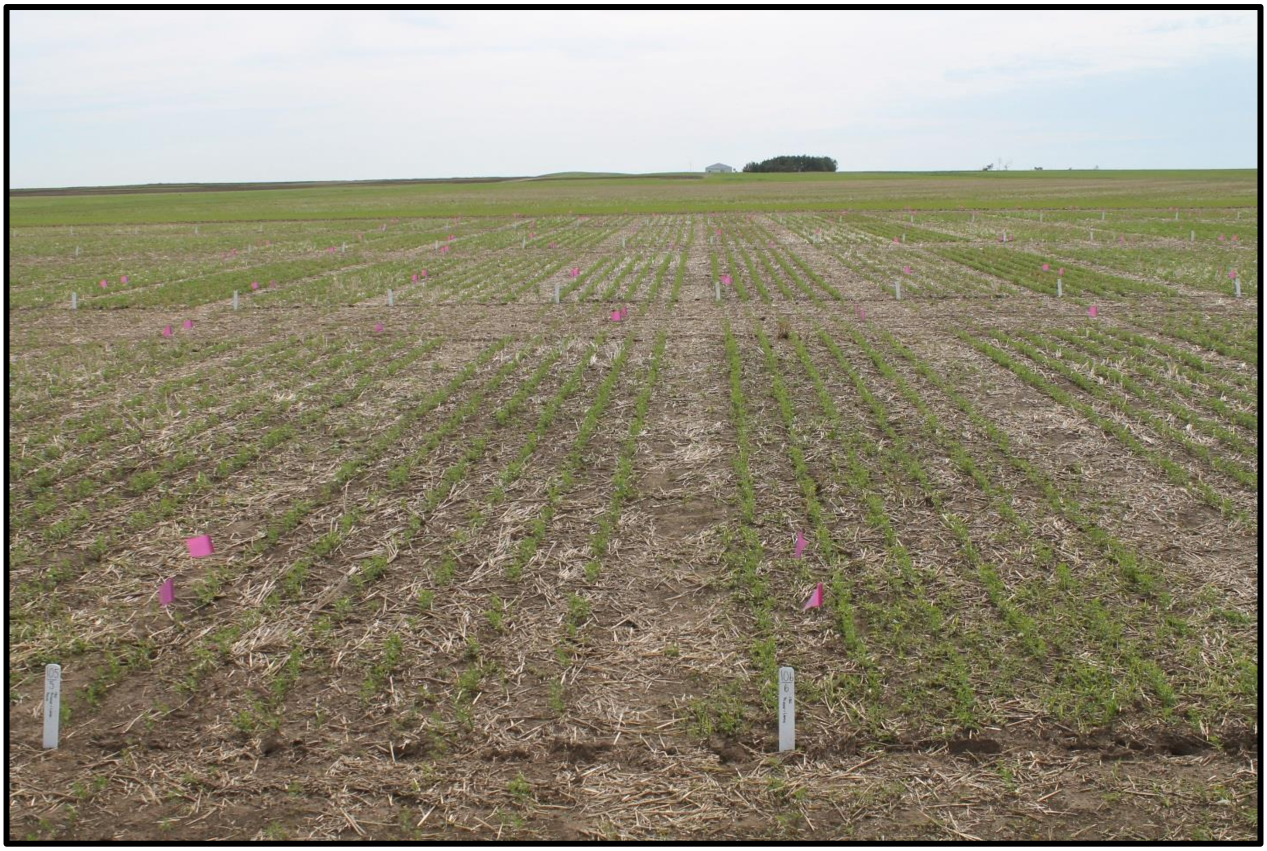
2019 Final Report

for the

Saskatchewan Ministry of Agriculture (ADF Program), Saskatchewan Pulse Growers (SPG) & Western Grains Development Commission (WGRF)

Project Title: Lentil Input Study

(Project #20160010)



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   Lentil input study (ADF#20160010)

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4. **Abstract/Summary:** An outline on overall project objectives, methods, key findings and conclusions for use in publications and in the Ministry database (Maximum of 500 words or one page in lay language).

Integrated management strategies are essential to improve weed control and disease management problems challenging lentil producers in western Canada. A study was conducted over a three-year period at five locations throughout Saskatchewan. The study included three seeding rates (130, 190 and 260 seeds/ m^2), three fungicide treatments (none, single, dual application) and two herbicide management practices (pre-seed burn-off vs. pre-seed residual) to total 18 treatments. The response variables measured were crop and weed density, crop and weed dry weight biomass, disease ratings prior to fungicide application, 7, 14, and 21 days after initial application (DAIA), days to flower, days to maturity, seed yield, thousand kernel weights and test weight. The results indicated that a pre-seed residual herbicide reduced early season annual weed populations by 66% compared to the traditional pre-seed burn-off strategy. Weed growth was largely influenced by both seeding rate and herbicide application. The least effective weed management strategy was utilizing the current seeding rate recommendation of 130 seeds/m^2 with glyphosate applied alone. If a burn-off strategy is to be used, the seeding rate must exceed 130 seeds/m^2 to reduce weed interference. A residual herbicide application was more effective than glyphosate applied alone at all three seeding rates (130, 190 and 260 seeds/m^2). The most effective weed management strategy utilized a seeding rate of 190 seeds/m2 combined with a residual herbicide to reduce weed biomass by 76%. Seeding rate also influenced disease severity throughout the growing season. Disease severity tended to increase with seeding rate (260 seeds/m^2 > 190 seeds/m^2 > 130 seeds/ m^2). Seeding rates of 190 seeds/m^2 resulted in disease levels similar to unsprayed lentil at the current seeding rate recommendation (130 seeds/m^2). This indicates that if seeding rates are to increase to 190 seeds/ m^2 then fungicide applications are likely required, particularly under moist conditions. Furthermore, dual fungicide applications tended to have the least amount of disease pressure compared to single applications and unsprayed. Yield was also largely influenced by seeding rate with 190 seeds/ m^2 resulting in the highest yield compared to seeding rates of 130 and 260 seeds/m^2. A seeding rate of 190 seeds/m^2 also provided the best economic returns, regardless of management strategy. The highest net returns occurred with a seeding rate of 190 seeds/m^2, unsprayed fungicide and a residual herbicide application. Although the cost of a fungicide typically reduced net returns compared to the unsprayed, the fungicides should be viewed as a form of insurance rather than an input cost, as disease management is essential for proper lentil production. Additionally, the 15 site- years of experiments were generally conducted under drought conditions with limited disease pressure and therefore may not show the economic benefits associated with fungicide applications. A second factor to consider is the use of a residual herbicide over a burn-down weed control method like glyphosate applied alone. In this study, there was limited weed pressure (< 58 plants/m^2) and therefore under weedy conditions there would likely be a significant profit with a residual herbicide. Additionally, economic and agronomic to herbicide layering and residual products are likely to be realized over the longer-term versus exclusively during the year of application and can also help to mitigate the development of herbicide resistance in weed populations.

5. **Key Messages:** *key outcomes and/or extension messages and their importance for producers/industry (3-5 bullet points in lay language).*
    - A pre-seed residual herbicide reduced early season annual weed populations by 66% compared to the traditional pre-seed burn-off strategy.
    - The least effective weed control strategy was utilizing the current seeding rate recommendation of 130 seeds/m^2 with glyphosate applied alone. The most effective weed management strategy utilized a seeding rate of 190 seeds/m2 combined with a residual herbicide to reduce weed biomass by 76%.
    - Disease severity tended to increase with seeding rate (260 seeds/m^2 > 190 seeds/m^2 > 130 seeds/ m^2). At 190 seeds/m^2, disease levels were similar to lentils unsprayed at the current seeding rate recommendation (130 seeds/m^2). A single fungicide application is required when a seeding rate targets a 190 seeds/ m^2, dual fungicide applications may be required under higher disease pressure.
    - A seeding rate of 190 seeds/ m^2 resulted in the highest yield compared to seeding rates of 130 and 260 seeds/m^2.
    - A seeding rate of 190 seeds/m^2 also resulted in higher net returns than 130 and 260 seeds/m^2, regardless of management strategy. The highest net returns occurred with a seeding rate of 190 seeds/m^2, no fungicide and a residual herbicide application.
    - The cost of a fungicide typically reduced net returns compared to the unsprayed. However, the fungicides should be viewed as a form of insurance rather than an input cost, as disease management is essential for proper lentil production. Additionally, the experiments in the 15 site- years were generally conducted under drought conditions with limited disease pressure and therefore may not show the economic benefits that might be associated with fungicide applications under a wider range of conditions.

6. **Introduction:** *Brief project background and rationale.*

Canadian lentil production in 2019 was estimated to be 2.2 million tonnes, which was similar to the 10-year average of 2.1 million tonnes (Statistics Canada, 2020). Saskatchewan continues to dominate lentil production in western Canada, accounting for about 94% of production, while Alberta accounts for about 6%. Red lentil is the predominant market class and accounts for about 60% of the lentil production in global trade (Saskatchewan Ministry of Agriculture, 2010). CDC Maxim, a red lentil cultivar, has gained popularity in Canada during recent years (Saskatchewan Pulse Growers, 2015). This lentil variety is high yielding compared with other red lentil varieties (Vandenberg and SK Crops Branch Saskatchewan Agriculture, 2010) and has good resistance to ascochyta blight (*Ascochyta lentis Vassilievsky*) and anthracnose (*Colletotrichum truncatum Schwein*) (Saskatchewan Seed Growers Association, 2016). In addition, CDC Maxim has been bred to tolerate imidazolinone (Group 2) herbicides, which aids in weed control (Saskatchewan Pulse Growers, 2015).

Although lentil production has become increasingly popular on the Prairies, a major limiting factor for lentil production continues to be weed control. Current chemical strategies typically consist of a non-selective pre-seed application followed by an in-crop Group 2 herbicide applications. However, the prevalence of Group 2 herbicide-resistant (HR) weeds such as wild mustard (McVicar et al. 2010), kochia (Heap 2014), stinkweed (Beckie et al. 2007) result in poor weed control with this strategy. Alternative herbicide modes of action may provide improved control of resistant weeds. Applying a pre-seed herbicide application with a residual component will provide extended early season weed control and management of Group 2 herbicide resistant weeds. A pre-seed weed control herbicide that was recently registered for fall and spring applications in lentils for grassy and broadleaf weed control is Focus©. Focus© combines a Group 14 (carfentrazone-ethyl) and Group 15 (pyroxasulfone) mode of action to effectively control weeds and aid in preventing the development of herbicide resistant weeds.

Utilizing two or three herbicides in sequence to improve weed control and prevent herbicide resistance is a technique called herbicide layering. Herbicide layering has been found to be a very effective tool for improved weed control and reduces the likelihood of Group 2 resistance developing in regions where it is not yet widespread. However, producers are hesitant to incorporate this technique into their farming practices due to the additional labor, time and herbicide costs associated with herbicide layering. Therefore, an economic analysis should be conducted in order to determine if herbicide layering in lentils is economically feasible.

Another effective integrated weed management practice that has been found to reduce crop-weed competition is combining herbicide applications with higher seeding rates (Blackshaw et al. 2005a; Barton et al. 1992). For example, O'Donovan and Newman (2004) documented improved weed control with increased seeding rates in a canola-barley rotation when a reduced rate of herbicide was used. Increased seeding rates improve crop competitive ability because the crop can occupy the available space earlier in the growing season, which will reduce nutrient, space and light availability required for weed growth (Redlick, 2017). The current lentil recommended seeding rate (130 plants/m^2) (Saskatchewan Pulse Growers, 2016) may not effectively reduce crop-weed competition. Furthermore, the seeding rate is lower than seeding rates used in other parts of the world. For example, in West Asia an optimal seeding rate ranges between 275 - 300 plants/m^2 (Silim et al. 1990), while an Italian study determined that the optimal seeding rate to be 177 - 250 plants/m^2 (Paolini et al. 2003). Baird et al. (2009) also determined that increasing the seeding rate to 375 seeds/m^2 in organic production provided the maximum yield and weed suppression, as well as maximum economic return. More recently, Kasper (2019) indicated that yield of small red lentil was optimized at a target plant population of 210 plants/m^2. Current literature suggests an increase in the recommended seeding rate, however, the extent in which the seeding rate should increase and how it will influence disease pressure in Saskatchewan has yet to be determined for small red lentil. An increased seeding rate results in a thicker canopy that is more prone to disease pressure (Davidson and Kimber, 2007) and therefore may require additional fungicide applications. However, multiple fungicide applications are a costly expenditure and may not be always be economically justifiable for producers.

