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:	Lentil response to soil residual nitrogen and rhizobial inoculation
Project Number:	20220365
Producer Group Sponsoring the Project:	Saskatchewan Pulse Crop Development Board
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, R.M. #156 (Indian Head Agricultural Research Foundation); Scott, R.M. #380 (Western Applied Research Corporation); Swift Current, R.M. #137 (Wheatland Conservation Area, Inc.)
Project start date *(month & year):*	10/1/2022
Project end date *(month & year):*	3/31/2024

Project Manager Contact

Full Name:	Chris Holzapfel
Organization:	Indian Head Agricultural Research Foundation
Mailing Address:	PO Box 156, Indian Head, Saskatchewan, S0G 2K0
Phone Number:	1 (306) 695-7761
E-mail:	cholzapfel@iharf.ca

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.

Field trials were initiated at three locations to demonstrate lentil response to high residual soil nitrogen (N) and inoculation. The twelve treatments were a combination of three residual N levels, two inoculant treatments, and two lentil classes. The high residual N levels were established by broadcasting pre-determined rates of urea to initially low N sites the previous fall. Across locations, spring soil tests showed a range of 22-89 kg NO3-N/ha in the residual N treatments. Responses varied across locations. At Indian Head, we saw a small protein advantage with low and a small yield increase with high residual N for small red but not large green lentils. At Scott, residual N levels had no impact on any variables. At Swift Current, despite late-season hail damage, the residual soil N response was positive for both lentil classes with respect to both yield and protein. While no responses to granular inoculant were observed, we still recommend this input due to the importance of biological N fixation in lentil production. While lentils are not an ideal crop to take advantage of high residual soil N, this project suggested that any negative impacts will be minimal and, in

some soils, responses could even be positive.

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 project objective was to demonstrate, across a range of environments, the agronomic response of both small red and large green lentils to rhizobial inoculant and varying soil residual N representing low, elevated, and extreme levels.

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?

In seasons of widespread drought and corresponding low yields, such as was experienced across much of the province during the 2021 growing season, high levels of residual soil nitrogen (N) may remain in the field, potentially available for uptake by the crop grown in the following season. It is not uncommon for soil test measurements after such conditions to report an excess of 80-100 kg/ha of residual N. Economically, it would be most advantageous to align fields with high levels of residual soil N with crops that cannot fix their own N and demand relatively high amounts, such as cereals and oilseeds, in the subsequent season to reduce the requirement for fertilizer derived N. However, for pulse crops that can meet their N requirements through biological N fixation (BNF), there is less of an advantage to planting pulse crops on fields with high levels of soil N. Although lentil does have a relatively high demand for N per unit of production (approximately 3 lb N uptake per bushel) and will preferentially utilize soil or fertilizer N opposed to expending energy and photosynthates required for BNF, there is a concern that too much N supply may have a negative impact on lentil yield, maturity, lodging, and disease. This concern is exacerbated with longer maturity and larger biomass producing cultivars such as those in the large green lentil class. Lentil crops have an indeterminant growth habit and will continue to flower and pod fill simultaneously providing that temperature and moisture remain adequate. Stresses imposed by a lack of moisture or reduced N help these crops to set seed and achieve maturity. Readily available soil N may promote increased biomass production and delay transition from the vegetative to reproductive stages. Increased biomass can be a risk to lentil growers as it may promote crop lodging and hasten canopy closure. Depending on the environmental conditions, these canopy conditions may create a micro-climate favourable for disease development. The perceived risk of growing pulses on fields with high levels of soil residual N may lead growers to temporarily remove pulses from rotation or lead them to alter their rotational sequence in a way that may not be advantageous from a disease or weed management perspective. This project was initiated to provide local growers with a reference for lentil response on varying levels of background soil N to better inform their rotational risk and help identify the best field selection for their lentil crops. The project may also provide insight into how much residual soil N may be too much to risk growing lentil under different environmental conditions and soil types. Furthermore, it was our hope that a fertility trial established in this way and designed to mimic in-field circumstances, might benefit growers by demonstrating the effect of inoculating lentil despite being planted on soil with high residual N.

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.

In the fall of 2022, field trials with lentil were initiated near Indian Head (thin Black soil zone), Scott (dark Brown soil zone), and Swift Current (Brown soil zone). The treatments were a factorial combination of three residual N levels (low, elevated, and extreme), two rhizobial inoculant treatments (none versus label rate of granular inoculant), and two lentil classes (small red versus large green). The residual N treatments were established in the fall. First, a composite soil sample was collected for the entire site to determine the initial levels of residual nitrate (NO3-N) to a depth of 60 cm. Next, untreated urea was broadcast in the elevated and extreme residual N treatments to bring the total N levels (residual soil NO3-N + fertilizer) up to 112 kg N/ha and 225 kg N/ha, respectively. The granular inoculant product was either Nodulator Duo SCG (BASF) at Indian Head and Scott or TagTeam BioniQ at Swift Current. At all sites, the inoculant products were applied in-furrow at the label recommended rates, adjusted for row spacing. At all locations, the small red lentil variety was CDC Impulse CL and the large green variety was CDC Lima CL. The twelve treatments were replicated four times and arranged in a randomized complete block design (RCBD).

Selected agronomic information and dates of operations are provided in Table 6 of the Appendices. At all locations, the lentils were seeded directly into cereal stubble. Plot size varied with location, depending on the specific seeding and spraying equipment. For both varieties, the lentils were seeded at a target rate of 190 viable seeds/m2, adjusted for seed size, damage, and germination. Registered fungicidal seed treatments were used at all sites to reduce the risk of root disease. Aside from (potentially) N, all nutrients were intended to be non-limiting with the specific products and sites varied at the discretion of individual site managers. Weeds, disease, and insects were all intended to be kept non-limiting throughout the season and were managed using registered crop protection products. A preventative foliar fungicide was applied in all cases, regardless of disease pressure and, in all cases, at least one insecticide application was required to manage local grasshopper populations.

