Agriculture Demonstration of Practices and Technologies (ADOPT)

Project Final Report

The final project report should be made available electronically (MS Word). Additional data tables and or graphs may be submitted in spreadsheet format. Due to formatting, printing and distribution requirements, final reports will not be accepted as PDF documents. Completed reports must be returned by email to Evaluation.Coordinator@gov.sk.ca.

Project Title:	Fall Rye Cover Crop Effects on Canola Establishment and Response to Nitrogen (Final Report)
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Project Location(s): *Provide the name or number of the rural municipality, nearest town or legal land location if possible. Provide the name of any cooperating landowner(s).*	Indian Head, Saskatchewan (R.M. #156)
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Abstract *(maximum 200 words)*

Detail key elements from the project objectives, methodology, results and conclusions to provide a short concise summary of the project. List extension activities such as field days or workshops and include the number of people who visited the project.

A three-year project was conducted to demonstrate the potential benefits and challenges associated with incorporating cover crops into annual cropping systems and implications for nitrogen (N) fertilizer requirements. Canola was the test crop, and the treatments were comprised of two cover crop treatments (none versus fall rye cover) and five N fertilizer rates ranging from 25-175 kg N/ha. In addition to soil test analyses, data collection included canola establishment, weed densities, seed yield, oil, and protein. Cover crop establishment was successful in 2021-22, the wettest of three seasons, but more challenging in 2021 and 2023 due to drought and delayed harvest. The 2021 and 2023 growing seasons were hot and dry while 2022 was wetter with slightly higher canola yield potential. Soil tests results suggested that any cover crop effects were negligible, and the cover crop never reduced weed populations. In 1/3 years, the cover crop resulted in slightly lower final plant populations. We saw consistently strong overall responses to N, but no cover crop effects on

seed yield, oil, or protein. The cover crop did not affect the optimal N fertilizer rate in any cases. Results from this project have been shared at numerous field days, winter extension meetings, and online, over its duration.

Project Objectives

Provide a short statement outlining the project objectives. Identify the key concept this project was designed to demonstrate. For example, you might use a statement such as *"This project was intended to demonstrate and compare the benefits of……" or "The objective of this project was to demonstrate the impact of…."*

The broader objectives of the proposed 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. Specifically, we aim to demonstrate the effects of a preceding cereal rye cover crop on:

- The overall establishment and yield of canola in addition to early season weed densities relative to canola grown with no cover crop.
- The N fertilizer requirements and overall response to N fertilization relative to canola grown with no cover crop.

Project Rationale

Briefly describe why this project is of interest to local producers. Why is it important to have this project? What are the potential beneficial outcomes? What is the perceived need?

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 how they are specifically established and where they fit into crop 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 perceived or 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. Despite the high level of interest and potential benefits, there can be a steep learning curve to successfully 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. 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.

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

Fully describe how the project was set up and run. You should provide enough information so that any reader can understand what you did, and where and when you did it. From that they can determine if your report has any relevance to their own operation. For example, your description should include all relevant items such as 1) the number and size of any field plots, 2) what was seeded, 3) what treatments were applied to the plots, 4) the schedule or timing of any relevant activities such as seeding, treatment application or harvest, and 5) what was measured to evaluate the success of any treatment. If your project dealt with animals, you should be sure to include 1) the number of animals in each trial group, 2) the treatment or procedure applied to each group, and 3) what was measured to evaluate the success of each treatment.

A field trial was first initiated near Indian Head, Saskatchewan in the fall of 2020 and repeated the following two growing seasons. The treatments were a factorial combination of two cover crop scenarios (either none 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 might impact soil N levels and subsequent fertilizer requirements. The 10 treatments were arranged in a four replicate RCBD.

Selected agronomic details and dates of operations for each of the three growing seasons are provided in Table 3 of the Appendices. The previous crop was canaryseed in 2021 and 2023 and oat in 2022. For perennial weed control, and to ensure that initial weed pressure was similar across the trial area, the sites were always sprayed with glyphosate before the fall rye emerged. The rye cover was seeded each of the preceding falls, as per protocol, with target seeding rates of 250 seeds/m^2 in 2020 and 300 seeds/m^2 in 2021 and 2022. The higher seeding rate was adopted the second year of the project to account for potentially high mortality and increase the likelihood for successful establishment of the cover crop. While we had aimed to seed in mid-September, the late harvest resulted in seeding being delayed until October 7 in 2022. 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 always seeded at a target rate of 105 seeds/m^2 and, each year, a glufosinate ammonium / pod shatter resistant hybrid was utilized. In addition to the pre-seed glyphosate applications, weeds were controlled using registered in-crop herbicides applications. Foliar fungicide was applied preventatively at early- to mid-bloom and foliar insecticide was applied both years to control grasshoppers in 2021 and flea beetles in 2022. No foliar insecticide was required in 2023. 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 when it was fit to do so.

Various data were collected throughout the season and from the harvested grain samples. To assess initial fertility levels and explore any cover crop impacts, 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 specific lab requirements. 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 samples were collected from the exact same plots for two depths (0-10 cm, 10-30 cm), sealed into plastic bags, refrigerated, and submitted to Western Ag Laboratories (Saskatoon, SK) for analyses. Plant densities were measured on two separate occasions, in the late spring and again post-harvest, by recording the number of plants in 4 × 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 dockage (determined using standard Canadian Grain Commission procedures) and to a uniform moisture content of 10%. Seed oil and protein concentrations were determined simultaneously using a FOSS NIR analyzer. Mean monthly temperatures and 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 from all three years were combined and analyzed using the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio. The effects of year (Yr), cover crop (CC), N rate (NR), and all possible interactions were treated as fixed while replicate effects were considered random. Heterogeneity of variance estimates (across years) was permitted and tested for; however, the more complex model was only utilized when doing so significantly improved convergence. Orthogonal contrasts were used to test whether select 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 Tukey's test was used to separate treatment means. The means were sliced by year to limit comparisons to what would be agronomically meaningful and improve our ability to detect differences.

Results *(you must provide the following information)*

Present and discuss any project results, including any data or measurements taken to evaluate the demonstration. Include things that didn't appear to work. These results are just as important to share. List extension activities such as field days or workshops. List the activity, the date it occurred, and the number of people who attended.

<u>*Growing season weather and residual soil nutrients*</u>

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

Focussing on the first season (2020-21), the fall months were extremely dry, and this followed an unusually dry growing season (May-August 2020). Consequently, there was essentially no germination of the cover crop in the fall of 2020. The following growing season (2021), temperatures were 0.4 °C above average and total precipitation was 121% of 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. Looking at 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 below the target of approximately 200 plants/m^2. In terms of growing season effects on the canola, the crop fared well overall with good initial establishment and yields which 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 warm and wet, however, which, combined with above-average snowfall and wet conditions the following May, led to successful cover crop establishment. The wet spring delayed canola seeding until relatively late in May and the rye plants were at early stem elongation when they were terminated. Over the four-month growing season (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, and this was the highest yielding season of the project.

For the final, 2022-23 season, cover crop establishment was, again, quite poor due to late seeding and dry fall weather. Spring soil moisture was abundant thanks to a late April snowstorm; however, winter survival of the cover crop was variable, and the plants were small at the time of termination. Temperatures in the 2023 growing season were considerably warmer than average, particularly in May and June, and precipitation was 49% of average with only 119 mm from May-August.

Table 1. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2021, 2022, and 2023 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 (+0.4)
2022	14.5	6.8	10.9	16.1	18.1	18.3	15.8 (+0.2)
2023	13.7	5.6	14.0	19.4	16.7	17.7	17.0 (+1.4)
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%)
2023	14.5	18.8	12.9	49.6	15.9	40.8	119 (49%)
LT	35.3	24.9	51.8	77.4	63.8	51.2	244

Conventional soil test analyses results are provided in Table 2 below while the Plant Root Simulator® analyses are deferred to Table 4 of the Appendices. The sites were consistently low in residual nitrate (NO_3-N), averaging 24, 11, and 22 kg NO_3-N/ha in 2021, 2022, and 2023, respectively. Variation in nutrient levels between cover crop treatment treatments was generally low and not always consistent. We had hypothesized that the cover group might draw down residual nutrients, particularly soil NO_3-N; however, the residual nutrient levels were likely too low to begin with for there to have been a meaningful impact and any observed differences were always within what might be expected with naturally occurring variability.

