individual treatment means from this season (Table C-3) revealed that, without herbicide, weed biomass increased linearly with increasing row spacing but RS had no impact on weed biomass when combined with an in-crop herbicide application.

In this experiment, row spacing effects on seed yield were significant in 2015 (P < 0.001) but not 2013 or 2014 (P = 0.24-0.41). In 2013, consistent with the previously discussed treatments, there was a tendency for higher yields with narrower row spacing which, based on the orthogonal contrasts for individual herbicide treatments (Table C-3), was more prominent when herbicides were applied. In 2015, the highest yields were achieved at the narrowest and widest row spacing levels with highly significant quadratic responses detected (P < 0.001-0.01) in all possible cases. With in-crop herbicide applications under heavy weed pressure, canola seed yields were increased by 77% in 2013 and by 27% in 2014 (Table 10). In 2015 under lower pressure, while the yield advantage with in-crop herbicide was significant it was much smaller at only 2%, or 63 kg ha^{-1}.

Table 10. Least squares means for the main effects of row spacing and herbicide treatment on above-ground crop biomass, weed biomass and canola seed yield at Indian Head (2013-15).

Treatment	Crop Biomass			Weed Biomass			Seed Yield		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Row Spacing	------------------------------ kg ha^{-1} ------------------------------								
25 cm	8445 a	5694 a	11096 a	1528 a	1374 a	54 b	2869 a	2556 a	3186 ab
30 cm	8149 a	5430 a	9334 b	1306 a	941 a	53 b	2610 a	2647 a	3115 bc
36 cm	8141 a	4071 a	9689 b	1497 a	1386 a	94 b	2445 a	2390 a	3060 cd
41 cm	7394 a	4417 a	8732 bc	1338 a	1052 a	57 b	2409 a	2595 a	3002 d
61 cm	6006 b	4282 a	8007 c	2061 a	1336 a	240 a	2420 a	2612 a	3254 a
Standard Error	428.5	522.4	326.0	409.2	255.7	38.4	161.7	107.6	63.7
Herbicide									
No Herbicide	6230 b	4126 b	9059 b	3031 a	2423 a	169 a	1841 b	2252 b	3155 a
Herbicide	9024 a	5431 a	9684 a	61 b	13 b	30 b	3260 a	2868 a	3092 b
Standard Error	293.7	398.1	186.8	335.7	183.0	27.4	108.8	74.2	60.1
Orthogonal Contrasts	------------------------------ Pr. > *F* ------------------------------								
Spacing – linear	< 0.001	0.039	< 0.001	0.131	0.760	0.001	0.099	0.687	0.015
Spacing – quadratic	0.723	0.063	0.030	0.316	0.482	0.176	0.106	0.534	< 0.001

Conclusions and Recommendations:

The objective of this ongoing project is to evaluate the feasibility of growing canola at row spacing levels exceeding 25 cm and to explore potential implications of doing so on response to side-banded N, seeding rates and competitiveness with weeds. Western Canadian canola growers have interest in this matter because there is a desire by some to adopt wider row spacing (30 cm or wider) to reduce equipment costs and horsepower requirements while allowing for seeding into heavy residues or between stubble rows more easily. Large commercial drills are currently available with row spacing as wide as 38 cm and, with simple modifications to existing equipment or with row crop planters, even wider spacing can be readily achieved. While growers see the obvious logistic advantages to the wider spacing, questions exist as to whether this spacing is too wide from an agronomic perspective for certain crop types and conditions.

In general, canola emergence declined as row spacing was increased, presumably due to higher intraspecific competition amongst seedlings. While significant, the observed reductions were typically too small to be of much agronomic concern, particularly amongst row spacing levels ranging from 25-41 cm. 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 much agronomic importance provided that adequate seeding rates 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 minimal or non-significant. While there were cases of higher yields at 25 cm row spacing relative to those ranging from 30-41 cm (i.e. 2013), in 2/3 years canola yields at 61 cm row spacing were also amongst the highest. 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 2014 and 2015. There was a slight increase in percent green seed in 2013 and 2015 when row spacing was increased from 25 cm to 61 cm; however, all treatment means remained below 1% during these years. In 2014 row spacing did not affect green seed; however, seeding rate had large and much more consistent impact on percent green seed.