Overall, it is critical to determine which integrated agronomic practices will result in the greatest productivity while remaining profitable. As many of these factors have yet to be reviewed when used in combination, it is unclear as to whether any interactive effects may occur. It is important to determine which factors best influence lentil production and if certain combinations of inputs may provide an interactive, or synergistic effect to improve lentil productivity in Saskatchewan.

7. Objectives and the progress towards meeting each objective

Objectives **(Please list the original objectives and/or revised objectives if Ministry-approved revisions have been made to original objective. A justification is needed for any deviation from original objectives)**	**Progress** **(e.g. completed/not completed)**
a) To determine which combination of the common agronomic practices will produce the greatest lentil yield	**Completed**
b) To determine which agronomic practices will provide the best economic return to producers	**Completed**

8. Methodology *Specify project activities undertaken during entire project period. Include approaches, experimental design, methodology, materials, sites, etc.*

The study was conducted over three years (2017-2019) throughout Saskatchewan in Scott with the Western Applied Research Corporation, Indian Head with Indian Head Agriculture Research Foundation, Outlook with Irrigation Crop Diversification Corporation, Swift Current with Wheatland Conservation Area. The study was also conducted at the East Central Research Foundation in Yorkton in 2017, then in 2018 and 2019 at the University of Saskatchewan at Saskatoon.

The experiment was conducted as a randomized complete block design (RBCD) with four replications. The treatments consisted of a 3 x 3 x 2 factorial design with three seeding rates (130, 190 and 260 seeds/m^2), three fungicide treatments (unsprayed, single, dual application) and two herbicide management practices (pre-seed burn-off vs. pre-seed residual) for a total of 18 individual input combinations. While certain aspects of the specific seeding equipment varied (i.e. row spacing, opener type) across locations, all plots were direct-seeded into cereal stubble and all fertilizer was side-banded during seeding. The single fungicide application consisted of Priaxor applied at beginning of flowering, while the dual fungicide application consisted of Priaxor followed by Lance WDG 10 to 14 days after the single application (DAA). The pre-seed burn off consisted of glyphosate and the pre-seed residual included glyphosate and Focus® co-formulated. Focus rates were applied based on soil type recommendations. The herbicide applications were applied three to five days prior to seeding. Post-emergent herbicide applications consisted of Ares and Centurion for all treatments. Fertilizer (N-P-K-S) was applied based on soil test recommendations to achieve a 30 bu per acre crop. Nodulator XL SCG pea and lentil inoculant was applied based on label recommendations with rates adjusted for row spacing.

Pertinent agronomic information for each location for each year are provided in Tables A-1, A-2, and A-3 of the Appendices. Specific management practices and decisions were largely left to individual site managers and tailored to regional practices, available equipment and pests encountered; however, all controllable factors other than seeding rate, herbicides, and fungicides were intended to be non-limiting. Seeding dates ranged from May 9 to May 26. Pre-harvest herbicides or desiccants were applied at or after the latest maturing plots reached physiological maturity if considered necessary or desirable. All plots were combined at maturity and, wherever possible, outside rows were excluded to minimize edge effects.

A composite soil sample (targeted depth intervals of 0-15 cm and 15-60 cm) was collected from each trial location in the early spring and submitted to laboratories of the individual sites choosing. The crop response data collected included crop and weed density, crop and weed biomass, disease ratings, days to flowering, days to maturity, seed yield, thousand kernel weights, and test weight.

Plant densities were determined by recording the number of emerged plants in 2 x 1-meter row lengths per plot approximately two weeks after emergence (WAE) and converting the values to plants/m^2. Weed densities were estimated prior to canopy closure in the front and back of each plot using 0.25 m^2 quadrants. Disease severity ratings were taken prior to the first fungicide application, 7, 14 and 21 days after initial application (DAIA). Plots were rated based on % total disease severity ranging from zero to ten (Table A-4). Crop biomass was collected from the front and back using 0.25 m^2 quadrants at crop physiological maturity and weed biomass was collected and separated from the crop. Days to flowering was recorded at beginning of flowering and days to maturity were recorded when the bottom third of the pods turned yellow to brown and rattled when shaken. Yields were determined from cleaned harvested grain samples and corrected to 14% moisture content. Thousand kernel weights and test weights were recorded for seed quality. Mean monthly temperatures and precipitation amounts were estimated for each location from the nearest Environment Canada or private weather station.

Statistical analysis was conducted on an individual and combined basis using the MIXED procedure in SAS software version 9.4 (SAS Institute, 2020). The fixed effects were seeding rate (or target plant population), herbicide and fungicide, while the random effects included site-year and replicate nested in site-year, as well as random interactions of site-year with the fixed effects. Prior to biomass analysis, an exploratory analysis was implemented and this resulted in a square root transformation to satisfy the assumptions of ANOVA. The assumptions of ANOVA included checking the data for normality (the normal distribution of residuals) and ensuring that variances were homogenous. A value of P <0.05 was used to determine the significance of treatment effect. An analysis of variance (ANOVA) was conducted on each data set and the least squared means (LS means) were used to establish treatment differences and the differences in least squared means were used to determine significance at a value of P<0.05. Results from the Type 3 Tests of fixed effects were used to distinguish differences between treatments. The process was used on crop and weed emergence, crop and biomass, disease ratings, yield, thousand kernel weights and test weights. An additional analysis was also conducted on weed biomass, disease ratings at 21 DAIA, and days to maturity using PROC GLM to investigate a linear regression of a continuous x categorical variables to determine the level of significance for the simple slopes and the dependency of the variables.

The economic analysis was conducted by calculating the cost and subsequent return of each agronomic practice. The economic equation took into consideration the yield (kg per hectare) per treatment and price per kilogram to determine gross income ($ per kg) minus the total cost [cost of seed ($ per kg), herbicide ($ per ha), fungicide ($ per ha), fertilizer ($ per ha), inoculant ($ per ha) and fuel ($ per ha)] to determine net profit ($ per ha). An additional analysis was conducted to determine if increased weed densities and consequentially increased yield losses would influence net profits. Yield losses were calculated based on three concepts: weed control as a percentage of reduced weed biomass (kg/ha) for glyphosate and residual herbicide calculated at 11 responsive site-years, correlating weed densities to weed biomass based on data collected and the principle that 1% yield loss occurs for every 56 kg/ha of weed biomass (Smitchger et al. 2012).

9. **Results and Discussion** *Describe results accomplished during the entire project period under each objective listed under section 6. The results need to be accompanied with tables, graphs and/or other illustrations. Provide discussion necessary to the full understanding of the results. Where applicable, results should be discussed in the context of existing knowledge and relevant literature. Detail any major concerns or project setbacks.*

Weather

Growing season temperatures and precipitation amounts for the 2017, 2018 and 2019 growing seasons (May-August) relative to the long-term averages are provided in Tables A-5, A-6, A-7 of the Appendices, respectively. The temperatures in 2017 were nearly identical to the long-term averages in all five locations. All five locations were considered relatively dry in 2017 with all locations reporting the total precipitation below their respective long-term averages. Swift Current was the driest location amongst all five locations, followed by Indian Head, Outlook, Yorkton and then Scott, SK. In 2018 the temperature at all five locations were above their respective long-term average by approximately 1-1.5°C. The warmest location was at Outlook, followed by (descending order) Swift Current, Saskatoon, Indian Head and Scott. Additionally, all five locations were drier than their long-term average, particularly at Outlook (184 mm lower) and Saskatoon (105.4mm lower), followed by Indian Head (96mm lower), Swift Current (91 mm lower) and Scott (55 mm lower). In 2019, all five locations were slightly cooler than their long-term average. Averaged over the 4-month growing season (May-August), there was a 0.9 to 1.2°C drop in temperature at Swift Current, Scott, Indian Head and Saskatoon compared to their respective long-term averages. The temperature at Outlook was 7.7°C lower than the long-term average. Indian Head, Swift Current, Saskatoon and Outlook also received less precipitation by approximately 12 mm, 14 mm, 31 and 77 mm than their respective long-term average. Scott was the only location that received more precipitation than the long-term average by 10 mm.

Treatment Effects on Lentil Emergence & Weed Density

The combined analysis for the 15 site-years indicated a significant (P <0.0001) linear response of lentil establishment (plants/m^2) to seeding rate (seeds/m^2) (Table 1). Lentil establishment increased with incremental increases to seeding rates. The average plant densities observed over 15 site-years was 186 plants/m^2, 146 plants/m^2 and 105 plants/m^2 at the targeted seeding rates of 260, 190 and 130 seeds/m^2, respectively. This translates to respective establishment percentages of 72, 77, and 82%. The combined analysis of 15 site-years had a significant (P=0.0011) interaction between site-year and seeding rate indicating that the seeding rate response varied amongst locations (Table 1). Lentil establishment at Indian Head exhibited a significant quadratic (P= 0.0144) response to seeding rate. This indicates that the maximum plant density of 219 plants/m^2 would occur if a seeding rate of 381 seeds/m^2 were used. In contrast, there was a linear seeding rate response at Scott, Outlook, Yorkton and Saskatoon (Table 2). A linear response to seeding rate indicates that lentil plant density will continue to increase when the targeted seeding rate exceeds 260 seeds/m^2. Additionally, mean plant density ranged considerably at each location with the highest plant density occurring in Outlook while Saskatoon had the lowest plant density (Table 2). The second lowest plant density was recorded in Swift Current where the linear response to seeding rate was only marginally significant (P=0.0638) for lentil establishment (Table 2). Although a significant linear effect was not detected, the highest seeding rate did produce the highest lentil establishment and lowest plant densities occurred at the lowest seeding rate.

The lowest establishment rates coincided with the driest springs recorded at Swift Current and Saskatoon, indicating that the poor soil moisture and lack of precipitation negatively influenced lentil emergence. There was no indication that the pre-seed herbicide applications of glyphosate or glyphosate with a residual herbicide influenced lentil establishment (Table 1). The effect of fungicide was not considered as application occurred after plant establishment counts were conducted.

Table 1. Overall tests of fixed effects for lentil establishment (plants/m^2) over all site-years (n=15). The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Lentil Establishment
Effect	--- p-values ---
Site-Year (S)	0.0086
Seeding Rate (SR)	<0.0001
Herbicide (HR)	0.8396
SR x HR	0.2281
S x SR	0.0011
S x HR	0.3164
S x SR x HR	NE [W]
SR – linear	<0.001
SR – quadratic	0.0801

[W] NE represents non-estimable value

Table 2. Main effect means for lentil establishment (plants/m²) averaged across years at Scott, Outlook, Swift Current, Indian Head in 2017 to 2019 and Saskatoon in 2018-2019 and Yorkton in 2017, Saskatchewan. Main effect means within a column followed by the same letter do not significantly differ.