Table 2. Conventional soil test results (AgVise Laboratories) for Indian Head (2021-23) collected from plots with and without a fall rye cover crop, just prior to cover crop termination and seeding of the subsequent canola cash crop.

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
2023								
No Cover Crop	0-15	7.6	42.4	5.8	9	11	510	16
	15-60	8.0	-	-	13	-	-	40
	0-60	-	-	-	22	-	-	56
Fall Rye Cover Crop	0-15	7.6	44.5	5.6	8	8	577	18
	15-60	8.0	-	-	13	-	-	40
	0-60	-	-	-	21	-	-	58

Treatment Effects on Emergence and Final Plant Populations

According to the overall tests of fixed effects (Table 5), spring emergence was affected by year (Yr; $P < 0.001$) with a significant Yr × N rate (NR) interaction ($P = 0.011$); however, neither the cover crop (CC) effect nor any interactions associated with it were significant ($P = 0.111$-0.448). Looking at the Yr effect (Table 6), emergence was best in 2023 (105 plants/m^2), followed by 2022 (83 plants/m^2), then 2021 (73 plants/m^2). The Yr × NR interaction was due to there being no effect of N rate on emergence in 2021 or 2023, but linear decline in plant densities with increasing N in 2022 (Table 3; Fig. 1). This was attributed to wet conditions during seeding in 2022 which resulted in poorer separation between the seed and side-banded N that year. Although the quadratic response in 2021 was also significant ($P = 0.021$), this was largely attributed to random variability with no significant overall sliced effect of N rate that year ($P = 0.518$), differences between means according to the Tukey's test, or biological basis for the response. Again, no cover crop effects on spring emergence were detected, either for individual years over averaged across them.

When final plant populations were estimated through post-harvest stubble counts, the significant Yr × NR response ($P = 0.023$) was like what was observed in the spring, with a linear decline in final plant populations with increasing N rate in 2022, but not in 2021 or 2023 (Table 9; Fig. 2). Notably, the observed final plant populations for 2022 were lower than what was measured in the spring, likely due to a combination of weaker plants not surviving the growing season and/or flea beetles thinning out populations after the spring counts were completed. For the post-harvest counts, there was a quadratic response in 2023 ($P = 0.003$) whereby plant densities were highest at intermediate N-rates. Although the sliced test of NR effects on final plant populations that year was only marginally significant ($P = 0.084$), it is possible that in-season mortality was slightly higher at the extreme N levels due to either weak, N deficient plants on the low end and some NH_3 toxicity at the high levels. In any case, overall plant densities were excellent in 2023 and this response was not considered important from a practical, agronomic perspective.

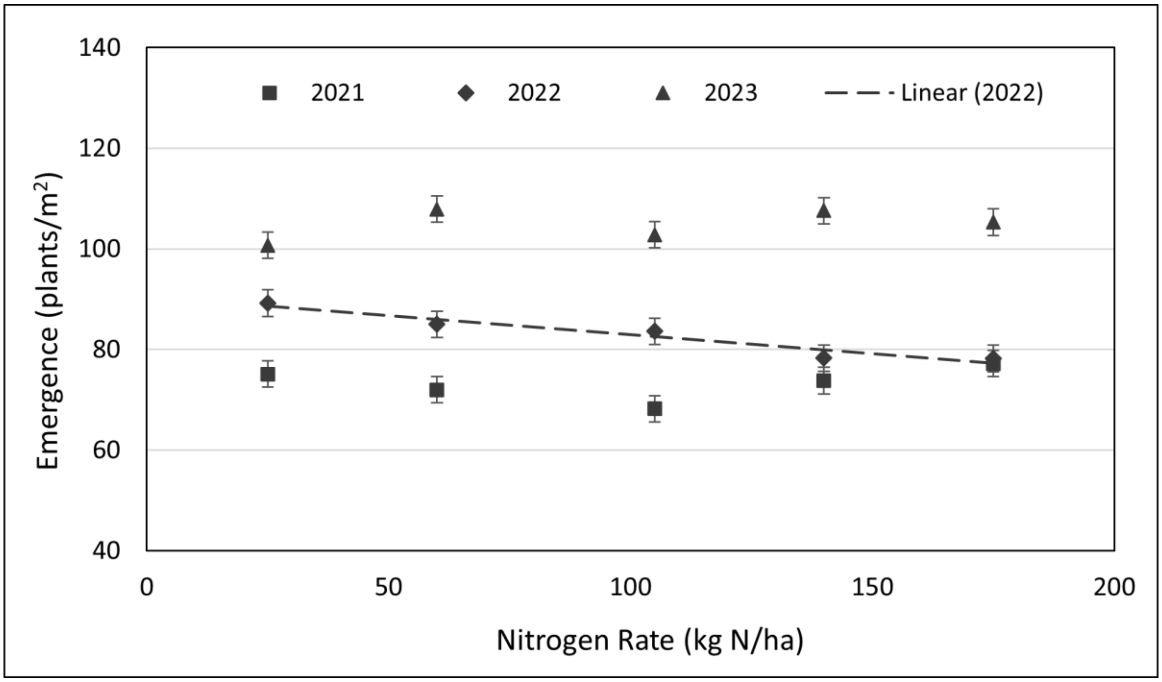

Figure 1. Significant year (Yr) × N rate (NR) effects on canola emergence at Indian Head, Saskatchewan. In 2022, spring plant densities declined linearly (*P* < 0.001) with increasing rate of side-banded urea, when averaged across cover crop treatments. Error bars are the standard error of the treatment mean (S.E.M.).

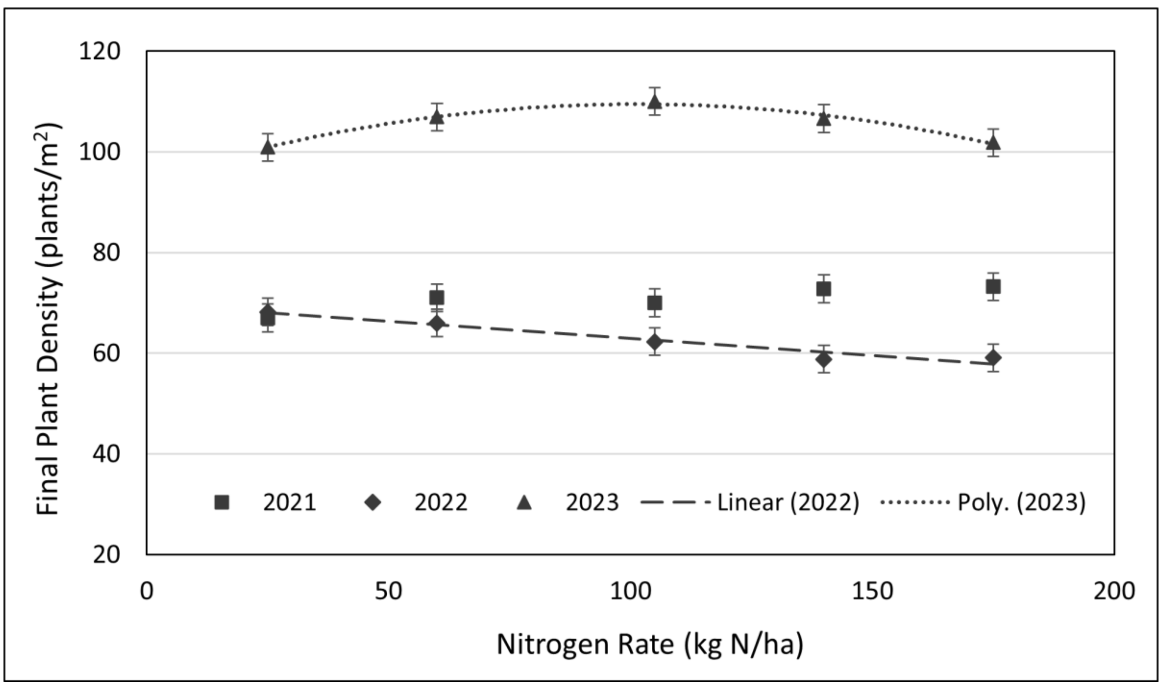

Figure 2. Significant year (Yr) × N rate (NR) effects on final canola plant densities at Indian Head, Saskatchewan. In 2022, final plant densities declined linearly (*P* = 0.003) with increasing rate of side-banded urea. In 2023, there was a quadratic (*P* = 0.005) response to N rates whereby plant populations were slightly lower at the extreme low and high versus intermediate levels. Error bars are the standard error of the treatment mean (S.E.M.).