Focussing on potential implications for side-banded N recommendations, there was a significant reduction in plant densities with 100-150 kg ha^{-1} of side-banded N in all three years. A significant interaction between row spacing and N rate was detected for this variable in 2014 but not in 2013 or 2015; however, the interaction in 2014 did not necessarily suggest that the potential for NH_3 toxicity from side-banded N was increasing with row spacing. 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% and 127% in 2013, 2014 and 2015, respectively. In both 2013 and 2015, significant row spacing by N rate interactions appeared to be due to higher yields at 61 cm in the 0N control but not in the fertilized plots. This may have partly been due to a maturity effect (i.e. higher shattering losses under low fertility) and may have also contributed to the yield bump observed at 61 cm during these years. Increasing N rate had a small but significant negative impact on seed size in 2013 and 2014 but a positive effect in 2014. A significant interaction in 2013 suggested that the negative impact of N rate on seed size was most prominent at 36-61 cm row spacing. Percent seed N was not affected by row spacing in 2013 but increased slightly with increasing row spacing in 2014, possibly due to more concentrated N at any given rate combined with the strong yield response to fertilizer. Agronomic nitrogen use-efficiency, on the other hand, was affected by row spacing in 2013 and was lowest at the 61 cm level. This was largely due to the higher yields in the unfertilized plots at this row spacing level combined with a relatively strong yield response to the highest rate of N at the narrowest spacing. In 2014, the row spacing effect on ANUE was not significant. ANUE was either unaffected by or increased with N rate, which was a reflection of the strong response to fertilizer, particularly in 2014 where both yields and seed N concentrations increased linearly with N rate. Seed N concentrations and, therefore, ANUE data, are not yet available for 2015. Overall, the results to date suggest that N requirements of canola are likely similar regardless of row spacing; however, very high rates 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 seeding rates evaluated were 1.5, 3.0, 4.5 and 6.0 kg ha^{-1}which worked out to approximately 30-120 seeds m^{-2}. Averaged across row spacing treatments, actual plant densities ranged from 20-71 plants m^{-2} in 2013, from 26-72 plants m^{-2} in 2014 and from 35-105 plants m^{-2} depending on the seeding rate; however, interactions with row spacing were detected in all three years. These interactions appeared to be largely due in part to the fact that the typical decline in plant populations with increasing row spacing did not occur or was less prominent at the lowest seeding rate. In addition, at 61 cm row spacing, actual plant populations no longer increased with seeding rates beyond approximately 4.5 kg ha^{-1} or 90 seeds m^{-2} while for the narrower spacing treatments plant density continued to increase with seeding rates right up to 6 kg ha^{-1} (~120 seeds m^{-2}). This suggests that intraspecific competition was limiting establishment at the widest row spacing and highest seeding rates. That said, only the lowest seeding rate resulted in plant populations that were below 40 plants m^{-2} at all row spacing levels except 61 cm where higher rates were required to meet this commonly recommended minimum threshold. These results suggest that seeding rates should not be reduced below typically recommended rates as row spacing is increased; however, at the same time, there was no benefit to using aggressive seeding rates (i.e. > 90 seeds m^{-2})combined with very wide row spacing (i.e. 61 cm). At the widest row spacing, plant populations reached a plateau at lower rates than seen at narrower spacing (i.e 25-41 cm); however, higher overall mortality with increasing row spacing made reducing seeding rates to < 90 seeds m^{-2} at 61 cm row spacing relatively risky. While only speculative, it is also 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. Seeding rate had a larger impact on canola development 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 3.0-6.0 kg seed ha^{-1} in all three years; however, yields were reduced by 3-9% at the 1.5 kg ha^{-1} seeding rate. It should be noted that, over the three years of this study, emergence was generally excellent, any 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, weed biomass was not affected by row spacing in either 2013 or 2014 (under heavy pressure) and none of the orthogonal contrasts were significant for this variable during these years. In 2015, while overall competition was much lower, significantly higher weed biomass yields were detected at 61 cm row spacing relative to any of the narrow treatments. There was, however, a significant interaction detected whereby this only occurred when no in-crop herbicides were applied. Despite extremely high weed pressure in 2013-14, a single in-crop herbicide application 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 less dramatic than the previous years; 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. 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 with similar losses regardless of row spacing.

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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 (2013-15).