Various data were collected prior to seeding, during the growing season, and from the harvested seed samples. To confirm the actual residual nitrate levels achieved using the previously described methods, we collected composite soil samples from within each residual N treatment just prior to seeding. These samples were analyzed specifically for residual nitrate and, except for Swift Current, we sampled to a depth of 60 cm. At Swift Current, the spring soil samples were only for the 0-30 cm depth; therefore, the observed values were multiplied by 1.5 to estimate residual nitrate to 60 cm and be consistent with both the fall composite samples and the other two locations. Emergence was assessed by recording the number of plants in 2 x 1 m sections of crop row, after emergence was complete, and converting the values to plants/m2. To assess the treatment impacts on vegetative growth and total dry matter production, we collected the above-ground biomass from 2 x 1 m sections of crop row either before (Swift Current), at (Indian Head), or slightly after (Scott) physiological maturity. Due to subtle variation in timing of these measurements, they can be used to compare treatment effects within sites, but should not be used to compare the overall productivity from one location to the other. Days from seeding to physiological maturity were recorded with the plots considered mature when the bottom 1/3 of pods had turned yellow or brown and rattled when shaken for most plants. Seed yield was determined from the harvested grain samples with the values adjusted for dockage and to uniform moisture contents of 13% for red or 14% for green lentils. Seed yields are expressed in kg/ha. For Indian Head and Scott, seed protein was determined by IHARF using a FOSS NIR grain analyzer with separate curves for red versus green lentils. Seed protein at Swift Current was determined by WCA using a different NIR analyzer and, therefore, may not be directly comparable to the values for the other two sites. IHARF plans to reanalyze the samples from Swift Current for consistency; however, only the original values could be included in the current report.

Except for spring soil residual nitrate levels, all response data were analyzed using the generalized linear mixed model (GLIMMIX) procedure of SAS with the effects of residual N levels, inoculant, lentil class, and all possible interactions considered fixed and the effects of replicate considered random. Treatment means were separated using Tukey's test; however, letter groupings for the interactions were only presented when they were significant according to the overall tests of fixed effects. All treatment effects and differences between means were considered significant at $P \leq 0.05$; however, p-values in the range of 0.5-1.0 and other meaningful trends may also be discussed. Due to subtle variation in the methods across locations and, more importantly, meaningful differences in the observed crop responses, data will not be combined across locations for statistical analyses nor will the averaged results be presented.

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.

Residual soil nutrients and growing season weather

Soil test results for the fall, whole site composite samples at each location are provided in Table 1. Again, the residual nitrate (NO_3-N) levels measured in these samples were used to determine how much N to apply to establish the residual N treatments. The fall composites were also used to derive other residual nutrient levels and basic physical/chemical soil properties. Broadly, the soils at each site were considered typical for each respective region with Indian Head having a pH of 7.9, 5% soil organic matter, and a C.E.C. of 44.2 meq, indicating a fine, predominantly clay soil texture. At Scott, the soil was more acidic with a pH of 5.8, organic matter was intermediate at 3.5%, and the C.E.C. of 16.1 meq was indicative of a much coarser soil texture compared to Indian Head. Finally, Swift Current had a neutral pH of 6.9, only 2% organic matter, and, at 16.8 meq, a similar C.E.C. as Scott.

Table 1. Selected soil test analyses results for lentil residual N demonstrations conducted at Indian Head, Scott, and Swift Current in 2023. Unless otherwise indicated, all measurements are representative of the 0-15 cm soil profile.

Parameter	IH-23	SC-23	SW-22
	------------------------ Fall Whole Site Composite Samples ------------------------		
pH	7.9	5.8	6.9
Organic Matter (%)	5.0	3.5	2.0
CEC (meq)	44.2	16.1	16.8
NO_3-N (kg/ha) ^{Z}	9	29	22
Olsen-P (ppm)	5	11	2
K (ppm)	528	266	135
kg S/ha (kg/ha) ^{Z}	56	215	40
	-------------- Spring Treatment Specific Residual NO_3-N Samples ---------------		
Low: NO_3-N (kg/ha) ^{Z}	11	40	15 ^{Y}
Elevated: NO_3-N (kg/ha) ^{Z}	71	80	49 ^{Y}
Extreme: NO_3-N (kg/ha) ^{Z}	90	93	84 ^{Y}

^{Z} Values for residual NO_3-N and S are for the 0-60 cm soil profile

^{Y} At Swift Current, spring NO_3-N was estimated for the 0-60 cm depth by multiplying 0-30 cm values by 1.5

While the fall residual nitrate levels were important for confirming that the sites were suitable for this project and for establishing the residual N treatments, our discussion will focus on the nitrate levels measured in the spring. For the low residual N treatments, where no additional N fertilizer was applied prior to seeding, we measured 11 kg NO_3-N/ha at Indian Head, 40 kg NO_3-N/ha at Scott, and 15 kg NO_3-N/ha at Swift Current. For the elevated residual N treatments, where we broadcast supplemental N fertilizer to bring the total (soil plus fertilizer) up to 112 kg N/ha, we measured 71, 80, and 49 kg NO_3-N/ha at Indian Head, Scott, and Swift Current, respectively. For the extreme residual N treatments, where the total (soil plus fertilizer) amount of N provided in the fall was 225 kg N/ha, the observed levels were 90, 93, and 84 kg NO_3-N. Given that the N fertilizer was broadcast quite late in the fall (October 20, October 19, and November 4 for Indian Head, Scott, and Swift Current, respectively) and the lentils were seeded relatively early in May, it is likely that some of the applied N was still in the NH_4-N form when the spring soil samples were collected and, as such, not measured in the spring soil tests but still available to the lentils over the course of the growing season.

