2022 Final Report

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and Fertilizer Canada

Project Title: Fall Rye Cover Crop Effects on Canola Establishment and Response to Nitrogen

(Project #20210957)

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Project Identification

1. **Project Title:** Fall rye cover crop effects on canola establishment and response to nitrogen
2. **Project Number:** 20210957
3. **Producer Group Sponsoring the Project:** Indian Head Agricultural Research Foundation
4. **Project Location(s):** Indian Head, Saskatchewan, R.M. #156
5. **Project start and end dates(s):** September-2020 to February-2022
6. **Project contact person & contact details:**

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Objectives and Rationale

7. **Project Objectives:**
The broader objectives of this project were to gain experience and expertise with cover crops while providing a forum for discussion on how they might be successfully incorporated into annual cropping systems under Saskatchewan conditions. Specifically, we aimed to demonstrate the effects of a preceding cereal rye cover crop on 1) the overall establishment and yield of canola in addition to early season weed densities and 2) the nitrogen (N) fertilizer requirements of canola.

8. **Project Rationale:**
Cover crops are not a new concept and have been used in annual cropping/mixed farming operations throughout the world, at least on regional basis, for a variety of reasons. Some of the potential benefits of cover crops include building soil organic matter, N fixation, boosting soil biology, erosion prevention, protecting nutrients from environmental loss, suppressing weeds, improving water infiltration, breaking pest cycles, and more. There are innumerable species that can potentially be used as cover crops and specifically how they are established and where they fit in rotations can also vary. The precise way cover crops are integrated into agricultural systems will depend on the intended purposes (i.e., erosion protection versus reducing salinity versus weed suppression, etc.), in addition to climate and crop rotation considerations. Published, regionally relevant research on the practical benefits and drawbacks of cover crops is limited; however, an appreciable number of producers are seeking ways to integrate them into their operations and there is growing interest in this practice from both farmers and consumers due to their potential positive impacts on soil health and environmental sustainability. One of the challenges in conducting research and demonstration activities with cover crops is that there are many species to choose from and ways in which they might be utilized. Much of the innovation and evaluation of cover crops in Saskatchewan cropping systems has been led by farmers and other industry professionals as opposed to by researchers and the academic community; however, both have a role to play in further developing this practice.

Despite the high level of interest and potential benefits, there is a steep learning curve to integrating cover crops into existing crop rotations. In many cases, our short growing season and unpredictable/extreme weather can make doing so difficult and creates unique challenges with respect to successful establishment and mitigating potential negative impacts on subsequent crops. The current project was initiated to demonstrate a potential application of cover cropping (fall rye preceding canola), provide insights into some of the potential benefits and challenges associated with this practice, and how it might affect other management considerations (i.e., N fertility). The rationale for choosing fall rye as a cover crop was that it establishes well under cool conditions (i.e., late fall), resumes growth earlier in the spring than most other winter cereals, and has allelopathic effects (particularly on other grassy plants such as volunteer cereals or wild oats). Canola was chosen as a test crop because it is economically important in Saskatchewan, benefits from early weed removal, is responsive to N fertility, and can be seeded later than other well-adapted broadleaf options (i.e., peas or lentils); thus, giving more time for cover crop growth in the early spring. The potential longer-term benefits to the fall rye cover are many, but some short-term effects might include more biologically active soil, early-spring weed suppression, and increased crop residues to help protect canola seedlings from extreme weather and reduce evaporation of soil moisture. That said, the rye may also potentially have negative impacts. If establishment is successful and enough growth occurs, it could tie up some nutrients early in the season which may result in increased fertilizer demands; however, it is also feasible that these nutrients will become available to the canola later and any impacts on fertilizer demands will be negligible. Under dry spring conditions, the fall rye may also utilize much of the initially available soil moisture and could potentially either negatively impact canola establishment (due to there being insufficient initial moisture for germination) and reduce the overall yield potential if dry conditions persist. Furthermore, it is also possible that the allelopathic effects of rye, which have the potential benefit of providing weed control benefits, could also impede canola emergence and/or establishment.

Methodology and Results

9. Methodology:

A field trial was initiated near Indian Head, Saskatchewan in the fall of 2020 and repeated the following growing season. The treatments were a factorial combination of two cover crop scenarios (either no cover crop or a fall rye cover crop) and five N fertilizer rates (25, 60, 105, 140, and 175 kg N/ha). The N fertilizer rates were not adjusted for residual soil NO_3-N because of the possibility that cover crops could have an impact on this parameter. The 10 treatments were arranged in a four replicate RCBD.

Selected agronomic details and dates of operations are presented in Table 6 of the Appendices. The previous crop was canary seed in 2021 and oat in 2022. For perennial weed control, the sites were sprayed with 894 g/ha prior to emergence of the cover crops. The fall rye cover crop was seeded as per protocol in the third week of September and seeding rates of 250-300 seeds/m^2. The higher seeding rate was implemented in the second year of the project to account for potentially high mortality and increase the likelihood for potential establishment of the cover crop. Each spring, the fall rye was terminated 1-5 days prior to seeding the canola with 894 g glyphosate/ha. Seeding was completed using an eight opener SeedMaster® drill at a target depth of approximately 2 cm. A blend of monoammonium phosphate, potassium chloride, and ammonium sulfate was side-banded to supply 36 kg P_2O_5/ha, 18 kg K_2O/ha, and 18 kg S/ha. Additional urea was side-banded to vary the total amount of N applied as per protocol. The canola was seeded at a target rate of 105 seeds/m^2

and the same glufosinate ammonium tolerant hybrid was used in both years. In addition to the glyphosate applications prior to seeding, weeds were controlled using registered in-crop herbicides applications. Foliar fungicide was applied preventatively at early- to mid-bloom to suppress sclerotinia. Foliar insecticide was applied both years to control grasshoppers in 2021 and flea beetles in 2022. After all treatments had reached physiological maturity, 894 g glyphosate/ha was applied for pre-harvest weed control and to terminate the crop. The centre five rows of each plot were straight-combined using a plot harvester as soon as possible after it was fit to do so.