In addition to the N responses, there was also a Yr x CC interaction detected ($P < 0.001$) for final plant populations whereby, in 2021, the densities were 15% less (11 plants/m^2) with the fall rye cover crop (Fig. 3). While the specific reasons for this response are unclear, it is possible that, under the extremely dry fall and early spring conditions, there were some allelopathic effects associated either with the canola emerging at the same time as some rye seeds or with decomposition of the late emerged rye after being kill by the in-crop herbicide application. While not specifically observed in 2022 or 2023, this effect was also significant when averaged over the three-year period.

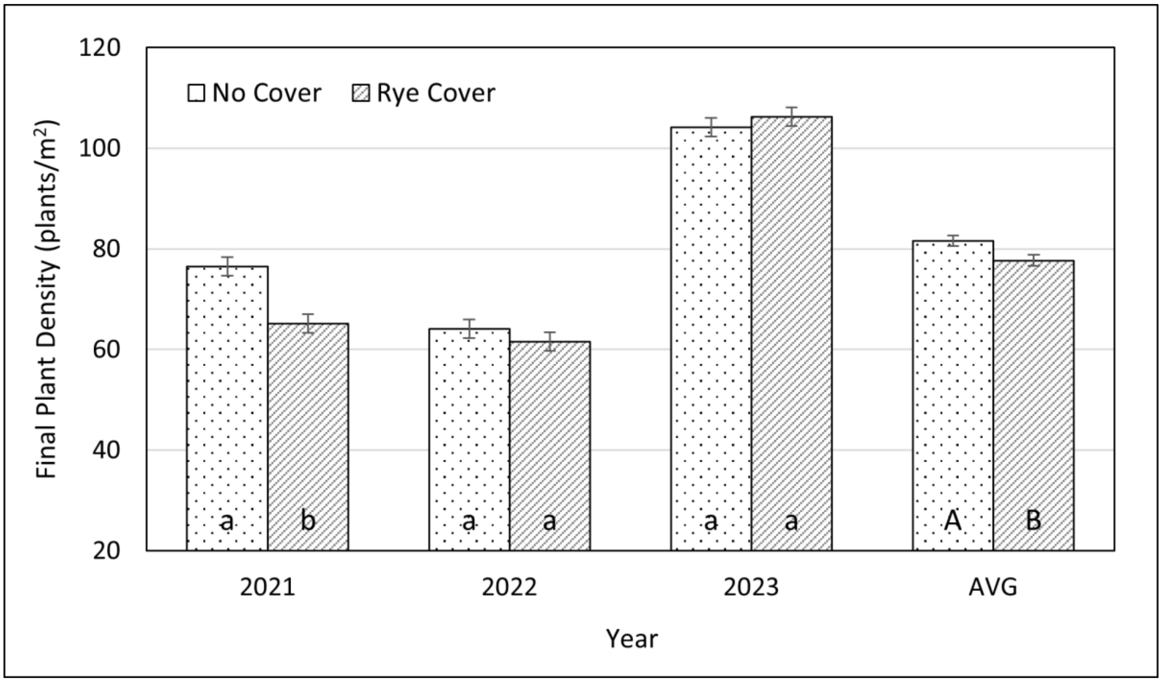

Figure 3. Significant year (Yr) × Cover Crop (CC) and overall CC effects on final canola plant densities at Indian Head, Saskatchewan. Columns within a year denoted by the same letter do not significantly differ (Tukey's, P ≤ 0.05). Error bars are the standard error of the treatment mean (S.E.M.).

Treatment Effects on Weed Populations

We were particularly interested in the potential impacts that a fall rye cover crop might have on weed population densities in the subsequent canola. The values presented were observed in early to mid-June, just prior to the in-crop herbicide application. Again, all plots received both a fall (prior to cover crop emergence) and spring (prior to seeding), burn-off with 894 g glyphosate/ha. While we did not attempt to do counts for individual species, we did separate broadleaf versus grassy weeds. Broadleaf weed populations were always low and affected by year ($P = 0.002$), but no other treatments or interactions ($P = 0.098$-0.500; Table 5). The year effect was such that broadleaf weed populations were highest in 2021 (5 weeds/m^2), followed by 2023 (1 weed/m^2), and then 2022 (0.1 weeds/m^2) which was, again, extremely low in all cases (Table 6). With such low populations, cover crop effects on broadleaf weed populations would be difficult to detect and, even if they had occurred, of little practical importance.

Grassy weed populations were consistently higher and, in addition to year ($P < 0.001$), the effect of CC was also significant ($P = 0.017$). The observed CC effect was such that there were slightly more grassy weeds observed with the cover crop (13.6 plants/m^2) as opposed to without (17.4 weeds/m^2). This effect was reasonably consistent in both 2021 and 2023; however, in 2022 there were essentially no grassy weeds observed for either treatment (Fig. 4; Table 13). We speculated that the higher grassy populations were late emerging rye plants as we did not attempt to differentiate them from the volunteer canaryseed or wild oats which were the dominant weed species. In any case, there was no evidence that the cover crop was suppressing weeds or would reduce the need for in-crop herbicide applications.

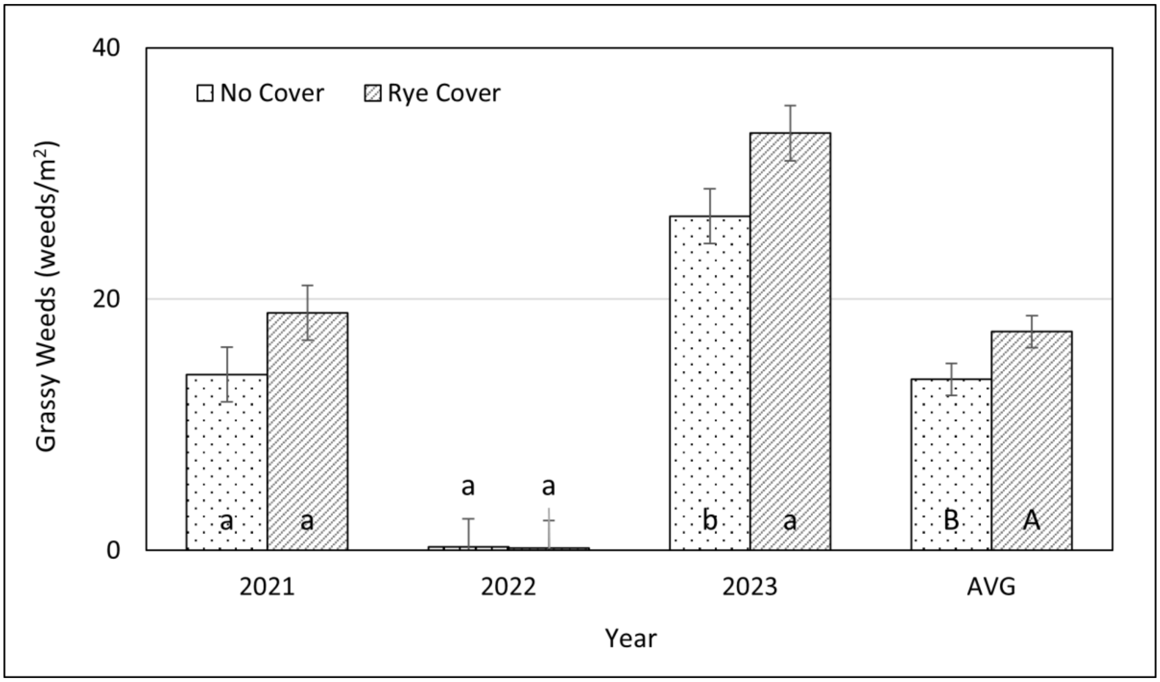

Figure 4. Significant year (Yr) × Cover Crop (CC) and overall CC effects on final canola plant densities at Indian Head, Saskatchewan. Columns within a year denoted by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment Effects on Canola Yield and Seed Quality