	Overall Means for Lentil Establishment (plants/m²)						
Treatment/ Main Effects	All Sites (n=15)	Scott (n=3)	Outlook (n=3)	Swift Current (n=3)	Indian Head (n=3)	Saskatoon (n=2)	Yorkton (n=1)
Seeding Rate				plants/m²			
130 seeds/m²	105 a	102 a	135 a	88 a	114 a	82 a	108 a
190 seeds/m²	146 b	142 b	180 b	126 b	160 b	118 b	154 b
260 seeds/m²	186 c	188 c	225 c	169 c	199 c	143 c	196 c
				p-values			
SR – linear	<0.001	0.0076	0.0364	0.0638	<0.001	0.0287	0.0301
SR - quadratic	0.0801	0.7048	0.3897	0.4688	0.0144	0.1779	0.3399
Herbicide				plants/m²			
Glyphosate	145 a	149 a	176 a	123 a	157 a	112 a	155 a
Glyphosate & Residual	144 a	145 a	175 a	123 a	154 a	116 a	151 a

Weed densities were not collected at Saskatoon in 2018 and therefore were excluded from the analysis. The combined analysis of 14 site-years indicated that the pre-seed herbicide application had a significant effect on weed densities (P<0.0001) (Table 3). At 9 of the 14 site-years the pre-seed residual herbicide provided superior weed control than glyphosate applied alone. There was a 66% increase in annual weed control including green foxtail, cleavers, redroot pigweed, volunteer canary seed, and suppression of kochia and wild oats. The pre-seed residual herbicide did not provide greater weed control than glyphosate alone 36% of the time (5 / 14 site-years). At Indian Head (2017), glyphosate applied alone resulted a significant weed control response (P=0.0427) and resulted in a 23% increase in weed control compared to glyphosate with a residual application. However, the two dominant weeds present at Indian Head (2017) were volunteer canola and Canadian thistle, both of which are not registered for control with the residual herbicide applied. Additionally, the Canadian thistle population was sporadic and therefore does not provide a clear insight as to the efficacy of the residual application compared to glyphosate alone. As such, the unusual results at Indian Head 2017 were primarily attributed to naturally occurring spatial variability. The remaining four site-years (Yorkton in 2017 and Outlook in 2017, 2018, 2019) had no effect of herbicide (P= 0.5196) and this was largely attributed to the low weed density, excellent early season weed control with glyphosate alone, and the late flushes of millet and volunteer canola, neither of which are registered for weed control with this residual herbicide (Figure 1). A component that was expected to hinder the efficacy of the residual herbicide was the dry spring conditions, as soil moisture is required for activation. However, results from Swift Current, one of the driest locations indicated excellent weed control (Figure 1).

Table 3. Overall tests of fixed effects weed densities (plants/m²). The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Weed Density		
	All Sites (n=14)	**Responsive Sites (n=9)**	**Non-Responsive Sites (n=5)**
Effect	-------------------	p-values	-------------------
Site-Year (S)	0.2607	0.3181	0.0866
Seeding Rate (SR)	0.6061	0.6606	0.8223
Herbicide (HR)	<0.001	<0.001	0.2262
SR x HR	0.2688	0.2688	0.5356
S x SR	NE [W]	NE	NE
S x HR	0.0066	0.266	NE
S x SR x HR	NE	NE	NE

[W] NE represents non-estimable value

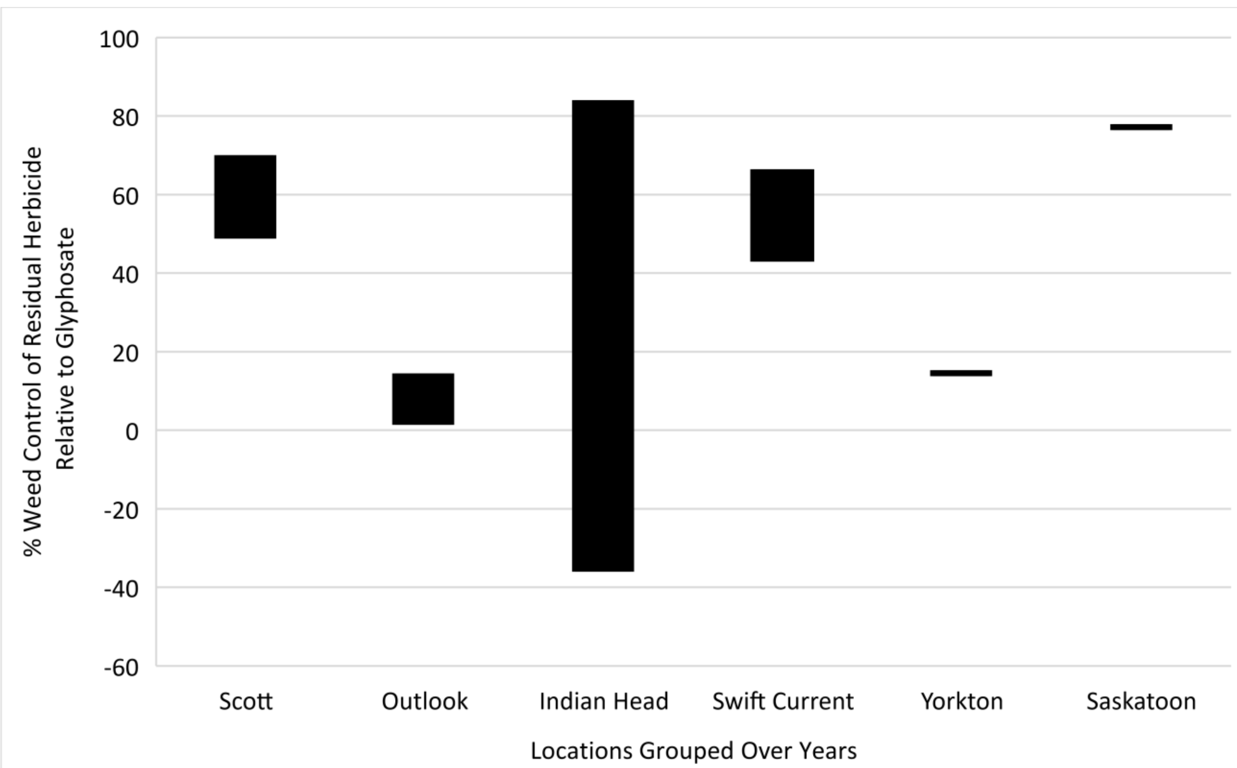

Figure 1. Weed control (%) of residual herbicide relative to glyphosate applied alone combined over years at Scott (2017-2019), Outlook (2017-2019), Indian Head (2017-2019), Swift Current (2017-2019), Yorkton (2017) and Saskatoon (2019).

<u>Treatment Effects on Lentil & Weed Biomass</u>

The analysis of the lentil biomass data indicated that all 15 site-years could be combined (Table A-8) and that seeding rate significantly (P=0.0244) influenced lentil biomass. The highest seeding rate of 260 seeds/m^2 resulted in the highest crop biomass of 5451 kg/ha while the lowest seeding rate of 130 seeds/m^2 had the lowest biomass of 5293 kg/ha. Lentil biomass weights ranged throughout locations with Outlook (2017-2019) producing the highest lentil biomass averaging 8578 kg/ha, followed by Scott (2017-2019) with 6414 kg/ha and Yorkton (2017) with 5925 kg/ha. The lowest crop biomass was collected at the driest location at Swift Current (2017-2019) with 3683 kg/ha (data not shown). The locations with the greatest moisture typically resulted in the highest lentil biomass at the seeding rate of 260 seeds/m^2. In contrast, when averaged over three growing seasons, Swift Current had the lowest crop biomass at the highest seeding rate (260 seeds/m^2). The excessive plant densities associated with the 260 seeds/m^2 seeding rate combined with drought stress resulted in reduced crop development and ultimately limited growth relative to the lower seeding rates. The effect of herbicide and fungicide were negligible indicating that these factors had little influence on overall crop development (Table A-8).

Weed biomass data collected over 15 site-years indicated a significant difference between site-years and herbicide (P=0.0492), indicating that the effect of herbicide varied depending on the specific environment. The site-years were split amongst responsive and non-responsive sites (Table 4). The four non-responsive sites were Saskatoon in 2018 and Outlook in 2017, 2018, 2019. The weed populations at these locations were negligible and were not influenced by seeding rate or herbicide or the interaction of the two (Table 4). There were 11-site years that indicated a significant linear interaction between seeding rate and herbicide (P= 0.0237) (Table 4). The interaction indicated that the effect of seeding rate differed depending on the herbicide treatment. When glyphosate was applied alone, there was a steep linear reduction in weed biomass as seeding rate increased. A 1kg/ha increment in seeding rate resulted in 1.4 kg/ha reduction in weed biomass (Figure 2). In contrast, the seeding rate effect was not significant (P=0.6859) when combined with a residual herbicide; thus, indicating that all seeding rates resulted in similar weed biomass yields when combined with a residual herbicide (Figure 2). Weed biomass yields were reduced with the residual herbicide application (relative to glyphosate applied alone) at all three seeding rates but the difference was greatest at the low, 130 seeds/m^2, seeding rate (Figure 2). Increased seeding rates can improve crop competitive ability because the crop can occupy the available space earlier in the growing season, subsequently reducing the nutrient, space and light availability required for weed growth (Redlick, 2017). These associated benefits with an increased seeding rate were most apparent when glyphosate was applied alone because this treatment provided less long-term weed control than the residual herbicide. In contrast, the effects of seeding rate were less apparent and influential when combined with the residual herbicide product.

In contrast, the seeding rate effect was not significant (P=0.6859) when combined with a residual herbicide; thus, indicating that all seeding rates resulted in similar weed biomass yields when combined with a residual herbicide (Figure 2). Weed biomass yields were reduced with the residual herbicide application (relative to glyphosate applied alone) at all three seeding rates but the difference was greatest at the low, 130 seeds/m^2, seeding rate (Figure 2). Increased seeding rates can improve crop competitive ability because the crop can occupy the available space earlier in the growing season, subsequently reducing the nutrient, space and light availability required for weed growth (Redlick, 2017). These associated benefits with an increased seeding rate were most apparent when glyphosate was applied alone because this treatment provided less long-term weed control than the residual herbicide. In contrast, the effects of seeding rate were less apparent and influential when combined with the residual herbicide product.

Table 4. Overall tests of fixed effects for weed biomass (kg/ha). The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. Data were analysed using the Mixed procedure of SAS.			
	Overall Tests of Fixed Effects for Weed Biomass		
	All Sites (n=15)	**Responsive Sites (n=11)**	**Non- Responsive Sites (n=4)**
Effect	---------- p-values ----------		
Site-Year (S)	0.0247	0.047	0.2194
Seeding Rate (SR)	0.0033	0.0014	0.9392
Herbicide (HR)	<0.0001	0.0003	0.5108
SR x HR	0.0329	0.0237	0.2465
S x SR	0.0508	0.071	NE
S x HR	0.0492	0.0771	NE
S x SR x HR	NE [W]	NE	NE

[W] NE represents non-estimable value

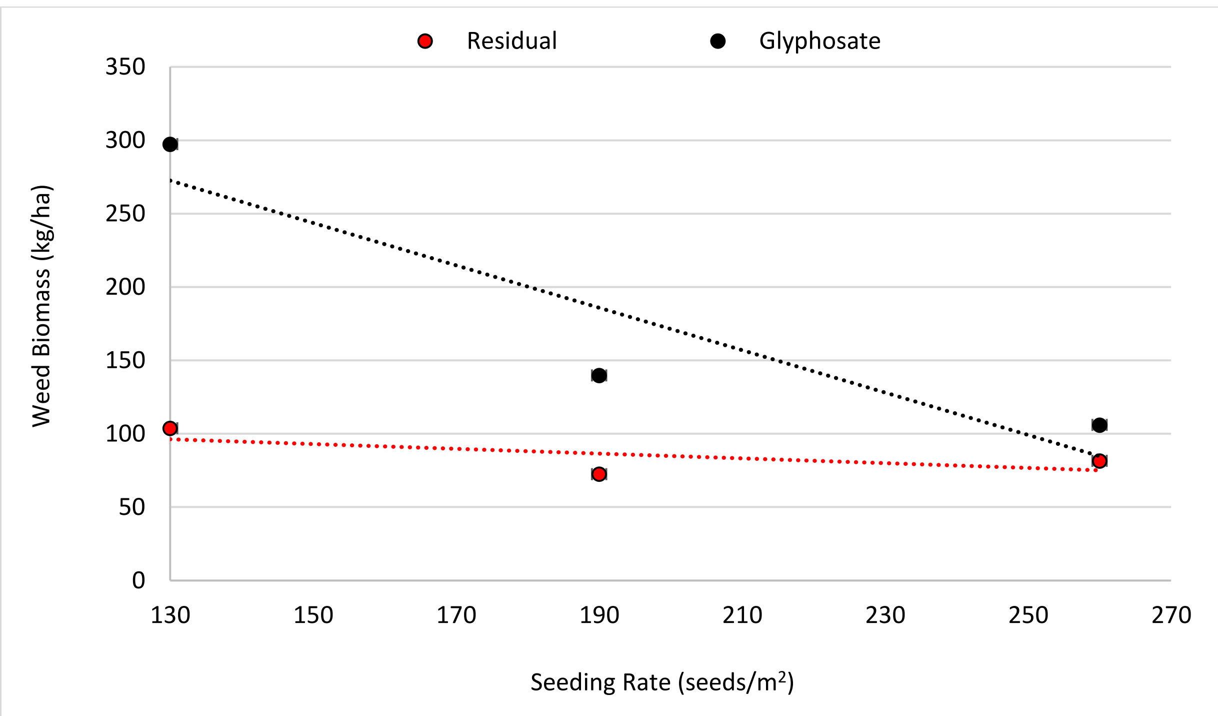

Figure 2. Effect of seeding rate and herbicide applications on weed biomass at physiological maturity. Points represent 11 responsive site years. Line equation for the glyphosate applied alone: y= -1.445x +460.32; R^2= 0.8469. Line equation for the residual herbicide is y= -0.1627 x + 117.41; R^2= 0.4324