Agronomic Factor / Field Operation	**2013**	**2014**	**2015**
Previous Crop	Spring Wheat	Canaryseed	Spring Wheat
Soil Nutrient Sampling	May-23	May-13	May-7
K_2SO_4 broadcast application	May-29	May-13	May-7
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})
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
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
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})
	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
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})
Pre-harvest application	—	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 (0, 50 kg N ha^{-1}) Sep-17 (100, 150 kg N ha^{-1})	Sep-14 (0, 50 kg N ha^{-1}) Sep-15 (0, 50 kg N ha^{-1})	Sept-3 (all treatments)

^{Z}N fertilizer rates varied as per protocol

Table A-2. Tests of fixed effects for row spacing and nitrogen rate effect on selected canola response variables at Indian Head (2013-15).									
Variable	**Rowing Spacing (RS)**			**Nitrogen Rate (NR)**			**RS × NR**		
	2013[Z]	2014	2015	2013	2014	2015	2013	2014	2015
	----------	----------	----------	----------	Pr > *F*	----------	----------	----------	----------
Emergence (plants m^{-2})	<0.001	0.046	< 0.001	<0.001	<0.001	< 0.001	0.095	0.016	0.106
Maturity	<0.001	0.040	< 0.001	<0.001	<0.001	< 0.001	0.021	0.800	< 0.001
Seed Yield (kg ha^{-1})	0.024	0.195	0.009	<0.001	<0.001	< 0.001	<0.001	0.391	< 0.001
Seed weight (g 1000 $seeds^{-1}$)	0.129	0.008	< 0.001	<0.001	<0.001	< 0.001	0.002	0.666	0.089
Grain N (%)	0.149	<0.001	—	<0.001	<0.001	—	<0.001	0.132	—
ANUE (%)	0.026	0.069	—	0.281	<0.001	—	0.279	0.457	—

[Z] The 41 cm row spacing treatments were absent in 2013 due to an error at seeding

Table A-3. Orthogonal contrasts examining the linear and quadratic responses to N rate at varying row spacing levels for plant density, days to maturity and seed yield at Indian Head (2013-15).

Treatment	Plant Density			Days to Maturity			Seed Yield		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	------------------------------ Pr > *F* ------------------------------								
					25 cm row spacing				
N Rate - linear	< 0.001	0.017	0.104	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
N Rate – quadratic	0.246	0.582	0.550	< 0.001	0.020	0.089	< 0.001	0.062	0.003
					30 cm row spacing				
N Rate - linear	0.012	0.591	0.060	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
N Rate – quadratic	0.312	0.083	0.461	0.779	0.011	0.389	< 0.001	< 0.001	< 0.001
					36 cm row spacing				
N Rate - linear	0.411	0.098	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
N Rate – quadratic	0.425	0.130	0.050	0.266	< 0.001	0.666	< 0.001	0.291	< 0.001
					41 cm row spacing				
N Rate - linear	—	0.270	0.044	—	< 0.001	< 0.001	—	< 0.001	< 0.001
N Rate – quadratic	—	0.331	0.465	—	0.108	0.389	—	0.132	< 0.001
					61 cm row spacing				
N Rate - linear	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
N Rate – quadratic	0.177	0.969	0.134	0.057	< 0.001	0.199	< 0.001	< 0.001	< 0.001

Table A-4. Orthogonal contrasts examining the linear and quadratic responses to N rate at varying row spacing levels for seed weight, seed N concentrations and agronomic N use-efficiency (ANUE) at Indian Head (2013-15).

Treatment		Seed Weight			Seed Nitrogen Concentration			ANUE	
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	----------	----------	----------	----------	Pr > *F*	----------	----------	----------	----------
					25 cm row spacing				
N Rate - linear	0.388	< 0.001	< 0.001	< 0.001	0.040		0.043	0.019	
N Rate – quadratic	0.004	< 0.001	< 0.001	< 0.001	< 0.001		0.464	0.787	
					30 cm row spacing				
N Rate - linear	0.807	< 0.001	< 0.001	< 0.001	0.175		0.547	0.389	
N Rate – quadratic	0.253	< 0.001	< 0.001	0.621	< 0.001		0.210	0.105	
					36 cm row spacing				
N Rate - linear	< 0.001	< 0.001	< 0.001	< 0.001	0.195		0.711	0.003	
N Rate – quadratic	0.034	< 0.001	< 0.001	1.000	< 0.001		0.176	0.870	
					41 cm row spacing				
N Rate - linear	—	< 0.001	< 0.001	—	< 0.001		—	0.002	
N Rate – quadratic	—	< 0.001	0.019	—	< 0.001		—	0.941	
					61 cm row spacing				
N Rate - linear	< 0.001	< 0.001	0.467	< 0.001	0.408		0.781	0.063	
N Rate – quadratic	0.051	< 0.001	0.001	0.136	<0.001		0.247	0.789	