Various data were collected through the season and from the harvested grain samples. To assess initial fertility levels on the site and any impacts of the fall rye cover crop, soil samples were collected just prior to seeding with separate composites for the plots with and without the fall rye cover crop. The composites consisted of a minimum of 12 samples per treatment and were collected using two separate methods, depending on the instructions of the labs for which they were destined. Conventional samples were collected for two separate depths (0-15 cm, 15-60 cm), dried at 30-35 °C, ground, and submitted to AgVise Laboratories (Northwood, ND, USA) for various analyses. The Plant Root Simulator (PRS®) probe analyses samples were collected from the same plots for two depths (0-10 cm, 10-30 cm), sealed into plastic bags, refrigerated until they could be shipped, and submitted to Western Ag Laboratories (Saskatoon, SK) for analyses. Plant densities were measured on two separate occasions, in the late spring and again after harvest, by recording the number of plants/stubble in 4 x 1 m sections of crop row and calculating plants/m^2. Yields were determined from the mass of the harvested grain samples and are corrected for both dockage and to a uniform moisture content of 10%. Seed oil and protein concentrations were determined simultaneously using a FOSS NIR analyzer. Mean monthly precipitation amounts were estimated from the nearby Environment and Climate Change Canada weather station, located approximately 2-3 km from the trial sites.

Response data were analyzed separately for each season using the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio. The effects of cover crop (CC), N rate (NR), and the CC x NR interaction were treated as fixed while replicate effects were considered random. Orthogonal contrasts were used to test whether responses to NR were linear, quadratic (curvilinear), or not significant. Treatment effects and differences between means were considered significant at $P \leq 0.05$ and the conservative Tukey-Kramer test was used to separate treatment means.

10. Results:

Growing season weather and residual soil nutrients

Weather data for each of the two growing seasons and the preceding fall months are presented alongside the long-term averages in Table 1 below.

Focussing on the first season during which the trials were conducted, the fall months of September and October (2020) were extremely dry with 15 mm of total precipitation in September and less than 4 mm in October. For the two months combined, this amounted to 31% of the long-term average. Furthermore, this dry fall followed an unusually dry growing season (May-August 2020) where only 46% of the long-term average precipitation was received. Consequently, there was essentially no germination of the cover crop in the fall of 2020. The following growing season, temperatures were 103% of the long-term average overall but May was cool. The hottest months were June and July, both of which were approximately 2 °C warmer than normal (11-12%). Total growing season precipitation was 121% of the average; however, 30% of this (~90 mm) came in the last two weeks of August, after the canola was terminated and too late to benefit the crop. Given the timing of precipitation, extremely dry start to the season, and above-normal summer temperatures, the season was still considered dry. Coming back to the fall rye establishment, many plants emerged in the early spring but, at the time of termination, they remained small, ranging from only 1-3 leaves. Although plant counts on the fall rye were not completed, the numbers were clearly well below the target of approximately 200 plants/m^2. In terms of growing season effects on the canola, the crop fared well overall. Initial establishment was excellent with a large precipitation event in late May, after the canola was seeded. The extreme heat in June and July resulted in some pod abortion and stress; however, timely rain in early June and mid-July helped sustain the crop through the season. Despite light hail and high winds during a July storm event, damage to the canola was negligible and yields were about average.

For the second season, soil conditions when the fall rye was seeded were relatively dry, despite the August precipitation, because of there being essentially no precipitation in September and substantial regrowth of the preceding oat crop which was swathed in early August. October was warmer and wetter than average which, combined with above-average snowfall and wet conditions the following May, cover crop establishment was slow but quite successful. The wet spring resulted in canola seeding being delayed until relatively late in May and the rye plants were at the early stem elongation stage at the time of termination. While June of 2022 was dry, soil moisture was abundant and nearly twice the long-term average precipitation was received in July. Precipitation in August was slightly below average and light hail occurred in the middle of the month; however, damage was minor and uniform across the study area. Over the four-month period (May-August), the 2022 growing season temperatures were approximately average and precipitation was 117% of average. Overall yield potential was considered slightly above-average for the region.

Table 1. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2021 and 2022 growing seasons at Indian Head, SK. Data for the fall period (September through October) were also reported.

Year	Prev. Sep	Prev. Oct	May	June	July	August	May-Aug
	---------- Mean Temperature (°C) ----------						
2021	11.5	1.4	9.0	17.7	20.3	17.1	16.0 (103%)
2022	14.5	6.8	10.9	16.1	18.1	18.3	15.8 (101%)
LT	11.5	4.0	10.8	15.8	18.2	17.4	15.6
	---------- Total Precipitation (mm) ----------						
2021	15.0	3.8	81.6	62.9	51.2	99.4	295 (121%)
2022	0.4	43.0	97.7	27.5	114.5	45.9	286 (117%)
LT	35.3	24.9	51.8	77.4	63.8	51.2	244