Treatment Effects on Lentil Disease Ratings

Disease severity ratings were combined over 13 site-years to demonstrate the prominent trends that occurred throughout the various locations and growing conditions. By doing so, we can provide growers with a general sense of what will occur under a range of conditions when various seeding rates and fungicide applications are utilized. Disease ratings at Saskatoon in 2018 and 2019 were not collected due to the very dry growing conditions. When all 13 site-years were combined there is a significant (P=0.0071) seeding rate effect on disease severity prior to fungicide application, indicating that seeding rates largely influence disease development early on in the growing season (Table 5). Disease severity (prior to fungicide application) was the highest at 12% at a seeding rate of 260 seeds/m^2 but dropped marginally to 11% at seeding rates of 190 seeds/m^2 and 130 seeds/m^2. Seven days after initial application (DAIA), disease severity increased to 15%, 14% and 13% when seeding rates targeted 260 seeds/m^2, 190 seeds/m^2, and 130 seeds/m^2, respectively. Fungicide applications also significantly (P<0.0001) influenced disease severity as the unsprayed lentils had 13% higher disease severity than lentil sprayed with a single and dual fungicide application. Disease severity was influenced by both seeding rate (P <0.0001) and fungicide applications (P<0.0001) at 14 DAIA. Disease severity was 25, 22, and 19% at respective seeding rates of 260, 190, and 130 seeds/m^{2,} respectively. Unsprayed lentil had the greatest disease pressure at 26% while the single and dual fungicide applications were similar with 21% and 20% of the plant area affected (Table 6).

Table 5. Overall tests of fixed effects for lentil severity disease ratings (%) conducted prior to fungicide application, 7, 14 and 21 Days After Initial Application (DAIA) at 13 site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Lentil Disease Severity (%)			
	Prior to Application (n=13)	**7 DAIA (n=13)**	**14 DAIA (n=13)**	**21 DAIA (n=13)**
Effect	---------- p-values ----------			
Site-Year (S)	0.0059	0.0062	0.0073	0.0076
Seeding Rate (SR)	**0.0074**	**0.0059**	**<0.0001**	<0.0001
Herbicide (HR)	0.7348	0.9643	0.0914	**0.0333**
Fungicide (FG)	0.5309	**<0.0001**	**<0.0001**	<0.0001
SR x FG	0.8337	0.9687	0.1561	**0.0217**
SR x HR	0.1573	0.2330	0.4044	0.2924
HR x FG	0.6026	0.8243	0.8678	0.5078
SR x HR x FG	0.7216	0.3539	0.5325	0.9947
S x Fungicide (FG)	0.0509	0.004	0.0006	0.0011
S x Seeding Rate (SR)	0.049	0.0873	0.001	0.0008
S x Herbicide (HR)	NE [W]	NE	0.0721	0.4301
S x SR x HR	0.4443	NE	0.1183	0.0371
S x FG x HR	NE	NE	NE	NE
S x FG x SR	0.2353	0.2353	0.0323	0.0079
S x SR x HR x FG	NE	NE	NE	0.3328
	---------- p-values ----------			
SR- linear	0.6009	0.8334	0.6501	0.0002
SR- quadratic	0.6765	0.9336	0.8638	0.4971

[W] NE represents non-estimable value

Table 6. Main effect means and interactions for lentil disease severity (%) collected prior to fungicide applied, 7, 14 and 21 days after initial application (DAIA) averaged across 13-site years in Scott, Outlook, Swift Current, Indian Head and Yorkton, Saskatchewan. Main effect means within a column followed by the same letter do not significantly differ.				
	Overall Estimates for Lentil Disease Severity (%)			
Treatment/ Main Effects	Prior to Application	7DAIA	14 DAIA	21 DAIA
Seeding Rate (SR)	-- Disease Severity (%) --			
130 seeds/m^2	11 a	13 a	19 a	21 a
190 seeds/m^2	11 ab	14 ab	22 b	26 b
260 seeds/m^2	12 b	15 b	25 c	31 c
Herbicide (HR)	-- Disease Severity (%) --			
Glyphosate	11 a	14 a	23 a	27 a
Glyphosate & Residual	11 a	14 a	22 a	25 b
	-- Disease Severity (%) --			
Fungicide (FG)				
None	11 a	15 a	26 a	31 a
Single	11 a	13 b	21 b	24 b
Dual	11 a	13 b	20 b	23 b
FG x SR	-- Disease Severity (%) --			
None x 260 seeds/m^2	12 a	16 a	30 a	38 a
None x 190 seeds/m^2	11 a	15 a	26 a	32 b
Single x 260 seeds/m^2	11 a	14 a	23 a	29 b
Dual x 260 seeds/m^2	12 a	14 a	23 a	27 bc
Dual x 190 seeds/m^2	11 a	13 a	21 a	24 cd
Single x 190 seeds/m^2	11 a	14 a	20 a	24 cd
None x 130 seeds/m^2	11 a	14 a	21 a	23 cd
Single x 130 seeds/m^2	11 a	13 a	18 a	20 d
Dual x 130 seeds/m^2	10 a	13 a	18 a	20 d

At 21 DAIA herbicide applications also significantly (P=0.0333) influenced disease severity (Table 5). Pre-seed herbicide application of glyphosate applied alone had 7% higher disease severity compared to glyphosate with a residual herbicide. As glyphosate was less effective in reducing weed biomass in 11 of the 15 site-years, the higher disease pressure could be attributed to the higher weed pressure and therefore thicker canopy and increased risk for disease development (Davidson and Kimber, 2007). Unlike the previous ratings, there was a significant interaction between seeding rate and fungicide (P=0.0217), indicating that the effectiveness of the fungicide was dependent on seeding rates (Figure 3). Disease severity ratings were statistically similar at 130 seeds/m^2 between the unsprayed, single and dual fungicide applications; however, disease severity was 26% higher with the unsprayed lentils compared to sprayed (single and dual applications) when the seeding rate exceeded 190 seeds/m^2. The dual fungicide application at 260 seeds/m^2 had slightly lower disease levels (9%) than the single fungicide but were not significantly different. The disease severity at 260 seeds/m^2 with a single and dual fungicide application had 21% and 13% more disease than the unsprayed lentils seeded at 130 seeds/m^2. In general, when seeding rates exceeded 130

seeds/m², the use of a fungicide (single or dual) was required to manage disease development and the seeding rate of 260 seeds/m² resulted in moderate (>25%) disease development regardless of multiple fungicide applications, even in dry growing conditions. It should be noted that, at 21 DAIA, the crop was beginning to maturity and it could be difficult to differentiate between disease and crop senescence.

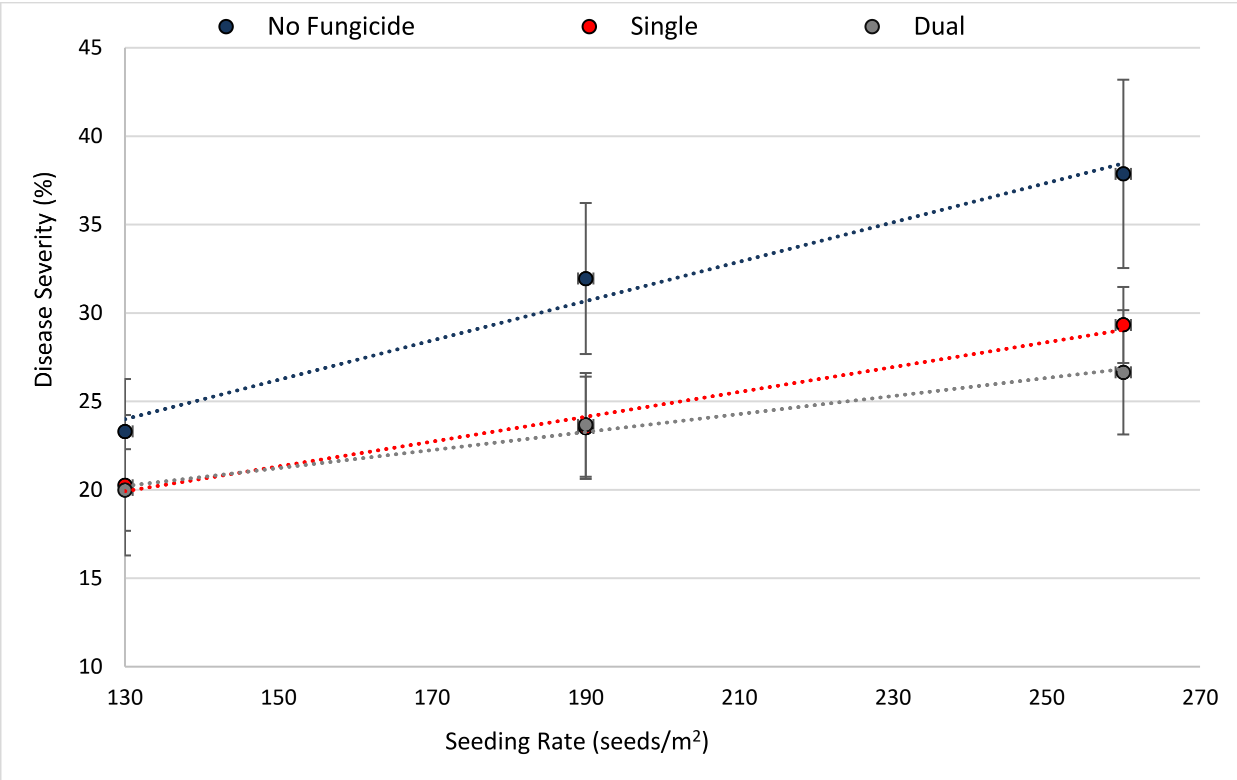

Figure 3. Effect of lentil seeding rate on disease severity ratings (0-100%) at 21 days after initial application (DAIA) with a significant interaction between a continuous (seeding rate) x categorical (fungicide) interaction (P= 0.0217) at 13 site-years. Standard error bars indicate significant differences between main effects. Line equation for no fungicide: $y=0.1113x + 9.5247$; $R^2 = 0.9771$. Line equation for single fungicide: $y = 0.0702x + 10.793$; $R^2 = 0.9863$. Line equation for dual fungicide: $y = 0.0509x + 13.594$; $R^2 = 0.9885$.