Moving on to the weather, all three locations experienced warmer than normal temperatures, particularly in May and June where the temperatures were 2.9-3.4 °C above the long-term average. July temperatures were either below average (Indian Head) or approximately average (Scott and Swift Current) and August was slightly (0.3-1.1 °C) above-average. The four-month (May-August) means in 2023 were 1.4 °C, 1.9 °C, and 1.6 °C above the long-term average at Indian Head, Scott, and Swift-Current, respectively. For precipitation, Indian Head started with reasonably good soil moisture reserves, thanks to a major snow storm in late April; however, the growing season was dry with only 119 mm of rain from May-August (49% of average). Scott was also dry, but not to the same extent, as this location received above-average precipitation in June and 159 mm of rain in total over the four months (70% of average). Rather unexpectedly, Swift Current received the most rain of the three locations with a total of 179 mm (95% of average); however, there was also a severe hail event at this location (July 22, 2023) which resulted in an estimated 60% yield loss. The storm occurred after the biomass/dry matter collections were completed and it was not expected to have impacted seed protein. While yields were much lower as a result, the damage appeared to be relatively uniform across the site and the yield results are considered to be valid.

Table 2. Mean monthly temperatures and precipitation amounts along with long-term (LT; 1981-2010) averages for the 2023 growing season at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan.

Year	May	June	July	August	May-Aug
	-- Mean Temperature (°C) --				
IH-23	14.0	19.4	16.7	17.7	17.0 (+1.4)
IH-LT	10.8	15.8	18.2	17.4	15.6
SC-23	14.9	17.2	17.1	17.4	16.7 (+1.9)
SC-LT	10.8	14.8	17.3	16.3	14.8
SW-23	14.8	17.7	18.4	18.8	17.4 (+1.6)
SW-LT	11.0	15.7	18.4	17.9	15.8
	-- Total Precipitation (mm) --				
IH-23	12.9	49.6	15.9	40.8	119 (49%)
IH-LT	51.8	77.4	63.8	51.2	244
SC-23	16.6	81.1	29.7	31.7	159 (70%)
SC-LT	38.9	69.7	69.4	48.7	227
SW-23	41.0	32.9	63.3*	42.1	179 (95%)
SW-LT	42.1	66.1	44.0	35.4	188

* Hailstorm at Swift Current on July 22/2023 resulted in an estimated 60% seed yield loss

<u>Crop Responses: Indian Head 2023</u>

Overall tests of fixed effects for all response variables at Indian Head 2023 are presented in Table 7 of the Appendices. Main effect means for this location are provided below in Table 3 while those for the interactions are deferred to

Tables 8 (two-way) and 9 (three-way) of the Appendices. All treatment means are provided, regardless of statistical significance.

The observed plant densities at this site were only affected by lentil class (P = 0.005), with no significant interactions detected. Although the seeding rates for both classes targeted 190 viable seeds/m^2, we saw slightly higher plant populations with the large green (208 plants/m^2) versus small red (191 seeds/m^2) lentil classes. This difference could have been due to either differences in mortality or variance/error between the seed specifications (TKW and germination). It is also possible that plant populations were slightly overestimated as some branching was beginning to occur close to or just below the soil surface at the time the measurements were completed. In any case, overall establishment was excellent and reasonably uniform at this location.

Table 3. Main effect means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Indian Head 2023. For each main effect, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Main Effect	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
Residual N	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low	197.2 A	6721 A	83.1 A	3007 A	23.9 A
Elevated	206.1 A	6646 A	82.4 A	2951 A	23.6 B
Extreme	195.5 A	6777 A	82.9 A	3034 A	23.5 B
S.E.M.	4.91	166.9	0.30	104.2	0.10
Inoculant					
No	199.6 A	6721 A	82.7 A	3013 A	23.6 A
Yes	199.6 A	6708 A	82.9 A	2982 A	23.8 A
S.E.M.	4.01	144.4	0.28	101.7	0.08
Class					
Small Red	191.1 B	6499 B	79.6 B	3196 A	24.7 A
Large Green	208.1 A	6930 A	86.0 A	2799 B	22.7 B
S.E.M.	4.01	144.4	0.28	101.7	0.08

Similar to plant density, lentil biomass yields at Indian Head 2023 were also only affected by class (*P* = 0.015). At 6930 kg dry matter/ha, the green lentils produced slightly, but significantly, more biomass than the red lentils (6430 kg/ha). There were no trends observed for any of the other main effects and no interactions were significant. There was no evidence of excessive vegetative growth or biomass production due to the excessive soil nitrate levels, nor was there any inoculant response.

As expected, the large green lentils took longer to mature at Indian Head (*P* < 0.001), averaging 86 days as opposed to 80 days for the small red lentil class. One concern with the higher residual N was that maturity may be delayed; however, this was not the case with only a 0.2 day difference in maturity between the lowest and highest residual N levels, when averaged across inoculant treatments and lentil classes. Aside from the difference between small red and large green classes, no other factors affected lentil maturity and no interactions were detected.

Despite the dry conditions, seed yields at Indian Head 2023 were quite high, averaging just under 3000 kg/ha across all treatments. Despite the latter producing more biomass, small red lentils yielded significantly (*P* < 0.001) higher than the large green lentils (3196 kg/ha versus 2799 kg/ha). The overall main effect of residual N levels was not significant (*P* = 0.339); however, the interaction between lentil class and residual N was (*P* = 0.049). While the interaction was too subtle for the Tukey's means separations to provide any insights, it appeared to have been due to differing trends whereby yields for the small reds trended higher at high residual N levels but essentially no response with green lentils. Granular inoculant had no impact on lentil yield (*P* = 0.507) and no other interactions were significant for this variable.

Seed protein at Indian Head was affected by residual N (*P* = 0.019) and class (*P* < 0.001); however, there were no interactions detected. The residual N effect, while small, was such that the highest protein levels were observed at the lowest residual N level compared to the elevated or extreme nitrate levels (23.9% versus 23.5-23.6%). Red lentils had a higher protein concentration (24.7%) than green lentils (22.7%). Despite the observed difference in classes, the lack of an N x C interaction (*P* = 0.637) and inspection of the corresponding means (Table 8) confirmed that the residual N effect on seed protein was consistent for both red and green lentil classes.