Again, soil sampling was completed just prior to terminating the fall rye with separate composites for each cover crop treatment and samples submitted to two separate labs which use contrasting approaches to assessing nutrient supply. The results from the conventional soil test analyses are presented below in Table 2 while the PRS® probe analyses results are deferred to Table 6 of the Appendices for interest's sake. Soil pH was consistent across treatments and sites at 7.9-8.0 for the upper 15 cm and 8.1-8.2 for the 15-60 cm sub-soil sample. Both cation exchange capacity (C.E.C.) and soil organic matter (S.O.M.) were reasonably consistent across years and, primarily being affected by soil parent material, texture, pH, climate, and long-term management, a single cover crop was not expected to have an impact on either of these parameters. Overall, the C.E.C. and S.O.M. were considered typical for the region, ranging from 42.5-44.1 meq/100 g and 4.8% in 2021 and 48.3-48.8 meq/100 g and 5.4-5.5% in 2022, respectively. Residual NO_3-N levels were relatively low in both years, ranging from 20-28 kg N/ha in 2021 and 9-12 kg N/ha in 2022. While the observed residual nitrate levels were lower with the cover crop in both years, we cannot confidently attribute this to the cover crop with confidence due to the lack of replication. Similar trends were observed with phosphorus (Olsen-P) and, to a lesser extent, sulphur (S). Realistically, with very little cover crop growth observed in 2020-21, and occasional inconsistencies with the PRS analyses, it is possible that any trends were more a result of random variability than nutrient uptake of the cover crop.

Table 2. Conventional soil test results (AgVise Laboratories) for Indian Head (2021 and 2022) collected from plots with and without a fall rye cover crop, just prior to cover crop termination and seeding.

Treatment	**Depth** (cm)	**pH**	**C.E.C.** (meq)	**S.O.M.** (%)	**NO_3-N** (kg/ha)	**Olsen-P** (ppm)	**K** (ppm)	**S** (kg/ha)
---------- 2021 ----------								
No Cover Crop	0-15	7.9	44.1	4.8	8	9	563	9
	15-60	8.1	-	-	20	-	-	34
	0-60	-	-	-	28	-	-	43
Fall Rye Cover Crop	0-15	7.9	42.5	5.0	7	4	572	7
	15-60	8.1	-	-	13	-	-	20
	0-60	-	-	-	20	-	-	27
---------- 2022 ----------								
No Cover Crop	0-15	8.0	48.3	5.4	3	6	553	11
	15-60	8.2	-	-	9	-	-	14
	0-60	-	-	-	12	-	-	24
Fall Rye Cover Crop	0-15	8.0	48.8	5.5	2	4	512	11
	15-60	8.2	-	-	7	-	-	10
	0-60	-	-	-	9	-	-	21

Crop Responses to Cover Crop Treatments and Nitrogen Fertility

Results from the overall tests of fixed effects are presented for the 2021 and 2022 growing seasons in Tables 8 and 9 of the Appendices, respectively. These results will be referred to, as necessary, in the following detailed discussion of individual response variables.

Main effect means for canola plant densities over the two seasons are presented in Table 3 below. In 2021, there was no effect of the cover crop on canola establishment when measured in the spring (P = 0.16), but the fall assessments revealed a 15% reduction in plant populations with the fall rye cover (77 versus 65 plants/m^2; P < 0.001). We can only speculate why this effect was observed in the fall, but not the spring. Canola seeding in 2021 was completed under dry conditions; however, timely and abundant rain fell within a week of seeding. Rye is known to have allelopathic effects both during emergence and when its residues are decomposing. It is probable that extremely dry conditions in the fall and early-spring left many rye seeds un-germinated prior to the late May rain. Some of these rye seeds likely germinated at a similar time as the canola, potentially having a slight negative effect on canola densities that was not fully realized at the time of the spring plant counts. Alternatively, the fall rye that did established was likely dying at approximately the same time as the canola was emerging. As such, decomposition of this plant material may have only begun to occur after the canola was established; hence delaying any allelopathic effects until after the spring measurements were completed. In any case, overall establishment was sufficiently high, and the negative effects of the cover crop were small enough that we did not expect this to have any adverse effects on the canola crop. According to the overall F-tests, N rate did not affect canola plant densities, regardless of when the measurements were completed (*P* = 0.17-0.58) and there were no CC x NR interactions (*P* = 0.59-0.60). While a quadratic relationship between N rate and spring plant densities was detected, with the best stands recorded at the lowest and highest N rates, it could not be explained by ammonium toxicity and was attributed to random variation. Individual treatment means are presented in Table 10 of the Appendices and neither the linear nor quadratic relationship were significant for spring plant densities in either of cover crop treatment individually.

Table 3. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on canola plant densities at Indian Head in 2021 and 2022, as measured in both the spring and fall (post-harvest). Main effect means followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

	------------------- 2021 -------------------		------------------- 2022 -------------------	
Main Effect	**Spring**	**Fall**	**Spring**	**Fall**
<u>Cover Crop</u>	---------- plants/m^2 ----------			
None	75.0 A	76.5 A	83.3 A	64.1 A
Fall Rye	71.6 A	65.1 B	82.4 A	61.6 A
S.E.M.	1.47	1.89	1.45	1.48
<u>Nitrogen Rate</u>				
25 kg N/ha	75.1 A	67.0 A	89.2 A	68.2 A
60 kg N/ha	72.0 A	71.0 A	85.0 AB	66.0 A
105 kg N/ha	68.2 A	70.0 A	83.6 AB	62.3 A
140 kg N/ha	73.8 A	72.8 A	78.3 B	58.8 A
175 kg N/ha	77.2 A	73.2 A	78.2 B	59.1 A
S.E.M.	2.49	2.96	2.50	2.34
Contrast	---------- Pr > *F* (p-values) ----------			
NR - linear	0.521	0.142	0.002	0.002
NR - quadratic	0.026	0.786	0.731	0.628