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 (2013-15).			
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 [Z]	29, 58, 86 or 115 seeds m^{-2}	29, 58, 86 or 115 seeds m^{-2}	29, 58, 86 or 115 seeds m^{-2}
Seeding Date	May-31	May-13	May-12
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})
	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-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})
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})
Straight-Combined	Sep-16 (4.5, 6.0 kg ha^{-1}) Sep-21 (1.5, 3.0 kg ha^{-1})	Sep-16 (all plots)	Sep-4 (all plots)

[Z] Seeding rates varied as per protocol

Table B-2. Tests of fixed effects for row spacing and seeding rate effect on selected canola response variables at Indian Head (2013-15).

Variable	Rowing Spacing (RS)			Seeding Rate (SR)			RS × SR		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	---------- Pr > *F* ----------								
Emergence (plants m^{-2})	< 0.001	0.020	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.027	< 0.001
Last Flower	< 0.001	0.291	< 0.001	< 0.001	< 0.001	< 0.001	0.025	0.149	0.014
Maturity	< 0.001	0.948	< 0.001	< 0.001	< 0.001	< 0.001	0.547	0.567	0.222
Seed Yield (kg ha^{-1})	0.002	0.216	< 0.001	< 0.001	< 0.001	< 0.001	0.748	0.807	0.072
Seed Weight (g 1000 $seeds^{-1}$)	0.003	0.115	< 0.001	0.160	0.002	< 0.001	0.856	0.947	0.020
Green Seed (%)	0.015	0.554	0.253	0.049	<0.001	0.093	0.616	0.756	0.610

Table B-3. Orthogonal contrasts examining the linear and quadratic responses for selected canola response variables to row spacing at varying seeding rates and to seeding rate at varying row spacing levels at Indian Head (2013-14).

Treatment	Plant Density		Days to Last Flower		Days to Maturity	
	2013	2014	2013	2014	2013	2014
	---------- Pr > *F* ----------					
			1.5 kg seed ha^{-1}			
Spacing - linear	0.126	0.590	<0.001	0.133	<0.001	0.970
Spacing – quadratic	0.960	0.124	0.924	0.667	0.559	0.243
			3.0 kg seed ha^{-1}			
Spacing - linear	<0.001	0.023	<0.001	0.010	<0.001	0.423
Spacing – quadratic	0.351	0.175	0.793	0.780	0.802	0.723
			4.5 kg seed ha^{-1}			
Spacing - linear	<0.001	0.758	<0.001	0.039	<0.001	0.254
Spacing – quadratic	0.298	0.195	0.825	0.975	0.264	0.279
			6.0 kg seed ha^{-1}			
Spacing - linear	<0.001	<0.001	<0.001	0.216	<0.001	0.246
Spacing – quadratic	0.307	0.050	0.834	0.426	0.617	0.409
			25 cm row spacing			
Seed Rate - linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Seed Rate – quadratic	0.248	0.139	0.016	0.485	0.107	0.961
			30 cm row spacing			
Seed Rate - linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Seed Rate – quadratic	0.333	0.060	0.141	0.469	0.744	0.505
			36 cm row spacing			
Seed Rate - linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Seed Rate – quadratic	0.558	0.589	0.141	0.538	0.194	0.509
			41 cm row spacing			
Seed Rate - linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Seed Rate – quadratic	0.800	0.361	0.030	0.002	0.107	0.005
			61 cm row spacing			
Seed Rate - linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Seed Rate – quadratic	0.865	0.184	0.141	0.001	<0.001	0.028

Table B-4. Orthogonal contrasts examining the linear and quadratic responses for selected canola response variables to row spacing at varying seeding rates and to seeding rate at varying row spacing levels at Indian Head (2013-14).