The combined 13 site-year analysis had a site-year by fungicide interaction at 7 DAIA, 14 DAIA and 21 DAIA and a site-year by seeding rate interaction at 14 DAIA and 21 DAIA indicating that specific locations had different responses to fungicide and seeding rates. In particular, Swift Current, the second driest location, exhibited slightly different trends than the 13 site-year analysis. Seeding rate alone had little impact on overall disease severity prior to fungicide application, and at 7 DAIA and 14 DAIA. This is likely due to the very dry conditions that persisted throughout much of the growing season. The dry conditions resulted in a thinner canopy at all three seeding rates and therefore disease development was quite limited (< 6%), even at the highest seeding rate. Similar to the 13 site-year trend, fungicide applications were effective in managing disease levels at 21 DAIA with unsprayed lentils having the highest disease severity while dual fungicide applications significantly reduced disease levels by 45%. Although seeding rate had little impact on disease pressure on its own, when combined with fungicide applications there was a significant interaction at 21 DAIA, indicating that seeding rate may influence fungicide efficacy in terms of disease management. For instance, the unsprayed lentils at 190 seeds/m² had approximately the same disease pressure as a single fungicide application combined with a 260 seeds/m² seeding rate. However, a dual fungicide at 260 seeds/m² was much more effective in minimizing disease pressure. In general, disease pressure was very low at this location (< 6%) but the use of a fungicide was helpful in managing disease levels. Disease pressure at this location may be attributed to the moisture levels but an additional factor to consider if previous cropping history. Lentils are very commonly grown in this location and therefore previous disease inoculum may contribute to disease pressure even in dry conditions. Therefore, proper seeding rate selection (< 260 seeds/m2) with the use of a fungicide is recommended to manage disease levels at Swift Current despite the drier weather that generally occurs.

Similar trends were also observed at Scott (2017-2019) and Outlook (2017-2019) compared to Swift Current and the 13-site year trends. Seeding rate and fungicide played an important role in disease management at 7 DAIA, 14 DAIA and 21 DAIA. However, an interaction between seeding rate and fungicide did not occur and therefore the response of the fungicide and seeding rate were independent of each other. For all four rating times, the highest disease levels occurred with 260 seeds/m^2 combined with no fungicide application. There was little difference between disease levels at the single and dual fungicide applications, regardless of seeding rate. This lack of difference could be attributed to the relatively drier growing conditions combined with the loam soil texture. In particular, the soil at Scott is considered to be relatively sandy with good drying properties. Therefore, the soil dries relatively quickly and less moisture is retained within the lower crop canopy resulting in less potential for disease development.

Lentil disease severity ratings at Yorkton varied from the 13 site-year trends as there was not a significant effect of seeding rate or fungicide at any of the four rating timings. However, trends indicated that a higher seeding rate resulted in greater disease severity and the use of a dual fungicide helped reduce disease pressure. This location is not well adapted for lentil production, but was selected for this trial to determine if location impacted seeding rate and fungicide application recommendations. Based on the trends from this location, it can be suggested that the highest seeding rate is not suitable and that a fungicide (single or dual) is preferred for disease management.

Another site that is not known for its lentil production is Indian Head. This location had the highest disease severity ratings, likely due to higher precipitation and its Black lacustrine (clay dominant) soil texture. A clay dominant soil has a higher water retention capacity compared to locations like Swift Current and Scott (Jong and Shields, 1988). This soil texture is capable of retaining soil moisture that can increase the humidity within the crop canopy to result in greater disease development. Although disease pressure was higher at Indian Head, similar trends were found at this location compared to Scott and Outlook and the 13 site-year trends. Seeding rate and fungicide applications largely influenced disease severity with a seeding rate of 260 seeds/m^2 and the unsprayed resulting in the greatest disease pressure at 7 DAIA. There was a seeding rate and fungicide interaction at 14 DAIA and 21 DAIA. The unsprayed lentils at 260 seeds/m^2 had the highest disease pressure. The disease severity dropped when a single and dual fungicide at 260 seeds/m^2 was applied, but disease severity was still quite high (>60%). The use of a single and dual fungicide at 190 seeds/m^2 were similar to disease severity compared to the unsprayed at 130 seeds/m^2. The lowest disease pressure recorded occurred at 130 seeds/m^2 with a single and dual fungicide application. In general, this location is not well suited for a seeding rate of 260 seeds/m^2 even with a single and dual fungicide application. A seeding rate of 190 seeds/m^2 may be utilized but a single or dual fungicide is required to manage disease and still poses a risk of excessive disease pressure under moisture rich conditions.

Another factor to consider is the lentil variety selected for this study, CDC Maxim. This variety and has good resistance to ascochyta blight (*Ascochyta lentis Vassilievsky*) and anthracnose (*Colletotrichum truncatum Schwein*) (Saskatchewan Seed Growers Association, 2016). The combination of drought conditions and relatively strong genetic disease resistance may limit the impact of fungicide applications. In general, the biggest factors to affect disease development are genetic resistance levels, moisture conditions, soil texture and previous cropping history. If one or more of these factors are high risk (high moisture, heavy clay, frequent cropping) there will likely be a seeding rate by fungicide interaction. This indicates to the producer that the selected seeding rate will influence your fungicide efficacy. If you are in a high-risk zone with a seeding rate exceeding >130 seeds/m^2 a single fungicide is required as a minimum. A moderate to low risk zone may utilize a higher seeding rate (190 seeds/m^2) with a single fungicide with relatively low risk of excessive disease pressure. Utilizing 260 seeds/m^2 is considered risky even under ideal conditions with dual fungicide applications.

Treatment Effects on Lentil Flowering and Maturity Timing

Days to flowering was combined over 14 site-years, Saskatoon 2018 was excluded as data was not collected. The most influential main effect on days to flowering in lentils was seeding rate (P=<0.0001); however, the overall effect of seeding rate on days to flowering was agronomically unimportant with only a 0.2 days difference between the longest and shortest days to flowering. The highest seeding rate resulted in the shortest days to flowering of 48 days. The effect of fungicide, herbicide or any combination of the three main effects was not significant over 14 site-years (Table A-9). When individual locations were combined over years, there were several differences in days to flowering. Scott, Indian Head and Yorkton were not influenced by seeding rate, fungicide, herbicide or any combination of the three main factors. The largest differences in days to flowering were observed amongst the locations indicating that environment was more important than any of the other factors evaluated for this variable. The average days to flowering was 49, 51 and 52 days at Scott, Indian Head and Yorkton, respectively. There was a significant effect of fungicide (P=0.0303) at Outlook (2017-2019), with the dual and single (45.3 days) fungicide resulting in 0.2-day difference from the unsprayed lentils (45.1 days). Days to flowering was significantly influenced by seeding rate (P=0.0007) at Swift Current (2017-2019) and (P=0.0004) Saskatoon (2019). At Swift Current, the lowest seeding rate of 130 seeds/m^2 had the longest days to flowering (45 days) compared to the two higher seedings rates (44 days). Similarly, the days to flowering ranged from 51, 50 and 49 days at 130 seeds/m^2, 190 seeds/m^2 and 260 seeds/m^2 at Saskatoon, 2019 (Table 7). In general, increasing seeding rate at the two driest locations resulted in a minor delay in flowering while the locations with moderate moisture did not detect any significant differences.

Table 7. Main effect means for lentil days to flowering combined over at 14 site-years (n=14). Data were analysed using the Mixed procedure of SAS.

Overall Means for Lentil Days to Flowering							
Treatment/ Main Effects	**All Sites (n=14)**	**Scott (n=3)**	**Outlook (n=3)**	**Swift Current (n=3)**	**Indian Head (n=3)**	**Yorkton (n=1)**	**Saskatoon (n=1)**
Seeding Rate	---------- Days to Flowering ----------						
130 seeds/m^2	48.2 a	49.4 a	45.3 a	44.7 a	51 a	51.5 a	50.5 a
190 seeds/m^2	48.2 a	49.4 a	45.2 a	44.4 ab	51 a	52.0 a	50.1 ab
260 seeds/m^2	48.0 b	49.5 a	45.2 a	44.1 b	51 a	51.4 a	49.5 b
Herbicide	---------- Days to Flowering ----------						
Glyphosate	48.1 a	49.5 a	45.3 a	44.4 a	51 a	51.6 a	50.0 a
Glyphosate & Residual	48.1 a	49.4 a	45.2 a	44.5 a	51 a	51.6 a	50.1 a
Fungicide	---------- Days to Flowering ----------						
None	48.2 a	49.4	45.1 a	44.5 a	51 a	51.6 a	49.7 a
Single	48.1 a	49.4	45.3 ab	44.3 a	51 a	51.8 a	50.1 a
Dual	48.1 a	49.4	45.3 b	44.4 a	51 a	51.4 a	50.3 a

Days to maturity was combined over 14 site-years, Saskatoon 2018 was excluded as data was not collected. The most influential main effect on days to maturity in lentils was seeding rate (P=<0.0001). The overall effect of seeding rate on days to maturity was minor with a 0.5 days difference between the longest and shortest days to maturity. The highest seeding rate resulted in the shortest days to maturity of 97 days. The effect of fungicide, herbicide or any combination of the three main effects was not significant over 14 site-years (Table A-10). When individual locations were combined over years, there were several differences in days to maturity. A main effect of seeding rate on days to maturity was significant at both Scott (P=0.00346) and Indian Head (P < 0.0001) (Table A-10). At Scott, the lowest seeding rate resulted in the longest days to maturity of 97 days while the highest seeding rate had the shortest maturity of 96.5 days. There was a slightly larger maturity difference recorded at Indian Head with 86, 84 and 83 days corresponding with seeding rates of 130 seeds/m^2, 190 seeds/m^2 and 260 seeds/m^2, respectively. Additionally, a seeding rate (P=<0.0001) and herbicide (P=0.0251) effect was significant in Saskatoon (Table A-10). The maturity length ranged from 93, 92 and 91 days with a 130 seeds/m^2, 190 seeds/m^2 and 260 seeds/m^2 and the application of glyphosate with a residual herbicide resulted in a 0.4-day difference in maturity compared to glyphosate applied alone (Table 8). Swift Current and Yorkton had a significant interaction between seeding rate and herbicide (P=0.0291; 0.0204). Seeding rate was the dominant factor at both locations as the highest seeding rate had the shortest maturity length of 80 days at Swift Current and 97 days at Yorkton. The effect of herbicide was less consistent as glyphosate applications at Yorkton tended to have longer maturity days while glyphosate with a residual herbicide typically had the shortest maturity. This inconsistency could be attributed to the difference in herbicide efficacy between locations as the residual herbicide was less effective at Yorkton than it was in Swift Current. A seeding rate and fungicide interaction (P=0.0074) also occurred at Outlook (2017-2019) (Table A-10). Seeding rate was also the dominant factor at Outlook with the highest seeding rates having the shortest maturity length; however, the application of a fungicide typically delayed maturity at this location (Table 8). However, the difference in maturity from the shortest to the longest was 0.9 days and had little overall effect on maturity.