In 2022, canola plant densities were considerably higher in the spring (83 plants/m^2) than in the fall (63 plants/m^2), but not affected by cover crop for either measurement period (*P* = 0.25-0.72). The NR effect, however, was significant in both cases (*P* = 0.03) and showed a consistent, linear (*P* = 0.002) decline in plant densities with increasing rates of side-banded N. Averaged across cover crop treatments, the magnitude of the observed reductions was 9-11 plants/m^2, or 12-13%, as the N rate was increased from 25 kg N/ha to 175 kg N/ha. For the spring assessments, there was a significant CC x NR interaction (*P* = 0.04), whereby the negative N rate effect was only observed in the absence of the cover crop (Table 8); however, the N rate effect was consistent for both cover crop treatments when reassessed in the fall. The observed interaction was largely due to noticeably higher seedling densities at the lowest N rate in the absence of the cover crop; however, many of these crowded, N deficient plants appeared to have died off over the growing season. Unlike the previous season, the canola in 2022 was seeded under extremely wet conditions, followed by a period of dry weather. Separation between seed and side-banded fertilizer and seed placement is generally poorer in wet, heavy clay soils and the effects of this tend to be most severe when dry weather follows seeding. Despite the observed treatment effects, none of the observed plant populations were low enough that they were expected to affect canola yield or overall agronomic performance.

For the weed assessments, we waited until just prior to the in-crop herbicide applications to give as much time as possible for weeds to emerge and be counted. Main effect means and results of the multiple comparisons tests are provided in Table 4 below while individual treatment means are deferred to Table 11 of the Appendices.

Table 4. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on weed densities at Indian Head in 2021 and 2022, as measured just prior to the in-crop herbicide applications. In addition to the total populations, weeds were broadly categorized into broadleaves and grassy types. Main effect means followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

	2021			2022		
Main Effect	**Broadleaf**	**Grassy**	**Total**	**Broadleaf**	**Grassy**	**Total**
Cover Crop	weeds/m^2					
None	5.4 A	14.0 B	19.4 B	0.2 A	0.3 A	0.4 A
Fall Rye	4.7 A	18.9 A	23.5 A	0.1 A	0.2 A	0.3 A
S.E.M.	1.09	1.55	1.76	0.09	0.13	0.12
Nitrogen (NR)						
25 kg N/ha	6.0 A	17.1 A	23.1 A	0.2 A	0.3 A	0.5 A
60 kg N/ha	4.8 A	14.7 A	19.6 A	0.2 A	0.2 A	0.4 A
105 kg N/ha	5.0 A	17.6 A	22.6 A	0.2 A	0.1 A	0.3 A
140 kg N/ha	3.9 A	17.4 A	21.3 A	0.0 A	0.4 A	0.4 A
175 kg N/ha	5.4 A	15.3 A	20.7 A	0.0 A	0.2 A	0.2 A
S.E.M.	1.23	2.18	2.33	0.13	0.19	0.19
Contrast	Pr > *F* (p-values)					
NR - linear	0.369	0.931	0.677	0.138	0.996	0.345
NR - quadratic	0.163	0.728	0.866	0.630	0.737	0.995

In 2021, the plots were relatively clean with few broadleaf weeds observed and a modest number of grassy weeds. The dominant grassy weed was presumed to be volunteer canary seed, but we did not attempt to identify individual weed species beyond classifying them as broadleaf or grassy types. While N rate had no effect on weed populations, regardless of how they were classified (P = 0.372-0.785); the cover crop effect was significant for grassy and total weeds (P = 0.011-0.026), but not broadleaves (P = 0.28). No CC x NR interactions were detected for weed densities in 2021 (P = 0.33-0.72). The cover crop effects were such that grassy weed populations were 33% higher with the rye cover crop (19 plants/m^2) than without (14 plants/m^2). This result was not expected but can be reasonably explained. Again, it is feasible that, under the dry conditions, some of the fall rye seeds had not yet germinated when the cover crop was terminated, and the canola was seeded. Any such seeds that were still viable would have likely germinated after the major precipitation event in late May and would have had plenty of time to emerge prior to completing the weed counts. Despite the statistical significance, overall weed populations were, again, low overall and all were easily controlled with the in-crop herbicide application.

In 2022, with the much wetter fall/early spring and delayed seeding, weed populations prior to the in-crop herbicide applications were extremely low and, regardless of how they were classified, not affected by CC (P = 0.37-0.61), NR (P = 0.54-0.85), nor the CC x NR interaction (P = 0.33-0.72). With total weed populations less than 0.5/m^2, even if any treatment effects were significant, they would have been too small to be of any practical importance.

Main effect means for canola seed yield, oil, and protein concentrations are presented in Table 5 below while individual treatment means are in Table 12 of the Appendices. Because the responses of seed yield, oil, and protein to N fertilization are often related to one another, all three variables will be discussed together for each of the two years.

Table 5. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on canola seed yield, seed oil content, and seed protein content at Indian Head in 2021 and 2022. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Main Effect	2021 Yield	2021 Oil	2021 Protein	2022 Yield	2022 Oil	2022 Protein
Cover Crop	-- kg/ha --	%	%	-- kg/ha --	%	%
None	2218 A	43.7 A	19.0 B	2738 A	42.3 A	18.8 A
Fall Rye	2157 B	43.6 A	19.2 A	2654 A	42.2 A	18.9 A
S.E.M.	59.1	0.10	0.17	70.7	0.19	0.18
Nitrogen Rate						
25 kg N/ha	1050 E	44.6 A	17.5 D	1907 C	43.9 A	17.5 D
60 kg N/ha	1755 D	44.7 A	17.4 D	2490 B	43.3 B	17.7 D
105 kg N/ha	2476 C	43.9 B	18.8 C	2913 A	42.2 C	18.9 C
140 kg N/ha	2739 B	43.1 C	20.2 B	3051 A	41.4 D	19.6 B
175 kg N/ha	2917 A	41.8 D	21.5 A	3120 A	40.4 E	20.5 A
S.E.M.	62.0	0.12	0.19	81.0	0.21	0.20
Contrast	Pr > *F* (p-values)					
NR - linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
NR - quadratic	<0.001	<0.001	<0.001	<0.001	0.214	0.034