Canola yields varied across years (*P* = 0.001) and were affected by N rate (NR) with a significant Yr × NR interaction; thus, indicating that the response to NR differed across years (Table 5). The overall cover crop (CC) effect was marginally significant (*P* = 0.093); however, no interactions associated with CC were (*P* = 0.846-0.999). With the higher precipitation, average canola yields in 2022 (2695 kg/ha) were significantly higher than 2021 or 2023, which were statistically no different from each other (2187-2391 kg/ha). For all individual years and, when averaged across years, seed yields increased quadratically with increasing N rate (Table 15, Fig. 5). The quadratic nature of the response was due to there being diminishing yield increases with additional N inputs at the higher end of the range evaluated; however, the trend was always for yields to continue increasing right up to the highest N rate. The Yr x NR interaction was due to yields showing signs of levelling off at lower rates in 2022 (~105 kg N/ha) compared to either 2021 or 2023 (~140 kg N/ha). Averaged across years, seed yields at 140-175 kg N/ha did not significantly differ; however, they were numerically highest at the highest N level. The lack of CC × NR (*P* = 0.846) and Yr × CC × NR (*P* = 0.999) interactions suggested that the yield responses to NR were similar regardless of CC treatment in each of the three years individually and averaged across years. The overall CC effect on canola seed yield was only marginally significant (*P* = 0.093) but showed a trend for slightly lower seed yields with a cover crop (2399 kg/ha) compared to without (2451 kg/ha), when averaged across years and N rates (Table 15).

Like yield, canola seed oil concentrations were affected by year (*P* < 0.001) and NR (*P* < 0.001) with a Yr × NR interaction (*P* < 0.001) suggesting that the N rate response differed from year-to-year (Table 5). Neither CC effects (*P* = 0.405) nor those of any of the interactions associated with it were significant (*P* = 0.827-0.903). Overall seed oil concentrations differed each year (Table 6) and were highest in 2023 (45.9%), followed by 2021 (43.6%), then 2022 (42.3%). In 2021 and 2023, the seed oil response to N rate was quadratic with the rate of reduction increasing with increasing N rates (Table 17; Fig. 6). This was the inverse of the yield response where yields increased most rapidly with additional inputs of N fertilizer at the lower end of the range evaluated. In 2022, where yields were maximized at lower N rates, the seed oil response to N rate was more linear, falling at a consistent rate as N was increased across the full range for which it was evaluated. Averaged across the three years, canola seed oil concentrations fell quadratically (*P* < 0.001) from 45.3% at 25 kg N/ha to 42.0% at 175 kg N/ha, with similar values for N rates ranging from 25-60 kg N/ha (45.1-45.3%). With no overall CC effect or Yr × CC interaction, canola seed oil concentrations were within 0.1% both when averaged over the three years and for each year individually. The lack of CC × NR (P = 0.903) or Yr × CC × NR (P = 0.827) suggests that N rate responses were similar (Table 18).

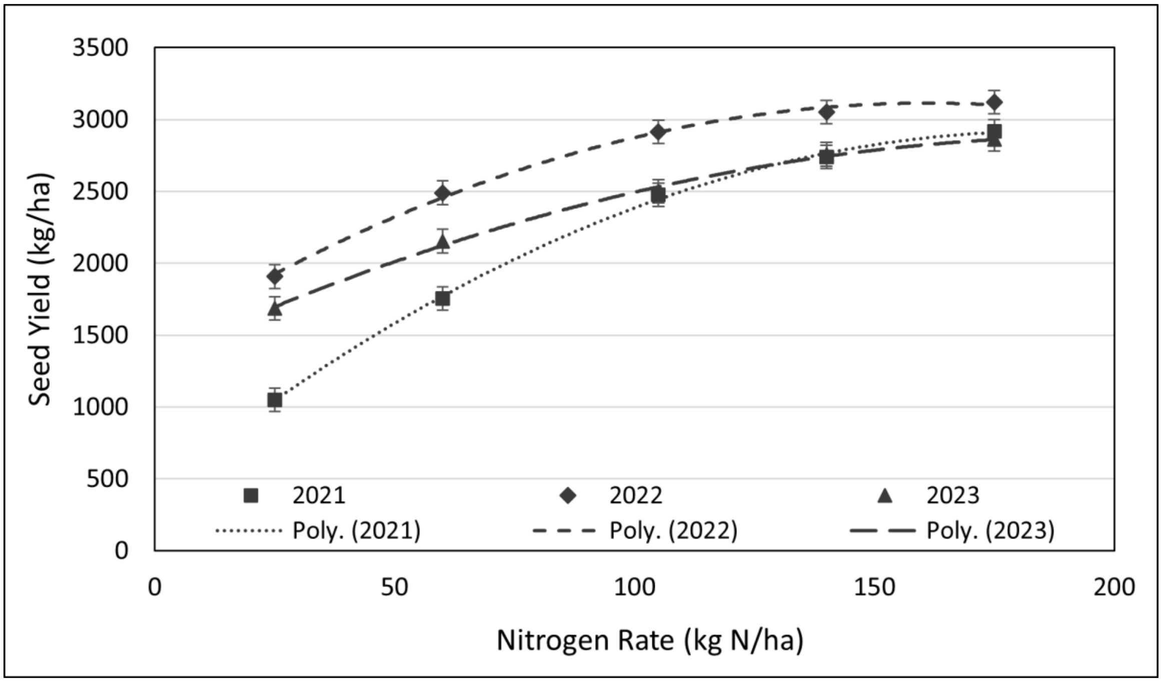

Figure 5. Significant year (Yr) × N rate (NR) effects on canola seed yield at Indian Head, Saskatchewan. For all years, yields increased quadratically with N rate (P < 0.001).

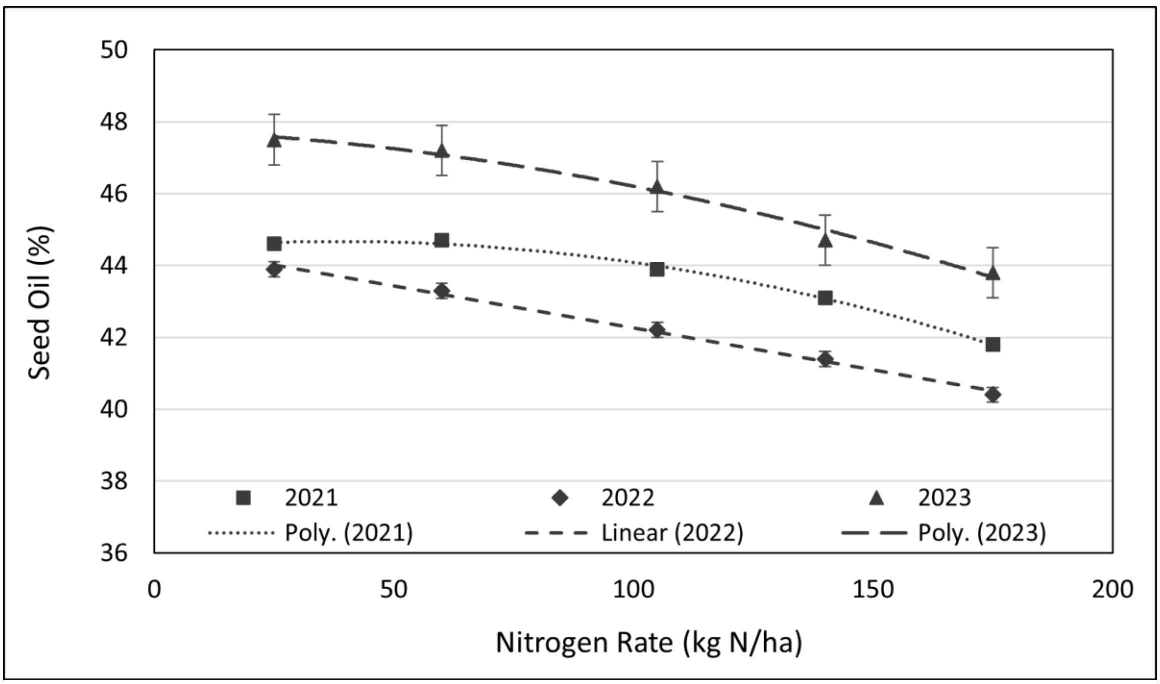

Figure 6. Significant year (Yr) x N rate (NR) effects on canola seed oil concentrations at Indian Head, Saskatchewan. Seed oil content decreased quadratically with N rate in 2021 and 2023 (P < 0.001) and linearly in 2022 (P < 0.001).