Table 8. Main effect means and interactions for lentil days to maturity combined over at 14 site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Means for Lentil Days to Maturity						
Treatment/ Main Effects	**All Sites (n=14)**	**Scott (n=3)**	**Outlook (n=3)**	**Swift Current (n=3)**	**Indian Head (n=3)**	**Yorkton (n=1)**	**Saskatoon (n=1)**
Seeding Rate (SR)	--- Days to Maturity ---						
130 seeds/m^2	88.7 a	97.0 a	85.3 a	81.7 a	86.2 a	98.9 ab	92.8 a
190 seeds/m^2	88.1 b	96.8 ab	84.9 b	81.0 b	84.5 b	99.8 a	92.3 a
260 seeds/m^2	87.5 c	96.5 b	84.8 b	80.6 b	83.3 c	98.1 b	91.3 b
Herbicide (HR)	--- Days to Maturity ---						
Glyphosate (Gly)	88.1 a	96.8 a	85.0 a	81.1 a	84.7 a	99.0 a	91.9 a
Glyphosate (Gly) & Residual (Res)	88.1 a	96.8 a	85.0 a	81.1 a	84.7 a	98.9 a	92.3 b
Fungicide (FG)	--- Days to Maturity ---						
None	88.2 a	96.8 a	84.9 a	81.1 a	84.6 a	99.8 a	92.0 a
Single	88.1 a	96.7 a	85.1 a	81.3 a	84.7 a	98.3 a	92.0 a
Dual	88.1 a	96.9 a	84.9 a	81.0 a	84.7 a	98.6 a	92.4 a

FG x SR (seeds/m²)			Days to Maturity				
None x 130	NS	NS	85.5 a	NS	NS	NS	NS
Single x 130	NS	NS	85.3 ab	NS	NS	NS	NS
Single x 190	NS	NS	85.1 abc	NS	NS	NS	NS
Dual x 130	NS	NS	85.0 abc	NS	NS	NS	NS
Dual x 190	NS	NS	85.0 abc	NS	NS	NS	NS
Single x 260	NS	NS	85.0 abc	NS	NS	NS	NS
None x 260	NS	NS	84.8 bc	NS	NS	NS	NS
Dual x 260	NS	NS	84.6 c	NS	NS	NS	NS
None x 190	NS	NS	84.5 c	NS	NS	NS	NS
HR x SR (seeds/m²)			Days to Maturity				
Gly & Res x 130	NS	NS	85.5 a	82.0 a	NS	98.0 b	NS
Gly x 130	NS	NS	85.3 ab	81.4 ab	NS	99.8 ab	NS
Gly x 190	NS	NS	85.1 abc	81.2 bc	NS	100.1 a	NS
Gly & Res x 190	NS	NS	85.0 abc	80.9 bc	NS	99.5 ab	NS
Gly x 260	NS	NS	85.0 abc	80.8 bc	NS	97.1 b	NS
Gly & Res x 260	NS	NS	85.0 abc	80.4 c	NS	99.1 ab	NS

Treatment Effects on Lentil Yield

The combined analysis over 15 site-years indicated a significant effect (P<0.001) of seeding rate on yield (Table A-11). The lowest seeding rate of 130 seeds/m² resulted in a 6% lower yield compared to the seeding rate of 190 seeds/m² (Table 9). There was no significant difference between the seeding rate of 190 and 260 seeds/m², however, 190 seeds/m² resulted in a slight yield gain of 29 kg/ha. There was a significant site-year by seeding rate interaction (P=0.0019) indicating that the seeding rate response varied amongst locations. When yield was analysed across years at each respective location, yield had a varied response to the main effects.

The effect of seeding rate on yield was significant at 5 of the 7 locations: Scott, Outlook, Indian Head, and Saskatoon (Table A-11). At Scott (2017-2019), yield had a quadratic seeding rate response in which the seeding rate of 216 seeds/m² resulted in the maximum yield of 4408 kg/ha. Yield tended to decline when the seeding rate exceeded 216 seeds/m² and was 11% lower when the seeding rate targeted 130 seeds/m². A fungicide response was also significant with a single and dual application resulting in a 10% and 8% yield gain compared to the unsprayed lentils. Herbicide applications did not quite have a significant effect (P=0.0618) on yield, however, applications of glyphosate with a residual herbicide tended to increase yield by 2% compared to glyphosate applied alone. A similar yield response occurred at Outlook (2017-2019). Yield was maximized when a seeding rate of 190 seeds/m² was utilized and yield declined significantly with a seeding rate of 260 seeds/m² (Table 9). There was no significant effect of fungicide or herbicide applications on yield; however, the highest yield occurred when a residual herbicide with a single fungicide application were used. In contrast to the seeding rate responses at Scott and Outlook, the highest seeding rate at Indian Head (2017-2019) was the most effective in producing the greatest yield gains. The seeding rate of 260 seeds/m² resulted in the maximum yield of 2721 kg/ha while a targeted seeding rate of 190 seeds/m² and 130 seeds/m² resulted in slightly lower yields of 2634 kg/ha and 2505 kg/ha, respectively. Fungicide applications did not significantly influence yield, however, the unsprayed lentils tended to have the lowest yields (Table 9). A seeding rate response also occurred at Saskatoon (2018-2019) whereby the highest seeding rate of 260 seeds/m² resulted in a 9% yield gain compared to the seeding rate of 130 seeds/m^2. Fungicide also had a significant effect on yield with the two highest yields of 1956 kg/ha and 1845 kg/ha occurring with a single and dual fungicide application while the unsprayed lentils had the lowest yield of 1822 kg/ha. Herbicide applications had little effect on overall yield. Swift Current (2017-2019) did not have a significant seeding rate response, however, the lowest seeding rate of 130 seeds/m^2 tended to yield 4% lower compared to the 190 seeds/m^2 seeding rate. There was a significant effect of herbicide (P=0.0123) whereby glyphosate applied alone resulted in a 5% yield loss compared to glyphosate applied with a residual herbicide. Additionally, the application of a single fungicide resulted in the greatest yield of 1916 kg/ha. Similarly, seeding rate did not have a statistically significant effect on yield at Yorkton (2017), however, yield declined from 3263 kg/ha to 2937 kg/ha when seeding rate dropped from 260 seeds/m^2 to 130 seeds/m^2. There was little effect of either herbicide and fungicide applications on yield at Yorkton.

Yield production was largely influenced by both environmental conditions and agronomic practise. Moisture was a limiting factor for most of the site-years, in particular at Swift Current and Saskatoon. The dry conditions that persisted over multiple growing seasons resulted in limited disease development, that ultimately had a negligible impact on yield. Yield responses to fungicides may not be attributed to disease management but alternative health benefits associated with fungicides. This is particularly likely at Saskatoon, as this location reported zero disease in 2018 and 2019 but reported a yield increase to fungicide applications. Strobulurin fungicides, such as Priaxor© used in the study, have been known to provide a “greening effect” in which the green leaf area of the crop is extended until later in the growing season, thereby maximizing the grain-filling period to result in a yield benefit (Bartlett et al. 2002). This “greening effect” may be important in very dry conditions, such as those that persisted in Saskatoon, as the grain-filling period may have been shortened due to the lack of moisture. The fungicide applications may have prolonged the grain-filling period and thus the yield benefit reported could be attributed to the greening effect rather than a disease reduction.

Agronomic practices can largely influence lentil yield production. In particular, seeding rate was the largest factor that influenced yield in the current project. Early season weed control during the critical period of weed control (CPWC) can also largely influence lentil yield. The CPWC is a phase of the crop growth cycle in which weeds must be controlled to prevent yield losses (Kasasian and Seeyave 1969). In order to prevent yield loss, weeds must be removed at the beginning of the CPWC and maintained until the end. The CPWC in lentils ranges between the 5-node to the 10-node stage or until canopy closure occurs (Fedoruk et al. 2011). The intensity of the weed population and the duration of weeds present during this time can largely influence yields. Fedoruk et al. (2011) found that yield decreased by 16% when weeds were removed by the 7-node stage but this loss dropped to 4% when the weeds were removed by the 5-node stage. Applying a pre-seed herbicide application with a residual component can provide extended early season weed control to reduce weed competition during the CPWC. Combining a residual herbicide with an increased seeding rate (>130 seeds/m^2) was shown to be the most effective weed control strategy in this study. The increased seeding rate hastened canopy closure to shorten the CPWC while the residual herbicide had extended activity on both grassy and broadleaf weeds. Although the residual herbicide combined with a 190 seeds/m^2 seeding reduced weed biomass by 76% in this study, it ultimately had little effect on overall yields. This is likely due to the relatively low (<58 plants/m^2) weed densities that persisted throughout most of the locations along with the relatively good control observed with pre-seed glyphosate and in-crop Ares. Under weedy conditions, a yield response to residual herbicide application would be more likely occur, especially if group 2 or glyphosate resistance is an issue. Overall, under less weedy conditions, the influence of more intensive herbicide management may become inconsistent but the effect of seeding rate will remain an essential factor for lentil production.

Table 9. Main effect means for lentil yield (kg/ha) combined over 15 site-years and at each location combined over years. The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Means for Lentil Yield (kg/ha)						
Treatment/ Main Effects	**All Sites (n=15)**	**Scott (n=3)**	**Outlook (n=3)**	**Swift Current (n=3)**	**Indian Head (n=3)**	**Yorkton (n=1)**	**Saskatoon (n=2)**
Seeding Rate (SR)	--- Yield (kg/ha) ---						
130 seeds/m^2	2516 a	3926 a	2164 a	1818 a	2505 a	2937 a	1785 a
190 seeds/m^2	2676 b	4355 b	2179 a	1888 a	2634 b	3229 a	1887 ab
260 seeds/m^2	2648 b	4273 b	1962 b	1888 a	2721 c	3263 a	1953 b
Herbicide (HR)	--- Yield (kg/ha) ---						
Glyphosate	2593 a	4144 a	2064 a	1816 a	2606 a	3252 a	1889 a
Glyphosate & Residual	2633 a	4225 a	2140 a	1913 b	2635 a	3034 a	1861 a
Fungicide (FG)	--- Yield (kg/ha) ---						
None	2596 a	4070 a	2119 a	1891 ab	2597 a	3260 a	1822 ab
Single	2642 a	4227 b	2056 a	1916 a	2640 a	3233 a	1956 a
Dual	2602 a	4257 b	2130 a	1787 b	2623 a	2936 a	1845 a

Treatment Effects on Thousand Kernel Weights and Test Weights

The combined analysis over 15 site years indicated that seeding rate significantly (P= 0.0407) influenced thousand kernel weights. The lowest seeding rate of 130 seeds/m^2 resulted in the highest thousand kernel weight of 38 g/1000s while a seeding rate of 190 and 260 seeds/m^2 resulted in a seed weight of 37 g/1000s. There was no effect of herbicide or fungicide on thousand kernel weights. Additionally, test weights analysed over 15-site years indicated that neither seeding rate, fungicide, herbicide nor any combination of these three factors influenced test weight.

Economic Analysis on Lentil Production

The economic analysis was conducted to determine which management strategy was the most economically feasible. The fixed costs that were included for each management strategy include fertilizer expenses priced at $0.54/lb at 30 lb/ac of 11-52-0 and granular inoculant costs at $36.57/ha. The cost of certified seed varied at each seeding rate with a base price of $1.26/ kg for a total of $50.41/ha, $75.61/ha, $100.82/ha at 130 seeds/m^2, 190 seeds/m^2, 260 seeds/m^2, respectively. Herbicide applications costs reflected the management strategy with glyphosate applied alone ($9.51/ha) and with a residual herbicide ($46.58/ha). Fungicide costs were based on an unsprayed, single ($58.03/ha) and dual application ($114.37/ha). Fuel costs ($41.27/ha) were included for each management strategy and increased by $9.88/ ha for each fungicide application. The market price ($/ha) was fixed at $0.4409/kg with actual yields used to calculate the values (Table 10). On average, the highest net return of $891/ha occurred with the seeding rate of 190 seeds/m^2. The overall highest net returns occurred with a seeding rate of 190 seeds/m^2, unsprayed fungicide and a residual herbicide application. Although the cost of a fungicide typically reduced net returns compared to the unsprayed, the fungicides should be viewed as a form of insurance rather than an input cost, as disease management is essential for proper lentil production. The lentils grown in the 15 site- years were generally under drought conditions with limited disease pressure and therefore may not show the economic benefits associated with fungicide applications. Additionally, the lentil variety selected, CDC Maxim, has excellent disease resistance and fungicide response may be cultivar related as well. A second factor to consider is the use of a residual herbicide over a burn-down weed control method like glyphosate applied alone. In this study, there was limited weed pressure (< 58 plants/m^2) and therefore under weedy conditions there would likely be a significant profit associated with a residual herbicide. For example, an economic analysis was conducted based on a weed density of 216 plants/m^2 to determine % yield gains of a residual herbicide over glyphosate applied alone. A net profit of 17%, 5% and 0% of residual compared to glyphosate applied alone at 130 seeds/m^2, 190 seeds/m^2 and 260 seeds/m^2 when weed densities were approximately 216 plants/m^2.

Table 10. Economic analysis of the production management strategies with yields based on the 15 site-year yield means (kg/ha) with market price fixed at $0.44/kg.