Crop Responses: Scott 2023

Results for the overall tests of fixed effects at Scott 2023 are provided in Table 10 of the Appendices. Main effect means appear in Table 4 below while means for the two- and three-way interactions are in Tables 11 and 12 of the Appendices, respectively. With an overall average of 189 plants/m^2, establishment was excellent at Scott and the stands were also quite uniform. Only class (*P* < 0.001) affected plant densities with an average of 177 plants/m^2 observed for the small red compared to 201 plants/m^2 for the large green lentils.

Moving on to biomass yields, the overall values were quite high at Scott 2023, averaging 6155 kg/ha across all treatments. There were no treatment effects for biomass were significant at the desired probability level (*P* = 0.059-0.931), indicating that biomass production was generally similar regardless of lentil class, residual N level, or granular inoculant. While the overall tests of fixed effects were marginally significant for both the N x I (*P* = 0.094) and N x C (*P* = 0.059), they appeared to be due more to high variability than any consistent or meaningful trends (Table 11). There was no indication that high residual nitrate levels were contributing to excessive vegetive growth at Scott.

Table 4. Main effect means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Scott 2023. For each main effect, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Main Effect	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
Residual N	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low	187.2 A	6082 A	85.0 A	3579 A	23.6 A
Elevated	189.4 A	6088 A	84.1 A	3650 A	23.6 A
Extreme	190.6 A	6294 A	84.4 A	3692 A	23.7 A
S.E.M.	4.74	231.2	0.40	139.2	0.13
Inoculant					
No	187.1 A	6196 A	84.8 A	3635 A	23.5 A
Yes	191.0 A	6113 A	84.3 A	3646 A	23.7 A
S.E.M.	4.10	214.9	0.34	132.5	0.11
Class					
Small Red	177.1 B	6139 A	84.0 B	3797 A	25.0 A
Large Green	201.1 A	6170 A	85.1 A	3484 B	22.2 B
S.E.M.	4.10	214.9	0.34	132.5	0.11

Similar to Indian Head, lentil maturity at Scott 2023 was affected by lentil class (*P* = 0.008), but no other main effects or interactions (*P* = 0.211-0.860). The class effect was such that, at 85.1 days, large green lentils took slightly longer to maturity than small red lentils which were estimated to have taken 84 days from seeding. This was the expected result and consistent with Indian Head; however, the magnitude of the difference between classes was considerably higher at

Indian Head.

Lentil seed yields at Scott were excellent; however, only the class effect was significant ($P < 0.001$). The response was consistent with Indian Head whereby, at 3797 kg/ha, small red lentils yielded significantly higher than large green lentils (3484 kg/ha). At $P = 0.056$, the residual N by inoculant (N x I) interaction was worth looking more closely at and appeared to be due to there being a trend for slightly higher yields with inoculant at the low and elevated N levels, but lower yields with inoculant at the extreme residual N level (Table 11). There is no reason to believe that inoculant might reduce yields when residual N was too high and, as such, it is probable that this trend was due more to random variability than an actual biological response. At best, it might suggest that the inoculant was less likely to be beneficial at the highest residual N level. Looking ahead to protein, we see that the trends were opposite to yield for inoculant effects at the highest N level; therefore, it may have simply been that unrelated factors were limiting yield in some of the extreme N, inoculated plots.

Lentil seed protein concentrations at Scott were affected by class ($P < 0.001$) with, similar to Indian Head, higher protein observed for small red (25%) as opposed to large green (22.2%) lentils. While not significant at the desired probability level ($P = 0.092$), there was a slight trend for granular inoculant to result in higher protein when averaged across residual N levels and classes (23.7% versus 23.5%). Although this trend makes sense, it was not particularly consistent when we looked at individual treatments. While none of the two-way interactions were significant ($P =$ 0.134-0.662), the three-way interaction for protein at Scott 2023 was ($P = 0.034$). The multiple comparisons tests did not provide any insights into the nature of this interaction and inspection of the means themselves suggested that it might be more random than due to important biological responses. For example, with red lentils, the highest protein was observed with the combination of elevated residual N and inoculant and this was also amongst the highest yielding treatments. For large green lentils, the highest protein was observed with the combination of extreme residual N and granular inoculant; however, this was amongst the lowest yielding individual treatments. There was no consist trend for either inoculant nor residual N levels for protein within individual classes.

Crop Responses: Swift Current 2023

Overall tests of fixed effects for all response variables at Swift Current 2023 are provided in Table 13 of the Appendices. Main effect means appear in Table 5 below and, similar to the previous sites, two- and three-way interactions are deferred to the Appendices and appear in Tables 14 and 15.

Similar to the previous locations, emergence at Swift Current was excellent overall; however, the densities were slightly lower and there was significant variation across treatments which was difficult to explain. This included an overall residual N level effect ($P < 0.001$), a residual N by inoculant (N x I) interaction ($P = 0.011$), and a residual N by class (N x C) interaction ($P = 0.019$). The overall N effect showed higher plant populations at elevated levels (193 plants/m^2) compared with either the low or extreme levels (172-177 plants/m^2); however, the interactions showed that this was not consistent. With the lack of consistency and no reason to expect residual N levels to affect initial emergence, we can only attribute this to random variation and will not discuss it any further. Plant populations for all treatments were more than adequate to optimize yield and the observed variation was not expected to have any agronomic impact.

Aboveground biomass yields were considerably lower at Swift Current than at Indian Head or Scott. While this may have been partly attributable to the generally drier environment, timing of the measurements likely also contributed. The samples at Swift Current were collected earlier than Indian Head or Scott and lentils accumulate biomass rapidly from the beginning of pod fill through physiological maturity. None of the treatments affected above-ground biomass at the desired probability; however, the overall residual N effect was noteworthy ($P = 0.070$). Main effect means for residual N showed a trend for increased biomass production at the elevated and extreme N levels (3166-3248 kg/ha) relative to the low residual N level (2907 kg/ha). Importantly, the biomass samples were collected prior to the July 22 hail at this location and, as such, were not affected by this important event.