Unlike oil concentrations, canola seed protein concentrations were statistically similar across years (P = 0.498), ranging from 18.5-19.1% (Table 6). Looking deeper into the overall tests of fixed effects (Table 5), seed protein was affected by NR (P < 0.001) with a Yr × NR interaction (P < 0.001), but not by cover crop (CC; P = 0.409) nor any interactions associated with CC (P = 0.214-0.789). Essentially the inverse of what was observed for seed oil, protein concentrations increased quadratically in 2021 and 2023 ($P < 0.001$) but more linearly ($P < 0.001$) in 2022; hence, the significant Yr × NR interaction (Fig. 7, Table 19). Averaged across years, seed protein increased quadratically from 17.2% at 25 kg N/ha to 20.9% at 175 kg N/ha. Focussing on the three-year averages, the quadratic nature of the response showed similar seed protein concentrations for N rates of 25-60 kg N/ha (17.2-17.3%) but increasing rates of protein accumulation with additional N at the higher end of the range. Mean protein concentrations for the cover crop treatments were essentially identical (18.8%) when averaged across years and N rates and the difference ranged from -0.1-0.2% for individual years. The lack of CC × NR ($P = 0.789$) or Yr × CC × NR effects indicate that the NR effect on seed protein was consistent, regardless of cover crop treatment.

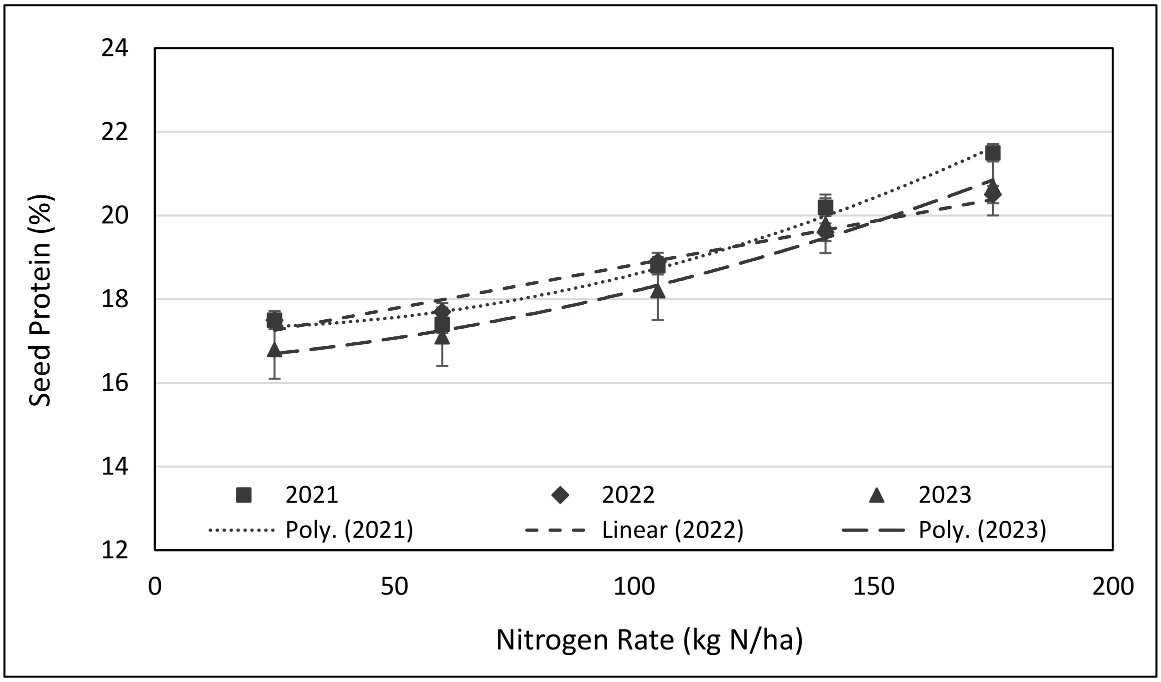

Figure 7. Significant year (Yr) x N rate (NR) effects on canola seed protein concentrations at Indian Head, Saskatchewan. Seed protein content increased quadratically with N rate in 2021 and 2023 (*P* < 0.001) and linearly in 2022 (*P* < 0.001).

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. Detailed results from the first year of the project were also presented during the IHARF Soil and Crop Management Seminar which was held virtually on February 2, 2022, and attended live by approximately 140 individuals and received approximately 75 post-webinar views. 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. In 2023, Chris Holzapfel provided a detailed discussion of results to date during the Indian Head Crop Management Field Day, attended by approximately 160 people. Thom Weir showed the plots during a Canola Council of Canada 4R Field Day on August 15; however, this event was poorly attended due to harvest being well underway in the area. A few highlights were shared by Chris Holzapfel during a canola establishment presentation at the 2023 Manitoba Agronomist's Conference, held December 13-14 in Winnipeg, MB and attended by 428 people (in-person and online). Reports from all years, including this cumulative, final report, have been and will continue to be available online (www.iharf.ca). Project results and highlights will continue to be presented where appropriate through oral presentations and other extension materials as opportunities to do so arise.

Conclusions and Recommendations

Describe what was learned from the demonstration. Highlight any significant conclusions and provide recommendations for the application and adoption of the project results. Be sure that you have presented the relevant data to support your conclusions. Identify any further research, development and communication needs, if applicable.

With dry weather and/or delayed harvest leading to poor establishment in two of this project's three growing seasons, the conditions encountered were not particularly favourable for cover cropping. 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. In one of three seasons (2022), cover crop establishment was quite successful with the rye reaching the stem elongation stage prior to termination in late May. When successful, the cover crop was seeded early in the third week of September, moisture was sufficient for fall establishment, and seeding the subsequent crop was delayed until late May by unusually wet spring weather.

While this data could not be statistically analyzed, cover crops did not appear to have any consistent or agronomically important effects on residual soil NO_3-N. Any significant effects on canola emergence or establishment were negative, with the sole response being slightly lower final plant populations in one of the three seasons. There were no benefits with respect to weed densities whereby the only observed effects were higher overall grassy weed populations with the fall rye cover crop. This could likely be attributed to late emerging rye plants; however, we did not attempt to identify and differentiate between the specific species counted. Canola seed yields, oil, and protein concentrations were all affected by N rate both for individual years and when averaged across years; however, no significant cover crop effects, whether beneficial or harmful, were ever detected for these variables. There was no evidence of cover crop affecting canola response to N fertilizer rate; however, our results may have differed if establishment of the fall rye had been more successful.