Seeds/m^2	Fungicide & Herbicide Application	Yield (kg/ha)	$/kg	Gross Revenue	Production Expenses	Net Revenue
130	Unsprayed & Glyphosate	2444.7	$ 0.44	$ 1,078	$ 178	$ 900
	Unsprayed & Residual	2500.0	$ 0.44	$ 1,102	$ 215	$ 887
	Single & Glyphosate	2532.3	$ 0.44	$ 1,116	$ 246	$ 870
	Single & Residual	2575.6	$ 0.44	$ 1,136	$ 283	$ 852
	Dual & Glyphosate	2516.3	$ 0.44	$ 1,109	$ 312	$ 797
	Dual & Residual	2527.6	$ 0.44	$ 1,114	$ 349	$ 765
190	Unsprayed & Glyphosate	2604.8	$ 0.44	$ 1,148	$ 203	$ 945
	Unsprayed & Residual	2708.2	$ 0.44	$ 1,194	$ 240	$ 954
	Single & Glyphosate	2715.5	$ 0.44	$ 1,197	$271	$ 926
	Single & Residual	2718.9	$ 0.44	$ 1,199	$ 308	$ 890
	Dual & Glyphosate	2636.6	$ 0.44	$ 1,162	$ 337	$ 825
	Dual & Residual	2673.8	$ 0.44	$ 1,179	$ 375	$ 804
260	Unsprayed & Glyphosate	2651.9	$ 0.44	$ 1,169	$ 229	$ 941
	Unsprayed & Residual	2666.0	$ 0.44	$ 1,175	$ 266	$ 910
	Single & Glyphosate	2615.7	$ 0.44	$ 1,153	$ 296	$ 857
	Single & Residual	2695.8	$ 0.44	$ 1,189	$ 334	$ 855
	Dual & Glyphosate	2609.0	$ 0.44	$ 1,150	$ 363	$ 788
	Dual & Residual	2648.0	$ 0.44	$ 1,167	$ 400	$ 768

10. Conclusions and Recommendations: Highlight significant conclusions based on the findings of this project, with emphasis on the project objectives specified above. Provide recommendations for the application and adoption of the project findings.

The results of this project indicated that a pre-seed residual herbicide reduced early season annual weed populations by 66% compared to the traditional pre-seed burn-off strategy of applying glyphosate on its own. Weed growth was largely influenced by both seeding rate and herbicide application. The least effective weed management strategy was utilizing the current seeding rate recommendation of 130 seeds/m^2 combined with glyphosate applied alone. If glyphosate is to be used alone during the pre-emergent herbicide application, the seeding rate must exceed 130 seeds/m^2 to reduce weed growth. A residual herbicide application was more effective than glyphosate applied alone at all three seeding rates (130, 190 and 260 seeds/m^2). The most effective weed management strategy utilized a seeding rate of 190 seeds/m^2 combined with a residual herbicide to reduce weed biomass by 76%. Seeding rate also influenced disease severity throughout the growing season. Disease severity tended to increase with seeding rate (260 seeds/m^2 > 190 seeds/m^2 > 130 seeds/ m^2). A seeding rate of 190 seeds/m^2 resulted in similar disease levels to unsprayed lentil at the current seeding rate recommendation (130 seeds /m^2). This indicated that if seeding rates are to increase to 190 seeds/ m^2 then fungicide applications are likely required, particularly under moist conditions. Furthermore, dual fungicide applications tended to have the least amount of disease pressure compared to single applications and unsprayed. Yield was also largely influenced by seeding rate with 190 seeds/ m^2 resulting in the highest yield compared to 130 and 260 seeds/m^2. A seeding rate of 190 seeds/m^2 also provided the highest net return, regardless of management strategy. The highest net returns occurred with a seeding rate of 190 seeds/m^2, no fungicide and a residual herbicide application. Although the cost of a fungicide typically reduced net returns compared to the unsprayed, the fungicides should be viewed as a form of insurance rather than an input cost, as disease management is essential for proper lentil production. Additionally, the lentils grown in the 15 site- years were generally under drought conditions with limited disease pressure and therefore our results may not reflect the potential economic benefits associated with fungicide applications under a wider range of conditions. Producers can also reduce their risk of yield loss from plant diseases by choosing a cultivar with excellent disease resistance. A second factor to consider is the use of a residual herbicide over a burn-down weed control method like glyphosate applied alone. In this study, there was limited weed pressure (< 58 plants/m^2) and therefore under weedy conditions there would likely be a significant profit associated with a residual herbicide. For example, an economic analysis was conducted based on a weed density of 216 plants/m^2 to determine % yield gains of a residual herbicide over glyphosate applied alone. A net profit of 17%, 5% and 0% of residual compared to glyphosate applied alone at 130 seeds/m^2, 190 seeds/m^2 and 260 seeds/m^2 when weed densities were approximately 216 plants/m^2. Furthermore, residual herbicides and herbicide layering are often part of a longer-term weed management strategy and the benefits of this application may continue to be realized in subsequent years.

11. Is there a need to conduct follow up research? Detail any further research, development and/or communication needs arising from this project.

The results from this project will continue to be communicated when opportunities arise and may come in the form of oral presentations, short written materials directed towards producers/industry personnel, and peer-reviewed publication. Without going into specifics, future research might take into consideration the effects of herbicide and fungicide management strategies on a large scale to determine if trends remain true.

12. Patents/ IP generated/ commercialized products: List any products developed from this research.

As expected, no patents, intellectual property, or commercialized products arose from this research.

13. List technology transfer activities: Include presentations to conferences, producer groups or articles published in science journals or other magazines.

- Weber, Jessica. What are pulses so difficult to grow: an agronomy update. Crop Opportunity, North Battleford. March 4th, 2020. Approx. 200 farmers and agronomists in attendance.
- Pulses of the Prairies Podcast: Maximizing Yields of Peas and Lentils. Jessica Weber and Sherrilyn Phelps. https://anchor.fm/saskpulse/episodes/Pulse-of-the-Prairies-Podcast-Maximizing-Pea--Lentil-Yields-eacfva
- Saskatchewan Pulse Growers Published Article. Setting up your peas and lentils for success. January 9th, 2020. https://saskpulse.com/files/newsletters/200108_Pea_and_Lentil_Yields.pdf
- Sherrilyn Phelps and Jessica Weber. Maximizing Yields of Pea &Lentil Optimizing Agronomy. Cropsphere. January 14th, 2020. Approximately 150 people in attendance.
- Weber, Jessica. Lentils: which agronomic inputs provide the best return? Agronomy Research Update. December 11th, 2019. Approximately 175 people in attendance.
- ICDC & Ministry Field Tour. Corn, Soybean and Field Bean. August 9th. Outlook, SK. Approx. 35 farmers and agronomists in attendance.
- CSIDC Field Day and Trade Show, July 12th, 2018, Outlook, SK. Presentation on management strategies for lentil production. Approx. 100 farmers and agronomists in attendance.
- Top Crop Manager Article. Donna Fleury. Higher seeding rates increase yields, improve crop competition and reduce weed biomass. December 2018.
- Weber, Jessica. Lentils: which agronomic inputs provide the best return?. Dry Beans, Lentils, Chickpeas Please, Regina. February 19th, 2018. Approx. 10 farmers in attendance.
- IHARF Field Day Tour, July 17th, 2018, Indian Head, SK. Presentation on management strategies for lentil production. Approx. 200 farmers and agronomists in attendance.
- Weber, Jessica. An economic approach to lentil production. Crop Opportunity, North Battleford. March 13th, 2018. Approx. 100 farmers and agronomists in attendance.
- WARC Field Day Tour, July 12th, 2017, Scott, SK. Presentation on management strategies for lentil production. Approx. 130 farmers and agronomists in attendance.
- Farmer Writers of Saskatchewan Field Tour. June 3rd, 2017, Scott, SK. Presentation on management strategies for lentil production. 6 reporters in attendance.
- FMC Agronomy Tour. July 19th, 2017, Scott, SK. Presentation on management strategies for lentil production. 10 agronomists in attendance.
- Indian Head Richardson- Pioneer Agronomy Tour. July 21th, 2017. presentation on fungicide efficacy and the influence of seeding rates in lentils. Approx. 40 agronomists in attendance.
- ECRF Field Day Tour, July 13th, 2017, Scott, SK. Presentation on management strategies for lentil production. Approx. 73 farmers and agronomists in attendance.
- ICDC Field Day Tour, July 13th, 2017, Scott, SK. Presentation on management strategies for lentil production. Approx. 150 farmers and agronomists in attendance.

14. List any industry contributions or support received.

Various crop protection products were provided in-kind with the specific donations varying from year to year and location to location. Several of the participants in the project (i.e. IHARF, ICDC, and WCA,) have close working relationships and memorandums of understanding with Agriculture and Agri-Food Canada which should also be acknowledged.

15. Acknowledgements. Include actions taken to acknowledge support by the Ministry of Agriculture and the Canada-Saskatchewan Growing Forward 2 bilateral agreement (for projects approved during 2013-2017) or Canadian Agriculture Partnership (For projects approved beyond 2017).

This project was jointly funded through the Canada-Saskatchewan ADF program (administered by the Saskatchewan Ministry of Agriculture), Saskatchewan Pulse Growers and Western Grains Research Foundation. Plot signs have acknowledged this support during field tours, appropriate logos and acknowledgements have been utilized during oral presentations, and the funding agencies/programs have been acknowledged in written materials wherever possible. In addition, the contributions of all three funding partners have been acknowledged in WARC's annual partners lists which are both available online and included on all WARC promotional materials (i.e. field day). Collaborating organizations take similar measures to acknowledge their many partners and program sponsors.

16. Appendices: Include any additional materials supporting the previous sections, e.g. detailed data tables, maps, graphs, specifications, literature cited.

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Table A- 1. Selected agronomic information for the lentil input study at five locations in western Canada (2017).

Factor / Field Operation	Indian Head	Scott	Swift Current	Outlook	Yorkton
Previous Crop	Barley	Wheat	Wheat	Barley	Wheat
Variety	CDC Maxim	CDC Maxim	CDC Maxim	CDC Maxim	CDC Maxim
Pre-emergent Herbicide	May 14&15	May 16	May 16	May 23	May 12&16
Seeding Date	May 9	May 19	May 19	May 26	May 15
Row spacing	30 cm	25 cm	23 cm	25 cm	25 cm
In-crop Herbicide	June 9	June 15 & 23	June 27	June 23	June 12
Fungicide	July 4&18	July 8&17	July 10&20	July 10&27	July 17&27
Insecticide	n/a	n/a	n/a	n/a	July 27th
Pre-harvest herbicide	August 3	August 25	August 16	August 29	September 7
Harvest date	August 16	September 1	August 23	September 5	September 17

Table A-2. Selected agronomic information for the lentil input study at five locations in western Canada (2018).

Factor / Field Operation	Indian Head	Scott	Swift Current	Outlook	Saskatoon
Previous Crop	Canary seed	Wheat	Durum	Potato	Canola
Variety	CDC Maxim	CDC Maxim	CDC Maxim	CDC Maxim	CDC Maxim
Pre-emergent Herbicide	May 11	May 11	May 7	May 24	May 4
Seeding Date	May 13	May 15	May 9	May 28	May 9
Row spacing	30 cm	25 cm	23 cm	25 cm	30 cm
In-crop Herbicide	June 11	June 18	June 5 & 8	July 3 & 6	June 4 & 7
Fungicide	June 28& July 9	July 6&17	June 25&July 4	July16&23	June 27&July 5
Insecticide	n/a	n/a	June 22 & July 7	n/a	n/a
Pre-harvest herbicide	July 31	August 13	n/a	August 22	n/a
Harvest date	August 11	August 21	August 7	August 31	August 20

Table A-3. Selected agronomic information for the lentil input study at 5 locations in western Canada (2019).