Lentil maturity at Swift Current was affected by residual N ($P < 0.001$), class ($P < 0.001$), and the residual N x class (N x C) interaction ($P = 0.039$). The overall N effect was such that we saw a slight delay in maturity as residual N increased, from 79.4 to 80.6 days. The class effects were consistent with the other locations and as expected in that large green lentils took slightly (1 day) longer to mature than small reds (Table 5). The N x C interaction was subtle, with similar trends for both classes, but a slightly more pronounced effect with large green lentils (Table 14). All the observed maturity responses at this location were too small to be of any practical, agronomic importance.

Table 5. Main effect means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Swift Current 2023. For each main effect, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Main Effect	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
Residual N	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low	176.6 B	2907 A	79.4 B	1000 B	24.7 C
Elevated	193.1 A	3248 A	80.0 AB	1171 A	25.3 B
Extreme	171.8 B	3166 A	80.6 A	1178 A	26.1 A
S.E.M.	4.7	120.5	0.18	27.9	0.08
Inoculant					
No	177.8 A	3065 A	80.1 A	1125 A	25.3 A
Yes	183.3 A	3149 A	79.9 A	1108 A	25.5 A
S.E.M.	4.3	104.2	0.15	22.8	0.07
Class					
Small Red	177.6 A	3044 A	79.5 B	1274 A	25.7 A
Large Green	183.4 A	3170 A	80.5 A	959 B	25.0 B
S.E.M.	4.3	104.2	0.15	22.8	0.07

Again, seed yields at Swift Current were greatly reduced by the late July hail storm that occurred; however, the damaged appeared to be uniform across the study area and the observed residual error was low. The overall average seed yield was 1117 kg/ha; however, without the hail would have easily exceeded 2000 kg/ha. Yields were affect by residual N ($P < 0.001$) and class ($P < 0.001$), but not inoculant ($P = 0.586$) nor any interactions ($P = 0.418$-0.925). The residual N effect was such that yields were significantly less at the low residual N level (1000 kg/ha) than at the elevated or extreme levels (1171-1178 kg/ha). While this difference was relatively small in absolute terms, it was an increase of over 17% when expressed as a proportion of the low residual N treatments. The class effect was consistent with the other locations with small red lentils yielding 1274 kg/ha compared to 959 kg/ha for large green lentils. Inspection of the N x I and N x C means confirmed that the observed residual N effects were highly consistent (Table 14), an observation which was consistent with the lack of any significant interactions.

Protein concentrations at Swift Current were affected by residual N ($P < 0.001$) and class ($P < 0.001$) with a significant interaction between these two variables ($P = 0.041$). Focussing on residual N effects, protein concentrations increased from 24.7% in the low N treatment to 25.3% and 26.1% at the elevated and extreme residual N levels, respectively. The class effects were similar to Indian Head and Scott with higher protein concentrations for red (25.7%) versus green (25.0%) lentils; however, the magnitude of the difference between classes was considerably less than for the previously discussed sites. The N x C interaction was subtle but due to there being a smaller increase in protein going from the low to elevated residual N levels with large green lentils when compared to the small reds (Table 14). For the large green class, seed protein concentrations with low and elevated residual N were statistically similar and significantly lower than at the extreme residual N level; however, the trend was for protein to increase with each subsequent increase in residual N. For the small red lentils, each incremental increase in residual N led to a substantial and statistically significant increase in seed protein. It is possible that the discrepancies in differences between classes across the three sites was partly due to equipment disparities, since a different NIR instrument was used at Swift Current than at Indian Head and Scott. While we intend to re-analyse samples from Swift Current for consistency, we do not expect the broader conclusions derived from these results to change.

Extension Activities

This project could not be shown during the Indian Head Crop Management Field Day for logistic reasons, but was shown to numerous farmers, agronomists, and industry representatives during informal tours conducted throughout the season. At Swift Current, the field trials were toured and discussed by Michael Brown of SaskPulse during the Wheatland/AAFC Annual Field Day on July 20, 2023 and was also featured on "Walk the Plots", a CKSW radio show hosted by Glenda Lee Allan, on July 25, 2023. At Scott, the report and a factsheet will be featured on WARC's website and social media outlets, along with the results being presented at Crop Opportunity on March 7th in North Battleford. Chris Holzapfel presented the 2023 results of the project during the SaskPulse Winter Pulse Meeting on January 23 at Swift Current. Presentations from this meeting were also broadcast online and there were nearly 300 combined attendees. Chris Holzapfel also plans to present results from the project at the IHARF Winter Meeting and AGM at Balgonie on February 7 and during the 2024 ICAN Conference on February 8 at Moose Jaw.

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.

Despite the hail at Swift Current and drier than average weather at Indian Head and Scott, the first year of this project provided valuable information regarding the feasibility of growing lentils on high residual N soils. The project also provided a sound proof of concept with respect to the methods used to establish the contrasting residual N levels and test the effects on subsequent crops. Overall, utilizing fall broadcast N treatments to simulate high residual N fields appeared to be a viable practice. All sites showed measurable increases in residual nitrate relative to the naturally occurring levels. The increase going from the initial to elevated levels was much higher than the increase observed going from the elevated to extreme levels. It is possible that more time was needed to convert the urea to nitrate at these extreme levels and that we may have observed greater treatment separation if could have applied the N earlier in the fall and/or we had also measured NH_4-N in the spring soil samples.

Moving on to crop responses, our results suggest that planting lentils into high residual N soils is likely to be a relatively low risk practice. That being said, non-N fixing crops may benefit more the high residual N; however, there are many other good reasons to stick to planned, diverse crop rotations. At Indian Head, we did see a slight protein advantage at the lowest residual N level; however, the effect was small and impacts on yield were minimal. The residual N by class interaction for yield at Indian Head suggested that green lentils might be more sensitive to high residual N than red lentils; however, the effect was small. At Scott, there were no negative or positive effects of residual N for any of the variable measured. At Swift Current, the effects of higher residual N were positive for both seed yield and protein. There were no signs of excessive vegetative growth or delayed maturity associated with the high residual N at Indian Head or Scott and the tendency for higher biomass yields with elevated N at Swift Current was coupled with significantly higher yield and protein. If anything, our results suggest that if residual N levels are extremely low in the coarse textured, low organic matter soils typical of southwest Saskatchewan, starter N would likely be recommended. Past SPG and ADOPT trials at Swift Current have also suggested this; albeit perhaps not quite so clearly. The responses at Swift Current were largely consistent for both small red and large green lentils. While we did not observe any benefits to granular inoculant in this project, we hesitate to suggest that this input is not required. Biological N fixation is simply too critical in lentil production to comfortably recommended excluding this input and native Rhizobium populations may vary across the landscape or from year-to-year. While it makes sense that biological N fixation might play less of a role when residual N levels are extremely high, completely eliminating inoculant could be risky. It is fair to suggest that utilizing higher than label recommended rates would be difficult to justify in fields with a history of pea, lentil, or faba bean production and less expensive, liquid formulations may be sufficient; however, the cost of inoculant is likely quite low compared to the losses that could occur if nodulation and subsequent N fixation in inadequate.