In 2021, canola yield was affected by both CC ($P = 0.008$) and NR ($P < 0.001$), but there was no CC x NR interaction ($P = 0.48$). The CC effect on yield was small, but negative, with a 61 kg/ha (3%) yield reduction associated with the cover crop. The NR response was such that yields increased from 1050 kg/ha at 25 kg N/ha to 2917 kg/ha at 175 kg N/ha. Yield increases with incremental additions of N were statistically significant right up to the highest rate, with a maximum yield benefit of 1867 kg/ha (178%); however, the significant quadratic response ($P < 0.001$) indicated diminishing returns at the higher end of this range. Oil content was affected by N rate ($P < 0.001$), but not cover crop ($P = 0.12$), and there was no CC x NR interaction ($P = 0.51$). Oil content was inversely related to NR and decreased significantly right to the highest N rate; however, the quadratic response ($P < 0.001$) differed from what was observed for yield. For oil content, there was relatively little impact going from 25 kg N/ha to 60 kg N/ha, but the magnitude of the reductions increased with further additions of N that also corresponded to diminishing yield increases. Like yield, seed protein content was affected by both cover crop ($P = 0.043$) and N rate ($P < 0.001$), but not the CC x NR interaction ($P = 0.896$). The CC effect on protein was the opposite of the observed effect on yield whereby, when averaged across N rates, protein was slightly but significantly higher with the cover crop (19.2%) than without (19.0%). In theory, cover crops could immobilize N early on but release it later in the season as residues decompose, potentially resulting in higher protein. However, under the conditions encountered, it is unlikely that there was enough cover crop growth for this to occur. It may have simply been that N availability was similar between cover crop treatments; therefore, with slightly lower yields in the cover crop treatments we ended up with slightly higher protein content. The NR effect on seed protein was essentially the opposite of what occurred for oil content. There was no impact on protein going from 25 kg N/ha to 60 kg N/ha, but substantial increases with each subsequent addition of N fertilizer. The lack of NR effects on oil or protein content at the lower N levels was attributable to the fact that yields were increasing rapidly at this point. As seen in cereal crops such as wheat, seed protein concentrations generally peak at higher N rates than are required to maximize yield. At lower N levels, the gains in seed yield with additions of N are generally much larger and often dilute the accumulated protein such that the protein concentrations (or percent protein) remain relatively stable. It is not usually until the yield increases with incremental increases in N begin to diminish that protein starts to increase more rapidly.

With much higher initial soil moisture reserves and cooler temperatures, yields were higher in 2022 compared to the previous season. The overall F-test for cover crop effects on yield were only marginally significant ($P = 0.08$); however, the trend was the same as the previous year whereby yields tended to be lower with the fall rye cover crop. While not significant at the desired level, the magnitude of the cover crop effect was comparable to the previous season at 84 kg/ha or 3%. Despite being slightly higher overall in 2022, maximum yields were achieved at lower N rates compared to the previous season with no statistically significant increases beyond 105 kg N/ha. Numerically, yields did continue to increase slightly with further increases in N, but to a much lesser extent and. as such, the overall average response was, again, quadratic ($P < 0.001$). With no CC x NR interaction and similar orthogonal contrast results, the yield response to N rate was similar, regardless of whether a cover crop was utilized (Table 12). Like yield, canola oil content in 2022 was not significantly affected by cover crop ($P = 0.21$) but was affected by N rate ($P < 0.001$), and there was no CC x NR interaction ($P < 0.96$). Across N rates, the oil content was 42%, slightly lower than the 44% average observed the previous year. The NR effect on oil content was purely linear ($P < 0.001$) and not quadratic ($P = 0.21$). Again, there was a negative relationship between N rate and oil content with values averaging 43.9% at 25 kg N/ha and significantly declining with each subsequent addition of N to 40.4% at 175 kg N/ha. The trend was like the previous year where the negative effects of N rate on oil content were less at the lower fertilizer rates; however, not nearly to the same extent. Seed protein content was not affected by cover crop ($P = 0.38$), but the NR effect was strong ($P < 0.001$) and the CC x NR interaction was significant ($P = 0.03$). The average NR effect (across cover crop treatments) on protein was also like the previous season in that it was largely quadratic ($P = 0.03$), with comparatively less effect of increasing N rates on protein at the low end of the range but stronger effects at the high end where incremental yield increases were greatly diminished. Focussing on the CC x NR response, however, the quadratic nature of this response was inconsistent and only apparent in the absence of a cover crop ($P = 0.07$) while, with the cover crop, the response was strictly linear ($P < 0.001$) and not quadratic ($P = 0.23$). While significant, the reason for this inconsistent response was unclear.

Extension Activities

In 2020-21, this demonstration was shown to approximately 70 participants on July 20 during a scaled back IHARF Crop Management Field Day. There was discussion of the potential merits and challenges of incorporating cover crops into annual cropping systems in the short, frequently dry, Saskatchewan growing seasons. Highlights from the project were also presented during the 2021 IHARF Soil and Crop Management Seminar which was held virtually on February 2, 2022, and attended by approximately 140 individuals. In the summer of 2022, the project was shown and discussed during a canola crop walk hosted by IHARF and SaskCanola and attended by approximately 45 individuals. The 2021 Interim report has been available for download on the IHARF website, and this 2022 report will also be posted online in the coming months. Project results and highlights will continue to be presented where appropriate through oral presentations and other extension materials as opportunities arise.