Factor / Field Operation	Indian Head	Scott	Swift Current	Outlook	Saskatoon
Previous Crop	Oat	Wheat	Durum	Wheat	Canola
Variety	CDC Maxim	CDC Maxim	CDC Maxim	CDC Maxim	CDC Maxim
Pre-emergent Herbicide	May 5&6	May 16	May 3	May 8	May 3
Seeding Date	May 8	May 20	May 6	May 14	May 7
Row spacing	30 cm	25 cm	21 cm	25 cm	30 cm
In-crop Herbicide	June 12	June 18 & 26	June 12	June 17 & 20	June 18
Fungicide	July 4&12	July 11&17	July4 &12	July 15&22	June 25 & July 3
Insecticide	July 29	n/a	n/a	n/a	n/a
Pre-harvest herbicide	August8&18	September 6	n/a	August 15	August 16
Harvest date	August 22	September 22	August 19	August 20	August 22

Table A-4. Disease severity ratings scale for total disease present score ranging from 0-10 collected over a minimum of five locations per plot.	
Disease Score	Class Range (%) for Total Disease Present
0	0
1	1-10%
2	11-20%
3	21-30%
4	31-40%
5	41-50%
6	51-60%
7	61-70%
8	71-80%
9	81-90%
10	91-100%

Table A-5. Mean monthly temperatures (ºC) and total monthly precipitation (mm) for the 2017 growing season relative to the long-term averages (1981-2010) at five locations in western Canada.

		Mean Monthly Temperature				
Location	Year	**May**	**June**	**July**	**August**	**Average**
		----------------------- ºC -----------------------				
Indian Head	2017	11.6	15.5	18.4	16.7	15.5
	LT [Z]	10.8	15.8	18.2	17.4	15.6
Scott	2017	11.5	15.1	18.3	16.6	15.4
	LT [Z]	10.8	15.3	17.1	16.5	14.9
Swift Current	2017	12.3	15.7	20.6	18.3	16.7
	LT [Z]	10.9	15.4	18.5	18.2	15.8
Yorkton	2017	11.1	15.5	19	17.4	15.8
	LT [Z]	10.4	15.5	17.9	17.1	15.2
Outlook	2017	12.2	16.1	19.7	19.1	16.8
	LT [Z]	11.4	16.6	19.2	18.2	16.4
	Total Monthly Precipitation					
Location	Year	----------------------- mm -----------------------				
Indian Head	2017	10.4	65.6	15.4	25.20	116.6
	LT [Z]	51.7	77.4	63.8	51.2	244.1
Scott	2017	69.0	34.3	22.4	53	178.7
	LT [Z]	38.9	69.7	69.4	48.7	226.7
Swift Current	2017	21.0	35.3	11.0	28.0	95.3
	LT [Z]	48.5	72.8	52.6	41.5	215.4
Yorkton	2017	12.5	53.9	59.1	32.5	158
	LT [Z]	51	80	78	62	272
Outlook	2017	32.0	29.0	60.4	7.4	128.8
	LT [Z]	56.5	79.6	68.2	65.5	269.8

[Z] LT- Long-Term average (1981-2010)

Table A-6. Mean monthly temperatures (ºC) and total monthly precipitation (mm) for the 2018 growing season relative to the long-term averages at five locations in western Canada.						
		Mean Monthly Temperature				
Location	Year	**May**	**June**	**July**	**August**	**Average**
		---------- ºC ----------				
Indian Head	2018	13.9	16.5	17.5	17.6	16.4
	LT [Z]	10.8	15.8	18.2	17.4	15.6
Scott	2018	13.6	16.6	17.5	15.9	15.9
	LT [Y]	10.8	14.8	17.3	16.3	14.8
Swift Current	2018	14.6	17.1	18.8	18.7	17.3
	LT [Y]	11.1	15.5	18.5	17.9	15.8
Saskatoon	2018	15	17.8	19.1	16.6	17.1
	LT [Y]	11	16.4	18.4	17.8	15.9
Outlook	2018	22.5	24.7	25.6	25.3	24.5
	LT [Y]	18.3	22.4	25.1	24.7	22.6
	Total Monthly Precipitation					
Location	Year	**May**	**June**	**July**	**August**	**Total**
		---------- mm ----------				
Indian Head	2018	23.7	90	30.4	3.9	148
	LT [Z]	51.7	77.4	63.8	51.2	244.1
Scott	2018	29.6	47	74.7	20.2	171.5
	LT [Y]	38.9	69.7	69.4	48.7	226.7
Swift Current	2018	25.6	16.9	51.2	31	124.7
	LT [Y]	48.5	72.8	52.6	41.5	215.4
Saskatoon	2018	35	19.9	31.1	17.2	103.2
	LT	40.2	65.8	60.3	42.3	208.6
Outlook	2018	24.9	12.9	35.2	12.6	85.6
	LT [Y]	56.5	79.6	68.2	65.5	269.8

[Z] LT- Long-Term average (1994-2010)

[Y] LT- Long-Term average (1985-2014)

Table A-7. Mean monthly temperatures for the 2019 growing season relative to the long-term averages at 5 locations in western Canada.

		Mean Monthly Temperature				
Location	Year	**May**	**June**	**July**	**August**	**Average**
		---------- ºC ----------				
Indian Head	2019	8.9	15.7	17.4	15.8	14.4
	LT [Z]	10.8	15.8	18.2	17.4	15.6
Scott	2019	9.1	14.9	16.1	14.4	13.6
	LT [Y]	10.8	14.8	17.3	16.3	14.8
Swift Current	2019	9.5	15.8	17.7	16.8	14.9
	LT [Z]	11.1	15.5	18.5	17.9	15.8
Saskatoon	2019	9.7	16	17.8	15.4	14.7
	LT [Y]	11	16.4	18.4	17.8	15.9
Outlook	2019	9.9	16	18	16	14.9
	LT [Y]	18.3	22.4	25.1	24.7	22.6
	Total Monthly Precipitation					
Location	Year	**May**	**June**	**July**	**August**	**Total**
		---------- mm ----------				
Indian Head	2019	13.3	50.4	53.1	96	212.8
	LT [Z]	51.7	77.4	63.8	51.2	244.1
Scott	2019	12.7	97.7	107.8	18	236.2
	LT [Y]	38.9	69.7	69.4	48.7	226.7
Swift Current	2019	21	13.3	156	11.1	201.4
	LT [Z]	48.5	72.8	52.6	41.5	215.4
Saskatoon	2019	4.4	84.8	67.6	20.3	177.1
	LT	40.2	65.8	60.3	42.3	208.6
Outlook	2019	11.3	95.8	45.1	39.8	192
	LT [Y]	56.5	79.6	68.2	65.5	269.8

[Z] LT- Long-Term average (1981-2010)

[Y] LT- Long-Term average (1985-2014)

Table A-8. Overall tests of fixed effects for lentil biomass (kg/ha) combined over 15 site-years (n=15 Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Lentil Biomass
Effect	-- p-values --
Site-Year (S)	0.0045
Seeding Rate (SR)	0.0244
Herbicide (HR)	0.6256
Fungicide (FG)	0.0816
SR x HR	0.1447
SR x FG	0.4166
FG x HR	0.7391
FG x HR x SR	0.6284
S x SR	0.0587
S x HR	0.0613
S x FG	0.2344
S x FG x SR	NE [W]
S x FG x HR	NE
S x SR x HR	NE
S x SR x HR x FG	NE

[W] NE represents non-estimable value

Table A-9. Overall tests of fixed effects for lentil days to flowering combined over at 14 site-years and across years for individual locations. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Lentil Days to Flowering						
	All Sites (n=14)	**Scott (n=3)**	**Outlook (n=3)**	**Swift Current (n=3)**	**Indian Head (n=3)**	**Yorkton (n=1)**	**Saskatoon (n=1)**
Effect	--- p-values ---						
Site-Year (S)	0.0041	0.1604	0.1594	0.1588	NE	NE	0.2404
Seeding Rate (SR)	**<0.0001**	0.3427	0.3414	**0.0007**	NE	0.5125	**0.0004**
Herbicide (HR)	0.4475	0.2462	0.2436	0.4202	NE	1.00	0.6943
Fungicide (FG)	0.3017	0.7802	**0.0303**	0.4539	NE	0.7221	0.1052
SR x FG	0.9152	0.262	0.6453	0.4366	NE	0.8494	0.8231
SR x HR	0.4036	0.6988	0.8167	0.7726	NE	.0836	0.5324
HR x FG	0.4919	0.1883	0.7018	0.7726	NE	0.244	0.8564
SR x HR x FG	0.4605	0.3177	0.4017	0.9085	NE	0.2432	0.4862
S x FG	0.0606	NE	NE	0.2135	NE	0.230	0.2415
S x SR	0.0185	0.1137	0.0985	0.3143	NE	NE	NE
S x HR	NE [W]	0.2864	0.172	NE	NE	NE	NE
S x SR x HR	0.0771	NE	NE	0.1417	NE	0.2411	NE
S x FG x HR	0.4528	NE	0.4518	NE	NE	NE	0.3623
S x FG x SR	NE	NE	NE	NE	NE	NE	NE
S x SR x HR x FG	NE	NE	NE	NE	NE	0.2392	NE
	--- p-values ---						
SR- linear	0.9811	0.8836	0.9188	0.978	NE	0.2615	0.9439
SR- quadratic	0.9401	0.9114	0.929	0.9952	NE	0.2543	0.9676

[W] NE represents non-estimable value

Table A-10. Overall tests of fixed effects for lentil days to maturity combined over at 14 site-years and across years for individual locations. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Lentil Days to Maturity						
	All Sites (n=14)	**Scott (n=3)**	**Outlook (n=3)**	**Swift Current (n=3)**	**Indian Head (n=3)**	**Yorkton (n=1)**	**Saskatoon (n=1)**
Effect	------------------ p-values ------------------						
Site-Year (S)	0.0055	0.1591	0.1588	0.1591	0.1589	NE	NE
Seeding Rate (SR)	**<0.0001**	**0.0346**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0434**	**<0.0001**
Herbicide (HR)	0.8408	0.7149	0.6011	0.7612	0.9565	0.8379	**0.0251**
Fungicide (FG)	0.7594	0.5799	0.1285	0.2893	0.6443	0.0755	0.1611
SR x FG	0.174	0.6695	**0.0074**	0.6131	0.9505	0.6158	0.4225
SR x HR	0.4089	0.4446	0.9261	**0.0291**	0.2548	**0.0204**	0.6756
HR x FG	0.5736	0.7914	0.1154	0.3525	0.9009	0.443	0.529
SR x HR x FG	0.9121	0.9316	0.495	0.8824	0.378	0.3239	0.6117
S x FG	0.025	NE	0.1802	0.3134	NE	0.4355	NE
S x SR	0.002	0.0906	0.1055	0.3119	0.0976	NE	NE
S x HR	NE [W]	NE	NE	0.4287	NE	0.3839	NE
S x SR x HR	0.0051	0.3699	0.4227	0.1622	NE	NE	NE
S x FG x HR	NE	0.1319	NE	NE	NE	NE	NE
S x FG x SR	NE	NE	0.3714	0.3713	NE	0.0496	0.409
S x SR x HR x FG	NE		NE	NE	NE	NE	0.05
	------------------ p-values ------------------						
SR- linear	0.8179	0.9794	NE	NE	0.5958	NE	NE
SR- quadratic	0.9324	0.9988	NE	NE	0.7303	NE	NE

[W] NE represents non-estimable value

Table A-11. Overall tests of fixed effects for lentil yield (kg/ha) combined over at 15 site-years and across years at each location. Data were analysed using the Mixed procedure of SAS.

Treatment/ Main Effects	**All Sites (n=14)**	**Scott (n=3)**	**Outlook (n=3)**	**Swift Current (n=3)**	**Indian Head (n=3)**	**Yorkton (n=1)**	**Saskatoon (n=2)**
	------------------ p-values ------------------						
Seeding Rate (SR)	<0.0001	<0.0001	0.0078	0.2204	<0.0001	0.3189	0.0176
Herbicide (HR)	0.0911	0.0618	0.2237	0.0123	0.2528	0.2673	0.5627
Fungicide (FG)	0.2188	0.001	0.583	0.0163	0.3679	0.3144	0.0491
SR x FG	0.7183	0.6539	0.2302	0.3164	0.3771	0.5085	0.5955
SR x HR	0.9704	0.5766	0.9631	0.6731	0.8217	0.992	0.9536
FG x HR	0.9445	0.6674	0.7948	0.3406	0.5799	0.078	0.9782
SR x FG x HR	0.735	0.7648	0.6909	0.4819	0.8257	0.1492	0.4251