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)

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)
M. Brown (SPG) Presentation	WCA/AAFC Annual Field Day, Swift Current (July 20, 2023)	80 participants	n/a
Walk the Plots	CKSW Radio Show (July 25, 2023)	Not known	n/a
C. Holzapfel (IHARF) Presentation	2024 Winter Pulse Meeting – Swift Current (January 23, 2024)	300	https://saskpulse.com/events/
C. Holzapfel (IHARF) Presentation	2024 IHARF Soil and Crop Management Seminar & AGM (February 7, 2024)	Estimated 200	https://iharf.ca/iharf-soil-and-crop-management-seminar-agm/
C. Holzapfel (IHARF)	2024 ICAN Conference	TBD	https://www.icanhelpyourfarm.com/

Presentation	(February 8, 2024)		
Full Report – Available online	IHARF Website	Not known	https://iharf.ca/full-reports/

Acknowledgements

Include actions taken to acknowledge support by the Ministry of Agriculture, the Canadian Agriculture Partnership (for projects approved between 2017 and 2023) and the Sustainable Canadian Agriculture Partnership (for projects approved between 2023 and 2028).

Financial support was provided under the Sustainable Canadian Agricultural Partnership, as federal-provincial-territorial initiative. Additional financial support was provided by the Saskatchewan Pulse Crop Development Board, who also administered the project in-kind. The inoculant, herbicide, and fungicide products utilized at Indian Head were provided in-kind by BASF. We would also like to acknowledge the Board of Directors from each of the participating organizations in addition to the many technical and professional staff without whom this project could not have been completed. IHARF, WARC, and WCA also have strong working relationships and memorandums of understanding with Agriculture and Agri-Food Canada which should be acknowledged and help to make work like this possible.

Appendices

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

Table 6. Selected agronomic information and dates of operations for the 2023 field trials (Lentil Response to High Levels of Residual N) at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan.

Activity	IH-23	SC-23	SW-22
Previous Crop	Wheat	Wheat	Wheat
Fall Soil Sampling	Oct-7 (2022)	Oct-6 (2022)	Sep-19 (2022)
Fall N Application	Oct-20 (2022)	Oct-19 (2022)	Nov-4 (2022)
Spring Soil Sampling	May-8 (2023)	Apr-28 (2023)	Apr-26
Pre-seed Herbicide	894 g glyphosate/ha (May-11)	894 g glyphosate + 21 g carfentrazon/ha (May-8)	667 g glyphosate/ha (Apr-28)
Seeding Date	May-8	May-9	May-9
Row Spacing	31 cm	25 cm	21 cm
Fertilizer Applied (kg N-P_2O_5-K_2O-S/ha)	8-40-27-9	4-17-0-0	12-56-66-22
In-crop Herbicide 1	15 g imazomox + 15 g imazethapyr + 37 g quizalofop-p-ethyl/ha (Jun-6)	20 g imazomox + 37 g quizalofop-p-ethyl/ha (Jun-2)	20 g imazomox + 171 g sethoxydim/ha (Jun-7)
Foliar Insecticide	7 g deltamethrin/ha (Jun-16) 50 g chlorantraniliprole/ha (Jun-22 & Jul-21)	7 g deltamethrin/ha (Jul-7)	7 g deltamethrin/ha (Jul-7)
Emergence Counts	Jun-5	Jun-15	Jun-5
Foliar Fungicide	80 g fluxapyroxad + 80 g pyraclostrobin/ha (Jun-26)	80 g fluxapyroxad + 80 g pyraclostrobin/ha (Jun-26)	1977 g chlorothalonil/ha
Biomass Collections	Jul-27	Aug-3	Jul-17
Pre-harvest Herbicide / Desiccant	894 g glyphosate/ha (Aug-4) 410 g diquat/ha (Aug-14)	410 g diquat/ha (Aug-4)	410 g diquat/ha (Jul-31)
Harvest	Aug-19	Aug-8	Aug-16

Table 7. Tests of fixed effects for residual nitrogen level (N), inoculant treatment (I), lentil class (C), and all possible interactions for selected response variables at Indian Head in 2023. Data were analysed using the Generalized Linear Mixed Model procedure of SAS.

Effect	Num DF	Den DF	F-Value	Pr > F
		------ Plant Density ------		
Nitrogen (N)	2	33	1.34	0.276
Inoculant (I)	1	33	0.00	0.999
N x I	2	33	0.38	0.687
Class (C)	1	33	8.93	0.005
N x C	2	33	0.11	0.893
I x C	1	33	0.93	0.341
R x N x C	2	33	0.09	0.912
		------ Biomass ------		
Nitrogen (N)	2	33	0.20	0.818
Inoculant (I)	1	33	0.01	0.942
N x I	2	33	0.27	0.763
Class (C)	1	33	6.63	0.015
N x C	2	33	1.02	0.371
I x C	1	33	0.08	0.783
R x N x C	2	33	2.44	0.103
		------ Maturity ------		
Nitrogen (N)	2	33	3.02	0.063
Inoculant (I)	1	33	1.29	0.264
N x I	2	33	1.29	0.288
Class (C)	1	33	840.6	<0.001
N x C	2	33	0.75	0.478
I x C	1	33	0.57	0.454
R x N x C	2	33	0.25	0.779
		------ Seed Yield ------		
Nitrogen (N)	2	33	1.12	0.339
Inoculant (I)	1	33	0.45	0.507
N x I	2	33	0.12	0.885
Class (C)	1	33	74.0	<0.001
N x C	2	33	3.50	0.049
I x C	1	33	1.62	0.212
R x N x C	2	33	0.12	0.890
		------ Seed Protein ------		
Nitrogen (N)	2	33	4.46	0.019
Inoculant (I)	1	33	3.52	0.070
N x I	2	33	0.10	0.903
Class (C)	1	33	284.9	<0.001
N x C	2	33	0.46	0.637
I x C	1	33	0.02	0.886
R x N x C	2	33	1.38	0.267