11. Conclusions and Recommendations

Due to the extremely dry fall and early-spring, the 2020-21 growing season at Indian Head was not particularly favourable for establishment of a fall rye cover crop. Nonetheless, the project demonstrated some of the challenges that can occur when incorporating cover crops into annual cropping systems with our short growing seasons and frequently dry weather. Although the fall rye was seeded relatively early in the fall, it was too dry for the seed to germinate prior to freeze up. The snow melt provided enough moisture for some germination to occur in the early spring; however, with extremely low initial soil moisture and below average snowpack, some seeds remained ungerminated and the plants that did establish never got past the 1-3 leaf stage. Apart from slightly higher seed protein without negatively affecting oil content, any significant cover crop effects on the canola were negative in the first year of this demonstration. For example, final plant densities were reduced by 15%, total weed populations were increased by 21% (presumably due to delayed germination of rye plants), and yields were reduced by 3%.

In 2022, conditions were better overall for cover crop establishment. Seeding was completed in mid-September and, with better soil moisture conditions than the previous fall, the crop established but the plants were small going into winter. Snowfall was above average, and seeding was delayed due to a late melt and wet May. In contrast to the previous season, this allowed for substantial cover crop growth prior to its termination. The cover crop did not affect establishment in 2022 when averaged across N rates, but was there a slight decline in plant populations as we increased the amount of side-banded N. This was presumed to be a result of poor seed/fertilizer placement and separation resulting from the wet conditions at seeding followed by a period of dry weather. The effect was less consistent in the spring assessments, only apparent in the absence of the cover crop where plant densities at the lowest N rate were considerably higher than all other treatments. Weed populations prior to the in-crop herbicide applications were extremely low in 2022 and not affected by any treatments. Seed yields, oil content, and protein were not affected by the cover crop and, for yield and oil content specifically, there was no interactive effect of the cover crop and N rate treatments. Focussing on seed protein, an interaction between cover crop and N rate was detected but it was subtle and difficult to explain.

Overall, when cover crop effects were detected over the two growing season, they were either negative or of little practical importance. Short windows for establishment and growth between the preceding cereal crop harvest and the canola test crop limited the potential for the rye cover crop to tie up nutrients in both years, but particularly in 2020-21. While the first year of project was dry, the cover crop was too poor to have used much soil moisture and, regardless, timely rain after seeding offset any negative impacts that it could have had on canola emergence. The second year was much wetter and the cover crop had potential to utilize up some of the excess soil moisture and improve seeding conditions; however, frequent heavy rains through the spring seeding period diminished any such positive effects. There were no weed control benefits under the conditions encountered and the cover crop did not have any meaningful impacts on canola yield, oil, or protein response to N fertilizer. The risk of wind or water erosion was low in our long-term, no-till soils. It is unclear, and beyond the scope of this project, whether the increased crop diversity and biological activity associated with the cover crop might have longer-term soil health benefits. In conclusion, producers who see merit in doing so are encouraged to be open to incorporating cover crops into their rotations where there is a reasonably high potential for success (i.e., early harvest, good fall soil moisture conditions). That said, if harvest is late and/or the fall is cool and dry, the likelihood of establishment and tangible benefits of the cover is relatively low. Furthermore, in addition to the potential for negative effects on productivity, there is a cost to this practice when seed, fuel, labour, and equipment is considered. Future research and demonstration activities might consider exploring the merits of other species (for both cover and cash crops) or alternative approaches for seeding the cover crops to improve the likelihood of successful establishment and realizing tangible benefits to the practice.

This project was established for a third and final season in the fall of 2022 and will be repeated this coming growing season to build upon these results.

Supporting Information

12. Acknowledgements:

This project was jointly funded by Fertilizer Canada and the Agricultural Demonstration of Practices and Technologies (ADOPT) initiative under the Canadian Agricultural Partnership bi-lateral agreement between the federal government and the Saskatchewan Ministry of Agriculture. IHARF has a strong working relationship and a memorandum of understanding with Agriculture and Agri-Food Canada which should be acknowledged and IHARF provided the land, equipment, and infrastructure required to complete this project. Special thanks are extended to all the IHARF staff who worked on the project.

13. Appendices:

Table 6. Selected agronomic information and dates of operations for canola cover crop and nitrogen response demonstration at Indian Head in 2021 and 2022.

Factor / Operation	2020-21	2021-22
Previous Crop	Canaryseed	Oat
Cover Crop Seeding Date	Sep-19-2020	Sep-15-2021
Cover Crop Seed Rate	250 seeds/m^2 (98 kg/ha)	300 seeds/m^2 (118 kg/ha)
Soil Sampling Date	May-13-2021	May 25-2022
Pre-emergent Herbicide	894 g glyphosate/ha (May-13-2021)	894 g glyphosate/ha (May-26-2021)
Canola Seeding Date	May-14-2021	May-31-2022
Canola Seed Rate	105 seeds/m^2 (5.3 kg/ha)	105 seeds/m^2 4.8 kg/ha)
kg P_2O_5-K_2O-S ha^{-1}	36-18-18	36-18-18
Spring Plant Density	Jun-18-2021	Jun-27-2022
Weed Counts	Jun-16-2021	Jun-27-2022
In-crop Herbicide	593 g glufosinate-ammonium/ha + 30 g clethodim/ha (Jun-19-2021)	593 g glufosinate-ammonium/ha + 30 g clethodim/ha (Jun-28-2022)
Foliar Fungicide	242 g boscalid/ha + 86 g pyraclostrobin/ha (Jul-2-2021)	242 g boscalid/ha (Jul-18-2022)
Foliar Insecticide	872 g malathion/ha (Jul-27-2021)	7.4 g deltamethrin/ha (Jun-28-2022)
Pre-harvest herbicide	894 g glyphosate/ha (Aug-15-2021)	894 g glyphosate/ha (Sep-10-2022)
Harvest date	Sep-2-2021	Sep-26-2022
Fall Plant Density	Sep-7-2021	Oct-5-2022