Overall, any negative agronomic effects of fall rye cover cropping on the subsequent canola were small and did not affect yield potential or response to N fertilizer. That said, there were never any positive effects, and this practice would undoubtedly have increased production costs and labour requirements. This, along with the challenges in establishing the cover crop with enough success that it was likely to have any effect on soil quality and/or conservation, suggests that growers should be selective with respect to where and when they choose to integrate cover crops into their rotations. With frequently dry fall/early-spring weather, narrow windows for fall seeding, and short growing seasons, there are likely to be many years during which establishing cover crops and realizing benefits under continuous cropping, no-till management in Saskatchewan will prove challenging. That said, results may differ under wetter overall conditions and when harvest/cover crop seeding can be completed earlier in the fall. Furthermore, other crop types or methods/timing of cover crop establishment may result in more successful establishment and greater potential for realising tangible benefits. It is broadly recommended to keep an open mind with respect to cover cropping and, if interested, seek out the environmental conditions and establishment practices where they are most likely to be successfully established and beneficial to either the subsequent crop or longer-term soil quality. Growers should not necessarily force cover crops into their crop rotations without clear objectives in mind and under conditions where the probability of success is not sufficiently high.

Sustainable Canadian Agricultural Partnership (Sustainable CAP) Performance Indicators

a) List of performance indicators

Sustainable CAP Indicator	Total Number
Scientific publications from this project (List the publications under section b)	
• Published	0
• Accepted for publication	0
HQPs trained during this project	
• Master's students	0
• PhD students	0
• Post docs	0
Knowledge transfer products developed based on this project (presentations, brochures, factsheets, flyers, guides, extension articles, podcasts, videos). List the knowledge transfer products under section (c)	6 (and counting)

[1] Please only include the number of unique knowledge transfer products.

b) List of scientific journal articles published/accepted for publication from this project.

Title	Author(s)	Journal	Date Published or Accepted for Publication	Link (if available)
n/a	n/a	n/a	n/a	n/a

c) List of knowledge transfer products/activities developed from this project.

Knowledge Transfer Product or Activity	Event/Location Where Knowledge Transfer Was Conducted	Estimated Number of Producers Participated In Knowledge Transfer	Link (if available)
C. Holzapfel (IHARF) Plot Tour	Crop Mgt Field Day, Indian Head (Jul-20-2021)	70	https://iharf.ca/indian-head-crop-management-field-day/
C. Holzapfel (IHARF) Presentation	IHARF Soil and Crop Mgt Seminar & AGM, virtual (Feb-2-2022)	215	https://iharf.ca/iharf-soil-and-crop-management-seminar-agm/
Year 1 Interim Report – Online	IHARF Website	unknown	https://iharf.ca/full-reports/
Year 2 Interim Report – Online	IHARF Website	unknown	https://iharf.ca/full-reports/
C. Holzapfel (IHARF) Plot Tour	Crop Mgt Field Day, Indian Head (Jul-18-2023)	160	https://iharf.ca/indian-head-crop-management-field-day/
T. Weir and W. Ward (CCC) Plot Tour	CCC-IHARF SK 4R Field Day, Indian Head (Aug-15, 2023)	2	https://www.canolacouncil.org/event/saskatchewan-4r-field-day/
C. Holzapfel (IHARF) Presentation	2023 MB Agronomist Conf. Winnipeg/Virtual (Dec-14 2023)	428	https://umanitoba.ca/agricultural-food-sciences/school-agriculture /school-manitoba-agronomists-conference
Final Cumulative Report – Online	IHARF Website	unknown	https://iharf.ca/full-reports/

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Appendices

Identify any changes expected to industry contributions, in-kind support, collaborations or other resources.

Table 3. Selected agronomic information and dates of operations for canola cover crop and nitrogen response demonstration at Indian Head in 2021-23.

Factor / Operation	2020-21	2021-22	2022-23
Previous Crop	Canaryseed	Oat	Canaryseed
Cover Crop Seeding Date	Sep-19-2020	Sep-15-2021	Oct-7-2022
Cover Crop Seed Rate	250 seeds/m^2 (98 kg/ha)	300 seeds/m^2 (118 kg/ha)	300 seeds/m^2 (120 kg/ha)
Soil Sampling Date	May-13-2021	May 25-2022	May-18-2023
Pre-emergent Herbicide	894 g glyphosate/ha (May-13-2021)	894 g glyphosate/ha (May-26-2022)	894 g glyphosate/ha (May-20-2023)
Canola Seeding Date	May-14-2021	May-31-2022	May-21-2023
Canola Seed Rate	105 seeds/m^2 (5.3 kg/ha)	105 seeds/m^2 (4.8 kg/ha)	105 seeds/m^2 (5.0 kg/ha)
kg P_2O_5-K_2O-S ha^{-1}	36-18-18	36-18-18	36-18-18
Spring Plant Density	Jun-18-2021	Jun-27-2022	Jun-13-2023
Weed Counts	Jun-16-2021	Jun-27-2022	Jun-9-2023
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)	500 g glufosinate-ammonium/ha + 30 g clethodim/ha (Jun-9-2023)
Foliar Fungicide	242 g boscalid/ha + 86 g pyraclostrobin/ha (Jul-2-2021)	242 g boscalid/ha (Jul-18-2022)	173 g boscalid/ha + 104 g prothioconazole/ha (Jul-7-2023)
Foliar Insecticide	872 g malathion/ha (Jul-27-2021)	7.4g deltamethrin/ha (Jun-28-2022)	n/a
Pre-harvest herbicide	894 g glyphosate/ha (Aug-15-2021)	894 g glyphosate/ha (Sep-10-2022)	894 g glyphosate/ha (Aug-28-2023)
Harvest date	Sep-2-2021	Sep-26-2022	Sep-7-2023
Fall Plant Density	Sep-7-2021	Oct-5-2022	Sep-11-2023

Table 4. Plant Root Simulator (PRS) soil test results (Western Ag Laboratories) from Indian Head in 2021-23. 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
2023 – No Cover	7.9	28	42	82	25
2023 – Rye Cover	7.8	19	52	126	23

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 5. Tests of fixed effects for year (Yr), cover crop treatment (CC), nitrogen rate (NR), and all possible interactions for selected canola response variables at five Saskatchewan locations in 2023. Data were analysed using the Generalized Linear Mixed Model procedure of SAS. P-values less than 0.05 are considered significant while values below 0.1 may also be acknowledged.

Effect	Spring Plant Density	Fall Plant Density	Broadleaf Weeds	Grassy Weeds	Seed Yield	Seed Oil	Seed Protein
	------- Pr > F (p-value) -------						
Year (Yr)	<0.001	<0.001	0.002	<0.001	0.001	0.001	0.498
Cover Crop (CC)	0.111	0.005	0.500	0.017	0.093	0.405	0.409
Yr × CC	0.743	<0.001	0.202	0.196	0.593	0.261	0.214
N Rate (NR)	0.465	0.494	0.147	0.992	<0.001	<0.001	<0.001
Yr × NR	0.011	0.023	0.278	0.974	<0.001	<0.001	<0.003
CC × NR	0.448	0.857	0.136	0.899	0.846	0.903	0.789
Yr × CC × NR	0.190	0.727	0.098	0.846	0.999	0.827	0.389

Table 6. Overall year (Yr) effects on selected canola response variables. Values in parentheses are the standard error of the treatment means (S.E.M.) and means within a row followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Response Variable	2021	2022	2023
Spring Emergence (plants/m^2)	73.3 B (1.17)	82.9 B (1.17)	104.8 A (1.17)
Broadleaf Weeds (weeds/m^2)	5.0 A (1.04)	0.1 C (0.2)	1.0 B (0.2)
Grassy Weeds (weeds/m^2)	16.4 B (1.7)	0.2 C (1.7)	29.9 A (1.7)
Final Plant Density (plants/m^2)	70.8 B (1.43)	62.9 C (1.43)	105.3 A (1.43)
Seed Yield (kg/ha)	2187 B (63.0)	2696 A (63.0)	2391 B (63.0)
Seed Oil (%)	43.6 B (0.09)	42.3 C (0.18)	45.9 A (0.69)
Seed Protein (%)	19.1 A (0.16)	18.8 A (0.17)	18.5 A (0.17)

Table 7. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on spring canola emergence at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, $P \leq 0.05$).