Table 8. Two-way interaction means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Indian Head 2023. Letter groupings are only provided in cases where the interaction was significant according to the overall tests of fixed effects. In such cases, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Two-Way Interaction	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
N x I	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low-No	195.4	6784	83.1	3007	23.8
Low-Yes	198.9	6658	83.1	3007	24.1
Elevated-No	209.6	6682	82.1	2979	23.5
Elevated-Yes	202.6	6611	82.8	2923	23.7
Extreme-No	193.8	6697	82.9	3052	23.5
Extreme-Yes	197.3	6856	82.9	3016	23.6
S.E.M.	6.94	221.2	0.36	111.6	0.14
N x C					
Low-Red	187.8	6431	80.1	3166 a	24.9
Low-Green	206.5	7010	86.1	2848 b	23.0
Elevated-Red	199.5	6336	79.1	3103 a	24.6
Elevated-Green	212.6	6957	85.8	2800 b	22.5
Extreme-Red	186.0	6730	79.7	3319 a	24.5
Extreme-Green	205.0	6823	86.2	2750 b	22.6
S.E.M.	6.94	221.2	0.36	111.6	0.14
I x C					
No-Red	193.9	6482	79.6	3182	24.5
No-Green	205.3	6960	85.8	2844	22.6
Yes-Red	188.4	6516	79.7	3210	24.8
Yes-Green	210.8	6901	86.2	2755	22.8
S.E.M.	5.67	186.8	0.32	106.8	0.12

Table 9. Three-way interaction means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Indian Head 2023. Letter groupings are only provided in cases where the interaction was significant according to the overall tests of fixed effects. In such cases, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Three-Way Interaction	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
N x I x C	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low-No-Red	189	6219	80.1	3127	24.7
Low-No-Green	202	7348	86.0	2888	22.9
Low-Yes-Red	187	6643	80.0	3206	25.1
Low-Yes-Green	211	6672	86.1	2808	23.1
Elev-No-Red	207	6412	78.8	3117	24.4
Elev-No-Green	212	6952	85.4	2842	22.5
Elev-Yes-Red	192	6260	79.5	3089	24.8
Elev-Yes-Green	213	6962	86.1	2758	22.5
Extr-No-Red	185	6815	79.9	3302	24.5
Extr-No-Green	202	6579	86.0	2802	22.4
Extr-Yes-Red	188	6645	79.5	3335	24.4
Extr-Yes-Green	208	7068	86.4	2698	22.8
S.E.M.	9.8	301.6	0.45	125.1	0.20

Table 10. Tests of fixed effects for residual nitrogen level (N), inoculant treatment (I), lentil class (C), and all possible interactions for selected response variables at Scott in 2023. Data were analysed using the Generalized Linear Mixed Model procedure of SAS.

Effect	Num DF	Den DF	F-Value	Pr > F
------------ Plant Density ------------				
Nitrogen (N)	2	33	0.18	0.838
Inoculant (I)	1	33	0.67	0.420
N x I	2	33	0.80	0.456
Class (C)	1	33	25.24	<0.001
N x C	2	33	0.32	0.726
I x C	1	33	0.48	0.491
R x N x C	2	33	0.80	0.459
------------ Biomass ------------				
Nitrogen (N)	2	33	0.67	0.521
Inoculant (I)	1	33	0.23	0.633
N x I	2	33	2.54	0.094
Class (C)	1	33	0.03	0.860
N x C	2	33	3.09	0.059
I x C	1	33	0.01	0.931
R x N x C	2	33	2.00	0.152
------------ Maturity ------------				
Nitrogen (N)	2	33	1.63	0.211
Inoculant (I)	1	33	1.31	0.261
N x I	2	33	0.14	0.869
Class (C)	1	33	7.89	0.008
N x C	2	33	0.62	0.546
I x C	1	33	0.27	0.606
R x N x C	2	33	1.50	0.237
------------ Seed Yield ------------				
Nitrogen (N)	2	33	0.59	0.558
Inoculant (I)	1	33	0.02	0.890
N x I	2	33	3.14	0.056
Class (C)	1	33	13.60	<0.001
N x C	2	33	1.69	0.120
I x C	1	33	0.49	0.488
R x N x C	2	33	1.75	0.190
------------ Seed Protein ------------				
Nitrogen (N)	2	33	0.11	0.894
Inoculant (I)	1	33	3.01	0.092
N x I	2	33	2.14	0.134
Class (C)	1	33	464.3	<0.001
N x C	2	33	1.81	0.180
I x C	1	33	0.19	0.662
R x N x C	2	33	3.77	0.034

Table 11. Two-way interaction means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Scott 2023. Letter groupings are only provided in cases where the interaction was significant according to the overall tests of fixed effects. In such cases, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Two-Way Interaction	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
N x I	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low-No	181.7	6124	85.4	3516	23.6
Low-Yes	192.7	6041	84.6	3642	23.5
Elevated-No	187.1	5893	84.3	3552	23.3
Elevated-Yes	191.7	6282	84.0	3749	23.9
Extreme-No	192.6	6570	84.6	3835	23.6
Extreme-Yes	188.7	6017	84.3	3548	23.8
S.E.M.	6.29	274.4	0.53	157.5	0.17
N x C					
Low-Red	173.9	6287	84.8	3795	24.9
Low-Green	200.5	5878	85.3	3364	22.3
Elevated-Red	180.1	5786	83.4	3697	25.1
Elevated-Green	198.7	6389	84.9	3604	22.0
Extreme-Red	177.3	6345	83.8	3901	24.9
Extreme-Green	204.0	6242	85.1	3483	22.4
S.E.M.	6.29	274.4	0.53	157.5	0.17
I x C					
No-Red	173.5	6173	84.1	3762	24.9
No-Green	200.8	6218	85.4	3508	22.1
Yes-Red	180.7	6106	83.8	3833	25.1
Yes-Green	201.4	6121	84.8	3460	22.4
S.E.M.	6.75	246.4	0.45	145.5	0.14