Table 7. Plant Root Simulator (PRS) soil test results (Western Ag Laboratories) from Indian Head in 2021 and 2022. Separate samples were collected from plots with and without a fall rye cover crop, just prior to cover crop termination and seeding.

Treatment	pH	N	P_2O_5	K_2O	S
		-------------------- kg/ha --------------------			
2021 – No Cover	8.3	21	26	48	15
2021 – Rye Cover	8.2	54	66	55	78
2022 – No Cover	8.5	9	52	65	16
2022 – Rye Cover	8.3	8	33	84	17

Notes: Nutrient release values are based on 250 mm of total moisture and canola as the crop type. The sample depth is 10 cm for pH, P_2O_5, and K_2O and 30 cm for N and S. The high fertility observed in the 2021 fall rye cover treatments was unexpected and inconsistent with other soil samples from the broader research site.

Table 8. Tests of fixed effects of cover crop and nitrogen rate for canola establishment, weed densities, yield, oil content, and protein at Indian Head in 2021. P-values below 0.05 indicate that an effect was significant for the corresponding response variable.

Response Variable	Cover Crop (CC)	N Rate (NR)	CC x NR
	------------------------------ Pr > *F* (p-values) ------------------------------		
Spring Plant Density (plants/m^2)	0.157	0.173	0.603
Final Plant Density (plants/m^2)	<0.001	0.580	0.590
Broadleaf Weeds (weeds/m^2)	0.284	0.372	0.177
Grassy Weeds (weeds/m^2)	0.011	0.785	0.254
Total Weeds (weeds/m^2)	0.026	0.723	0.244
Seed Yield (kg/ha)	0.008	<0.001	0.477
Oil (%)	0.118	<0.001	0.511
Protein (%)	0.043	<0.001	0.896

Table 9. Tests of fixed effects of cover crop and nitrogen rate for canola establishment, weed densities, yield, oil content, and protein at Indian Head in 2022. P-values below 0.05 indicate that an effect was significant for the corresponding response variable.

Response Variable	Cover Crop (CC)	N Rate (NR)	CC x NR
	------------------------------ Pr > *F* (p-values) ------------------------------		
Spring Plant Density (plants/m^2)	0.720	0.029	0.038
Final Plant Density (plants/m^2)	0.250	0.029	0.658
Broadleaf Weeds (weeds/m^2)	0.475	0.538	0.718
Grassy Weeds (weeds/m^2)	0.610	0.783	0.555
Total Weeds (weeds/m^2)	0.372	0.852	0.328
Seed Yield (kg/ha)	0.077	<0.001	0.796
Oil (%)	0.205	<0.001	0.962
Protein (%)	0.383	<0.001	0.033

Table 10. Individual treatment means for cover crop (CC) by nitrogen rate (NR) effects on plant densities at Indian Head in 2021 and 2022, as measured in both the spring and fall (post-harvest). Results from the orthogonal contrasts which test whether N rate responses (within cover crop treatments) are linear, quadratic (curvilinear), or not significant are also included. Means followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

	------------------ 2021 ------------------		------------------ 2022 ------------------	
Treatment	**Spring**	**Fall**	**Spring**	**Fall**
CC x NR	---------------------- plants/m^2 ----------------------			
None - 25 kg N/ha	76.9 a	73.4 ab	96.4 a	70.7 a
None - 60 kg N/ha	72.2 a	77.5 ab	84.1 ab	65.6 a
None - 105 kg N/ha	72.4 a	71.6 ab	81.8 ab	65.4 a
None - 140 kg N/ha	72.8 a	78.6 ab	80.6 ab	60.7 a
None - 175 kg N/ha	80.6 a	81.4 a	73.6 b	58.1 a
NR - linear (p-value)	0.518	0.229	<0.001	0.008
NR - quad (p-value)	0.078	0.467	0.463	0.958
Fall Rye - 25 kg N/ha	73.4 a	60.5 b	82.0 ab	65.6 a
Fall Rye - 60 kg N/ha	71.8 a	64.6 ab	85.9 ab	66.4 a
Fall Rye - 105 kg N/ha	64.0 a	68.5 ab	85.3 ab	59.3 a
Fall Rye - 140 kg N/ha	74.9 a	67.1 ab	76.1 b	56.8 a
Fall Rye - 175 kg N/ha	73.8 a	65.0 ab	82.9 ab	60.1 a
NR - linear (p-value)	0.794	0.371	0.481	0.051
NR - quad (p-value)	0.144	0.270	0.801	0.462
S.E.M.	3.60	4.18	3.62	3.31

Table 11. Individual treatment means for cover crop (CC) by nitrogen rate (NR) effects on weed densities at Indian Head in 2021 and 2022, as measured just prior to the in-crop herbicide applications. Means followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