Main Effect	2021	2022	2023	AVG
Cover Crop	Spring Emergence (plants/m^2)			
None	75.0 a	83.3 a	83.3 a	88.1 A
Fall Rye	71.6 a	82.4 a	82.4 a	85.9 A
S.E.M.	1.65	1.65	1.65	0.95
Pr > F (p-value)	0.150	0.716	0.333	0.111
Nitrogen Rate				
25 kg N/ha	75.1 a	89.2 a	100.7 a	88.3 A
60 kg N/ha	72.0 a	85.0 ab	107.9 a	88.3 A
105 kg N/ha	68.2 a	83.6 ab	102.8 a	84.9 A
140 kg N/ha	73.8 a	78.3 b	107.6 a	86.6 A
175 kg N/ha	77.2 a	78.2 b	105.3 a	86.9 A
S.E.M.	2.61	2.61	2.61	1.50
Pr > F (p-value)	0.153	0.017	0.241	0.465
Orthogonal Contrast	Pr > *F* (p-values)			
NR - linear	0.518	<0.001	0.304	0.306
NR - quadratic	0.021	0.728	0.395	0.288

Table 8. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on spring canola emergence at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, $P \leq 0.05$).

Treatment	2021	2022	2023	AVG
CC × NR	Spring Emergence (plants/m^2)			
None – 25 N	77 a	96 a	103 a	92 A
None – 60 N	72 a	84 ab	108 a	88 A
None – 105 N	72 a	82 ab	103 a	86 A
None – 140 N	73 a	81 ab	108 a	87 A
None – 175 N	81 a	74 b	108 a	87 A
Rye – 25 N	73 a	82 ab	99 a	85 A
Rye – 60 N	72 a	86 ab	108 a	88 A
Rye – 105 N	64 a	85 ab	103 a	84 A
Rye – 140 N	75 a	76 b	107 a	86 A
Rye – 175 N	74 a	83 ab	103 a	87 A
S.E.M.	3.7	3.7	3.7	2.13
Pr > F (p-value)	0.246	0.007	0.620	0.448

Table 9. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on final canola plant density at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Main Effect	2021	2022	2023	AVG
Cover Crop	Final Plant Density (plants/m^2)			
None	76.5 a	64.1 a	104.2 a	81.6 A
Fall Rye	65.1 b	61.6 a	106.3 a	77.7 B
S.E.M.	1.85	1.85	1.85	1.07
Pr > F (p-value)	<0.001	0.296	0.354	0.005
Nitrogen Rate				
25 kg N/ha	67.0 a	68.2 a	100.9 a	78.7 A
60 kg N/ha	71.0 a	66.0 a	106.9 a	81.3 A
105 kg N/ha	70.0 a	62.3 a	110.0 a	80.8 A
140 kg N/ha	72.8 a	58.8 a	106.6 a	79.4 A
175 kg N/ha	73.2 a	59.1 a	101.8 a	78.0 A
S.E.M.	2.74	2.74	2.74	1.58
Pr > F (p-value)	0.453	0.045	0.084	0.494
Orthogonal Contrast	Pr > *F* (p-values)			
NR - linear	0.092	0.003	0.793	0.512
NR - quadratic	0.758	0.662	0.005	0.115

Table 10. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on final canola plant populations at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Treatment	2021	2022	2023	AVG
CC × NR	Final Plant Density (plants/m^2)			
None – 25 N	73 ab	71 a	100 a	81.3 A
None – 60 N	78 a	66 a	106 a	83.1 A
None – 105 N	72 ab	65 a	107 a	81.4 A
None – 140 N	79 a	61 a	107 a	82.2 A
None – 175 N	81 a	58 a	100 a	79.9 A
Rye – 25 N	61 b	66 a	102 a	76.1 A
Rye – 60 N	65 ab	66 a	108 a	79.6 A
Rye – 105 N	69 ab	59 a	113 a	80.2 A
Rye – 140 N	67 ab	57 a	106 a	76.6 A
Rye – 175 N	65 ab	60 a	103 a	76.1 A
S.E.M.	3.8	3.8	3.8	2.19
Pr > F (p-value)	0.001	0.170	0.335	0.857

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Table 11. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on broadleaf weed populations at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Main Effect	2021	2022	2023	AVG
Cover Crop	Broadleaf Weeds (weeds/m^2)			
None	5.4 a	0.2 a	0.9 a	2.1 A
Fall Rye	4.7 a	0.1 a	1.2 a	2.0 A
S.E.M.	1.06	0.29	0.30	0.38
Pr > F (p-value)	0.083	0.844	0.438	0.500
Nitrogen Rate				
25 kg N/ha	6.0 a	0.2 a	1.7 a	2.6 A
60 kg N/ha	4.8 ab	0.2 a	1.1 a	2.0 A
105 kg N/ha	5.0 ab	0.2 a	0.3 a	1.8 A
140 kg N/ha	3.9 b	0.0 a	1.3 a	1.7 A
175 kg N/ha	5.4 ab	0.0 a	0.8 a	2.1 A
S.E.M.	1.11	0.45	0.46	0.43
Pr > F (p-value)	0.028	0.994	0.263	0.147
Orthogonal Contrast	Pr > *F* (p-values)			
NR - linear	0.140	0.679	0.256	0.082
NR - quadratic	0.024	0.895	0.239	0.056

Table 12. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on broadleaf weed densities at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Treatment	2021	2022	2023	AVG
CC × NR	Broadleaf Weeds (weeds/m^2)			
None – 25 N	6.9 a	0.2 a	0.8 a	2.6 A
None – 60 N	5.9 ab	0.4 a	1.2 a	2.5 A
None – 105 N	3.7 b	0.2 a	0.2 a	1.4 A
None – 140 N	4.3 ab	0.0 a	1.2 a	1.8 A
None – 175 N	6.1 ab	0.0 a	1.0 a	2.4 A
Rye – 25 N	5.1 ab	0.2 a	2.6 a	2.6 A
Rye – 60 N	3.7 ab	0.0 a	1.0 a	1.6 A
Rye – 105 N	6.3 ab	0.2 a	0.4 a	2.3 A
Rye – 140 N	3.5 b	0.0 a	1.4 a	1.6 A
Rye – 175 N	4.7 ab	0.0 a	0.6 a	1.8 A
S.E.M.	1.20	0.64	0.65	0.50
Pr > F (p-value)	<0.001	1.000	0.400	0.136

Table 13. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on grassy weed populations at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Main Effect	2021	2022	2023	AVG
Cover Crop	Grassy Weeds (weeds/m^2)			
None	14.0 a	0.3 a	26.6 b	13.6 B
Fall Rye	18.9 a	0.2 a	33.2 a	17.4 A
S.E.M.	2.19	2.19	2.19	1.26
Pr > F (p-value)	0.075	0.976	0.016	0.017
Nitrogen Rate				
25 kg N/ha	17.1 a	0.3 a	27.4 a	14.9 A
60 kg N/ha	14.8 a	0.2 a	30.8 a	15.2 A
105 kg N/ha	17.6 a	0.1 a	29.5 a	15.7 A
140 kg N/ha	17.4 a	0.4 a	29.2 a	15.7 A
175 kg N/ha	15.3 a	0.2 a	32.6 a	16.1 A
S.E.M.	3.20	3.20	3.20	1.85
Pr > F (p-value)	0.945	1.000	0.798	0.974
Orthogonal Contrast	Pr > *F* (p-values)			
NR - linear	0.955	1.000	0.369	0.627
NR - quadratic	0.818	0.985	0.902	0.960

Table 14. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on grassy weed densities at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Treatment	2021	2022	2023	AVG
CC × NR	Grassy Weeds (weeds/m^2)			
None – 25 N	14.6 a	0.2 a	27.9 a	14.2 A
None – 60 N	13.2 a	0.4 a	24.6 a	12.7 A
None – 105 N	15.7 a	0.0 a	26.0 a	13.9 A
None – 140 N	17.5 a	0.4 a	24.8 a	14.2 A
None – 175 N	9.1 a	0.4 a	29.7 a	13.1 A
Rye – 25 N	19.7 a	0.4 a	26.9 a	15.7 A
Rye – 60 N	16.3 a	0.0 a	37.0 a	17.6 A
Rye – 105 N	19.5 a	0.2 a	33.0 a	17.6 A
Rye – 140 N	17.3 a	0.4 a	33.6 a	14.2 A
Rye – 175 N	21.6 a	0.0 a	35.6 a	12.7 A
S.E.M.	4.40	4.40	4.40	2.54
Pr > F (p-value)	0.691	1.000	0.337	0.899