Treatment	Seed Yield		Seed Weight		Green Seed	
	2013	2014	2013	2014	2013	2014
	---------- Pr > *F* ----------					
			1.5 kg seed ha^{-1}			
Spacing - linear	0.547	0.219	0.002	0.021	0.008	0.394
Spacing – quadratic	0.001	0.985	0.143	0.356	0.072	0.537
			3.0 kg seed ha^{-1}			
Spacing - linear	0.580	0.128	0.003	0.190	0.377	0.442
Spacing – quadratic	0.081	0.414	0.143	0.895	0.768	0.702
			4.5 kg seed ha^{-1}			
Spacing - linear	0.217	0.344	0.105	0.377	0.764	0.708
Spacing – quadratic	0.001	0.864	0.805	0.828	0.398	0.909
			6.0 kg seed ha^{-1}			
Spacing - linear	0.597	0.240	0.106	0.340	0.013	0.873
Spacing – quadratic	0.006	0.338	0.692	0.087	0.062	0.995
			25 cm row spacing			
Seed Rate - linear	0.002	0.005	0.623	0.032	0.706	0.001
Seed Rate – quadratic	0.025	0.556	0.197	0.338	0.613	0.162
			30 cm row spacing			
Seed Rate - linear	<0.001	0.225	0.592	0.224	0.706	0.245
Seed Rate – quadratic	0.108	0.894	0.549	0.185	0.866	0.860
			36 cm row spacing			
Seed Rate - linear	0.019	0.251	0.448	0.254	0.651	0.010
Seed Rate – quadratic	0.347	0.245	1.000	0.065	1.000	0.674
			41 cm row spacing			
Seed Rate - linear	<0.001	0.004	0.349	0.163	0.763	0.005
Seed Rate – quadratic	0.081	0.066	0.549	0.021	0.500	0.030
			61 cm row spacing			
Seed Rate - linear	0.006	0.240	0.022	0.505	0.880	0.040
Seed Rate – quadratic	0.029	0.338	0.582	0.648	0.009	0.229

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. Tests of fixed effects for row spacing and herbicide treatment effects on above-ground crop biomass, weed biomass and seed yield for canola at Indian Head (2013-15).

Effect	**Row Spacing (S)**			**Herbicide (H)**			**S X H**		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
	---------- Pr. > *F* ----------								
Crop Biomass	0.007	0.064	< 0.001	< 0.001	0.002	0.017	0.129	0.989	0.101
Weed biomass	0.440	0.546	0.011	< 0.001	< 0.001	< 0.001	0.657	0.594	0.012
Seed Yield	0.237	0.414	< 0.001	< 0.001	< 0.001	0.019	0.435	0.818	0.192

Table C-3. Least squares means for individual row spacing / herbicide treatments and orthogonal contrasts examining the linear responses of selected canola response variables to row spacing and weed control treatment.									
Treatment	**Crop Biomass**			**Weed Biomass**			**Seed Yield**		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Spacing X Herbicide	---------- kg ha^{-1} ----------								
25 cm – Weedy	6093 ef	4990 abc	10570 ab	3046 ab	2726 a	82 b	2061 c	2192 c	3107 cde
25 cm – Sprayed	10797 a	6398 a	11623 a	10 c	22 b	25 b	3677 a	2921 a	3266 ab
30 cm – Weedy	6972 e	4618 bc	8980 cde	2559 b	1882 a	77 b	1935 c	2418 bc	3099 cde
30 cm – Sprayed	9326 ab	6242 ab	9688 bc	53 c	0.00 b	29 b	3286 ab	2875 a	3131 cd
36 cm – Weedy	7347 cde	3466 c	10048 bc	2977 ab	2752 a	162 b	1610 c	2052 c	3054 de
36 cm – Sprayed	8936 abc	4675 abc	9330 bcd	18 c	19.3 b	26 b	3281 ab	2727 ab	3066 de
41 cm – Weedy	5918 bc	3863 c	8044 ef	2651 ab	2104 a	84 b	1635 c	2267 c	3004 e
41 cm – Sprayed	8871 bcd	4971 abc	9419 bcd	25 c	0.00 a	30 b	3183 ab	2923 a	3000 e
61 cm – Weedy	4819 f	3691 c	7652 f	3921 a	2648 a	439 a	1965 c	2330 c	3194 bc
61 cm – Sprayed	7193 de	4872 abc	8361 def	201 c	25 b	40 b	2874 b	2894 a	3314 a
Standard Error	588.2	649.9	417.7	508.6	344.3	51.8	223.7	138.2	69.2
Orthogonal Contrast	---------- Pr. > *F* ----------								
Weedy – Linear	0.023	0.154	< 0.001	0.070	0.681	<.0001	0.922	0.616	0.080
Weedy – Quadratic	0.723	0.195	0.155	0.200	0.342	0.0642	0.094	0.640	0.010
Sprayed – Linear	<0.001	0.072	< 0.001	0.742	0.983	0.8254	0.028	0.918	0.051
Sprayed – Quadratic	0.366	0.116	0.033	0.893	0.964	0.9697	0.507	0.639	< 0.001