	2021			2022		
Treatment	**Broadleaf**	**Grassy**	**Total**	**Broadleaf**	**Grassy**	**Total**
CC x NR	weeds/m^2					
None - 25 kg N/ha	6.9 a	14.5 a	21.4 a	0.2 a	0.2 a	0.4 a
None - 60 kg N/ha	5.9 a	13.2 a	19.1 a	0.4 a	0.4 a	0.8 a
None - 105 kg N/ha	3.7 a	15.7 a	19.5 a	0.2 a	0.0 a	0.2 a
None - 140 kg N/ha	4.3 a	17.5 a	21.8 a	0.0 a	0.4 a	0.4 a
None - 175 kg N/ha	6.1 a	9.0 a	15.1 a	0.0 a	0.4 a	0.4 a
NR - linear (p-value)	0.300	0.499	0.294	0.153	0.646	0.612
NR - quad (p-value)	0.040	0.163	0.523	0.526	0.624	0.973
Fall Rye - 25 kg N/ha	5.1 a	19.7 a	24.8 a	0.2 a	0.4 a	0.6 a
Fall Rye - 60 kg N/ha	3.7 a	16.3 a	20.0 a	0.0 a	0.0 a	0.0 a
Fall Rye - 105 kg N/ha	6.3 a	19.5 a	25.7 a	0.2 a	0.2 a	0.4 a
Fall Rye - 140 kg N/ha	3.5 a	17.3 a	20.8 a	0.0 a	0.4 a	0.4 a
Fall Rye - 175 kg N/ha	4.7 a	21.6 a	26.3 a	0.0 a	0.0 a	0.0 a
NR - linear (p-value)	0.815	0.579	0.639	0.496	0.641	0.405
NR - quad (p-value)	0.902	0.358	0.382	0.963	0.987	0.965
S.E.M.	1.42	2.95	3.06	0.18	0.25	0.27

Table 12. Individual treatment means for cover crop (CC) by nitrogen rate (NR) effects on canola seed yield, seed oil content, and seed protein content at Indian Head in 2021 and 2022. Results from the orthogonal contrasts which test whether N rate responses (within cover crop treatments) are linear, quadratic (curvilinear), or not significant are also included. Means followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

	------------------- 2021 -------------------			------------------- 2022 -------------------		
Treatment	**Yield**	**Oil**	**Protein**	**Yield**	**Oil**	**Protein**
CC x NR	-- kg/ha --	-------------- % --------------		-- kg/ha --	-------------- % --------------	
None - 25 kg N/ha	1096 e	44.7 a	17.4 d	1981 d	44.1 a	17.4 e
None - 60 kg N/ha	1756 d	44.7 a	17.3 d	2501 bc	43.5 a	17.3 e
None - 105 kg N/ha	2529 c	43.9 b	18.8 c	2980 a	42.3 b	18.9 cd
None - 140 kg N/ha	2779 ab	43.3 d	20.0 b	3053 a	41.4 bc	19.7 ab
None - 175 kg N/ha	2930 a	41.9 e	21.4 a	3176 a	40.5 cd	20.5 a
NR - linear (p-value)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
NR - quad (p-value)	<0.002	<0.001	<0.001	<0.001	0.462	0.066
Fall Rye - 25 kg N/ha	1004 e	44.5 ab	17.5 d	1834 d	43.8 a	17.5 e
Fall Rye - 60 kg N/ha	1754 d	44.6 a	17.6 d	2478 c	43.2 a	18.1 de
Fall Rye - 105 kg N/ha	2423 c	44.0 bc	18.8 c	2845 ab	42.1 b	18.9 cd
Fall Rye - 140 kg N/ha	2698 b	43.0 d	20.4 b	3048 a	41.4 b	19.4 bc
Fall Rye - 175 kg N/ha	2905 a	41.7 e	21.6 a	3065 a	40.4 d	20.5 a
NR - linear (p-value)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
NR - quad (p-value)	<0.001	<0.001	<0.001	<0.001	0.302	0.226
S.E.M.	66.5	0.15	0.22	95.7	0.25	0.24

Abstract

14. Abstract/Summary

With funding from the Saskatchewan Ministry of Agriculture's ADOPT program and Fertilizer Canada, a project was conducted to demonstrate potential benefits and challenges associated with incorporating cover crops into annual cropping systems and implications for nitrogen (N) fertilizer requirements. The project was initiated in the fall of 2020 and repeated the following season. Field trial were located near Indian Head, Saskatchewan, and the test crop was canola. The treatments were a factorial combination of two cover crop treatments (no cover versus fall rye cover) and five N rates (25, 60, 105, 140, and 175 kg N/ha). Nitrogen rates were not adjusted for residual soil N as we anticipated this could be affected by the cover crops and hoped to measure any impacts on fertilizer requirements. In addition to soil test analyses, data collection included measurements of canola emergence and final plant populations, weed densities, canola seed yield, oil content, and protein. The two seasons contrasted each other in that the fall of 2020/early spring 2021 were extremely dry with poor cover crop establishment while the following season had sufficient fall soil moisture and an extremely wet spring, resulting in good cover crop establishment and substantial growth. While the 2021 growing season was warm dry overall, timely rains allowed for reasonably high yield potential. Moisture was generally non-limiting in 2022 and yields were slightly higher than the previous season. Soil tests showed trends of slightly lower residual NO_3-N with the cover crop, but the effects were small and could not be confidently attributed to the treatments. The cover crop never reduced weed populations and increased them slightly in 2021, presumably due to late emerging rye seeds under the extremely dry conditions. In 2021, the cover crop negatively affected final plant populations and, to a lesser extent, yield. In 2022, canola emergence and final plant populations declined slightly with increasing rates of side-banded urea but were not consistently affected by cover crop and yields were similar for both cover crop treatments. The cover crop did not appear to affect canola yield response to N rate in either year. This project is being repeated for the 2022-23 growing season to build upon these results.