Table 15. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on canola seed yield at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Main Effect	2021	2022	2023	AVG
Cover Crop	------------------------- Seed Yield (kg/ha) -------------------------			
None	2218 a	2738 a	2396 a	2451 A
Fall Rye	2157 a	2654 a	2386 a	2399 A
S.E.M.	68.2	68.2	68.2	39.4
Pr > F (p-value)	0.248	0.114	0.856	0.093
Nitrogen Rate				
25 kg N/ha	1050 d	1907 c	1685 d	1547 D
60 kg N/ha	1755 c	2490 b	2153 c	2132 C
105 kg N/ha	2476 b	2913 a	2501 b	2630 B
140 kg N/ha	2739 a	3051 a	2757 a	2849 A
175 kg N/ha	2917 a	3120 a	2860 a	2966 A
S.E.M.	82.0	82.0	82.0	1547
Pr > F (p-value)	<0.001	<0.001	<0.001	47.3
Orthogonal Contrast	------------------------- Pr > *F* (p-values) -------------------------			
NR - linear	<0.001	<0.001	<0.001	<0.001
NR - quadratic	<0.001	<0.001	<0.001	<0.001

Table 16. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on canola seed yield at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Treatment	2021	2022	2023	AVG
CC × NR	------------------------- Seed Yield (kg/ha) -------------------------			
None – 25 N	1096 e	1981 c	1705 d	1594 E
None – 60 N	1756 d	2501 b	2161 c	2139 D
None – 105 N	2529 bc	2980 a	2522 abc	2677 BC
None – 140 N	2779 abc	3053 a	2737 ab	2856 AB
None – 175 N	2930 a	3176 a	2854 ab	2986 A
Rye – 25 N	1004 e	1834 c	1664 d	1501 E
Rye – 60 N	1754 d	2478 b	2144 c	2126 D
Rye – 105 N	2423 c	2845 ab	2481 bc	2583 C
Rye – 140 N	2698 abc	3048 a	2777 ab	2841 AB
Rye – 175 N	2905 ab	3065 a	2866 a	2945 A
S.E.M.	100.8	100.8	100.8	58.2
Pr > F (p-value)	<0.001	<0.001	<0.001	0.846

Table 17. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on canola seed oil concentration at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Main Effect	2021	2022	2023	AVG
Cover Crop	-------------------------	Seed Oil Concentration (%)	-------------------------	
None	43.7 a	42.3 a	45.8 a	44.0 A
Fall Rye	43.6 a	42.2 a	45.9 a	43.9 A
S.E.M.	0.11	0.19	0.69	0.24
Pr > F (p-value)	0.296	0.212	0.392	0.405
Nitrogen Rate				
25 kg N/ha	44.6 a	43.9 a	47.5 a	45.3 A
60 kg N/ha	44.7 a	43.3 b	47.2 a	45.1 A
105 kg N/ha	43.9 b	42.2 c	46.2 b	44.1 B
140 kg N/ha	43.1 c	41.4 d	44.7 c	43.1 C
175 kg N/ha	41.8 d	40.4 e	43.8 d	42.0 D
S.E.M.	0.15	0.21	0.70	0.25
Pr > F (p-value)	<0.001	<0.001	<0.001	<0.001
Orthogonal Contrast	-------------------------	Pr > *F* (p-values)	-------------------------	
NR - linear	<0.001	<0.001	<0.001	<0.001
NR - quadratic	<0.001	0.221	<0.001	<0.001

Table 18. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on canola seed oil concentration at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Treatment	2021	2022	2023	AVG
CC × NR	-------------------------	Seed Oil Concentration (%)	-------------------------	
None – 25 N	44.7 a	44.1 a	47.5 a	45.4 A
None – 60 N	44.7 a	43.5 a	46.9 ab	45.0 A
None – 105 N	43.9 ab	42.3 b	46.3 b	44.1 B
None – 140 N	43.3 bc	41.4 c	44.7 cd	43.1 C
None – 175 N	41.9 d	40.5 d	43.8 e	42.1 D
Rye – 25 N	44.5 a	43.8 a	47.5 a	45.3 A
Rye – 60 N	44.6 a	43.2 a	47.6 a	45.1 A
Rye – 105 N	44.0 ab	42.1 bc	46.2 b	44.1 B
Rye – 140 N	43.0 c	41.4 bc	44.7 c	43.0 C
Rye – 175 N	41.7 d	40.4 d	43.8 de	42.0 D
S.E.M.	0.20	0.25	0.71	0.26
Pr > F (p-value)	<0.001	<0.001	<0.001	0.903

Table 19. Main effect means for cover crop (CC) and nitrogen rate (NR) effects on canola seed protein concentration at Indian Head in 2021, 2022, 2023, and averaged over the three years. Results from the orthogonal contrasts which test whether N rate responses are linear, quadratic (curvilinear), or not significant are also included. Main effect means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Main Effect	2021	2022	2023	AVG
Cover Crop	----------	Seed Protein Concentration (%)	----------	
None	19.0 a	18.8 a	18.6 a	18.8 A
Fall Rye	19.2 a	18.9 a	18.5 a	18.8 A
S.E.M.	0.17	0.18	0.69	0.24
Pr > F (p-value)	0.118	0.461	0.379	0.409
Nitrogen Rate				
25 kg N/ha	17.5 d	17.5 d	16.8 d	17.2 D
60 kg N/ha	17.4 d	17.7 d	17.1 d	17.4 D
105 kg N/ha	18.8 c	18.9 c	18.2 c	18.6 C
140 kg N/ha	20.2 b	19.6 b	19.8 b	19.8 B
175 kg N/ha	21.5 a	20.5 a	20.7 a	20.9 A
S.E.M.	0.21	0.21	0.70	0.25
Pr > F (p-value)	<0.001	<0.001	<0.001	<0.001
Orthogonal Contrast	----------	Pr > *F* (p-values)	----------	
NR - linear	<0.001	<0.001	<0.001	<0.001
NR - quadratic	<0.001	0.065	<0.001	<0.001

Table 20. Individual treatment means for cover crop (CC) and nitrogen rate (NR) effects on canola seed protein concentration at Indian Head in 2021, 2022, 2023, and averaged over the three years. Means within a column followed by the same letter do not significantly differ (Tukey, *P* ≤ 0.05).

Treatment	2021	2022	2023	AVG[Z]
CC × NR	----------	Seed Protein Concentration (%)	----------	
None – 25 N	17.4 d	17.4 d	16.7 d	17.2 D
None – 60 N	17.3 d	17.3 d	17.3 cd	17.3 D
None – 105 N	18.8 c	18.9 bc	18.2 c	18.6 C
None – 140 N	20.0 b	19.7 ab	19.8 b	19.8 B
None – 175 N	21.4 a	20.5 a	20.8 a	20.9 A
Rye – 25 N	17.5 d	17.5 d	16.8 d	17.3 D
Rye – 60 N	17.6 d	18.1 cd	17.0 d	17.6 D
Rye – 105 N	18.8 c	18.9 bc	18.1 c	18.6 C
Rye – 140 N	20.4 b	19.4 b	19.8 b	19.9 B
Rye – 175 N	21.6 a	20.5 a	20.6 ab	20.9 A
S.E.M.	0.26	0.26	0.72	0.268
Pr > F (p-value)	<0.001	<0.001	<0.001	0.789

Expenditure Statement

You must provide an expenditure statement showing how ADOPT funds were used. Expenditures must be reported using the budget categories shown in Appendix B of your contract. We recommend that you report your expenditures using the Excel spreadsheet we have developed for this purpose (ADOPT Expenditure Statement.xls). That spreadsheet is available from the research branch project manager or the evaluation coordinator.

Note that the ADOPT contract requires you to retain all receipts and financial records relating to the project for at least six years after the project is completed.

The expenditure statement was submitted in a separate document and is available upon request.