Table 12. Three-way interaction means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Scott 2023. Letter groupings are only provided in cases where the interaction was significant according to the overall tests of fixed effects. In such cases, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Three-Way Interaction	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
N x I x C	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low-No-Red	168.1	6529	85.5	3804	25.0 a
Low-No-Green	195.4	5719	85.3	3229	22.3 b
Low-Yes-Red	179.7	6045	84.0	3786	24.8 a
Low-Yes-Green	205.7	6038	85.3	3499	22.3 b
Elev-No-Red	172.0	5375	83.3	3558	24.7 a
Elev-No-Green	202.3	6412	85.3	3546	22.0 b
Elev-Yes-Red	188.3	6197	83.5	3835	25.6 a
Elev-Yes-Green	195.1	6367	84.5	3662	22.1 b
Extr-No-Red	180.4	6616	83.5	3923	25.1 a
Extr-No-Green	204.7	6524	85.8	3748	22.1 b
Extr-Yes-Red	174.2	6076	84.0	3879	24.8 a
Extr-Yes-Green	203.3	5959	84.5	3218	22.7 b
S.E.M.	8.59	344.8	0.72	188.9	0.23

Table 13. Tests of fixed effects for residual nitrogen level (N), inoculant treatment (I), lentil class (C), and all possible interactions for selected response variables at Swift Current in 2023. Data were analysed using the Generalized Linear Mixed Model procedure of SAS.

Effect	Num DF	Den DF	F-Value	Pr > F
		------ Plant Density ------		
Nitrogen (N)	2	33	13.06	<0.001
Inoculant (I)	1	33	2.39	0.132
N x I	2	33	5.14	0.011
Class (C)	1	33	2.61	0.116
N x C	2	33	4.50	0.019
I x C	1	33	1.66	0.207
R x N x C	2	33	2.54	0.094
		------ Biomass ------		
Nitrogen (N)	2	33	2.89	0.070
Inoculant (I)	1	33	0.48	0.495
N x I	2	33	1.11	0.343
Class (C)	1	33	1.07	0.309
N x C	2	33	0.17	0.842
I x C	1	33	0.16	0.696
R x N x C	2	33	0.10	0.906
		------ Maturity ------		
Nitrogen (N)	2	33	9.59	<0.001
Inoculant (I)	1	33	0.63	0.433
N x I	2	33	0.04	0.961
Class (C)	1	33	26.68	<0.001
N x C	2	33	3.59	0.039
I x C	1	33	0.16	0.694
R x N x C	2	33	0.51	0.603
		------ Seed Yield ------		
Nitrogen (N)	2	33	12.97	<0.001
Inoculant (I)	1	33	0.30	0.586
N x I	2	33	0.82	0.451
Class (C)	1	33	94.79	<0.001
N x C	2	33	0.08	0.925
I x C	1	33	0.55	0.463
R x N x C	2	33	0.90	0.418
		------ Seed Protein ------		
Nitrogen (N)	2	33	73.92	<0.001
Inoculant (I)	1	33	2.68	0.111
N x I	2	33	0.21	0.815
Class (C)	1	33	49.79	<0.001
N x C	2	33	3.51	0.041
I x C	1	33	0.87	0.357
R x N x C	2	33	1.38	0.266

Table 14. Two-way interaction means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Swift Current 2023. Letter groupings are only provided in cases where the interaction was significant according to the overall tests of fixed effects. In such cases, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Two-Way Interaction	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
N x I	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low-No	165.9 c	2813	79.5	1158	24.6
Low-Yes	187.4 ab	3001	79.4	842	24.8
Elevated-No	195.3 a	3132	80.1	1336	25.3
Elevated-Yes	190.9 a	3365	79.9	1007	25.4
Extreme-No	172.1 bc	3251	80.6	1326	26.0
Extreme-Yes	171.5 bc	3081	80.5	1029	26.2
S.E.M.	5.60	159.8	0.26	39.5	0.12
N x C					
Low-Red	167.4 c	2795	79.1 c	1158	24.9 c
Low-Green	185.9 abc	3018	79.8 bc	842	24.4 c
Elevated-Red	189.9 ab	3200	79.6 bc	1336	25.9 b
Elevated-Green	196.3 a	3296	80.4 b	1007	24.8 c
Extreme-Red	175.6 bc	3138	79.6 bc	1326	26.4 a
Extreme-Green	168.0 c	3194	81.5 a	1029	25.9 ab
S.E.M.	5.60	159.8	0.26	32.3	0.12
I x C					
No-Red	172.6	3026 a	79.5	1294	25.7
No-Green	182.9	3104 a	80.7	956	24.9
Yes-Red	182.7	3062 a	79.4	1253	25.8
Yes-Green	183.8	3235 a	80.4	962	25.2
S.E.M.	5.00	134.9	0.21	32.3	0.10

Table 15. Three-way interaction means and multiple comparison test results for residual nitrogen (N) level, inoculant treatment, and lentil class at Swift Current 2023. Letter groupings are only provided in cases where the interaction was significant according to the overall tests of fixed effects. In such cases, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Three-Way Interaction	Plant Density	Biomass Yield	Maturity	Seed Yield	Seed Protein
N x I x C	-- plants/m^2 --	----- kg/ha -----	------ days ------	----- kg/ha -----	-------- % --------
Low-No-Red	160.0	2762	79.0	1229	24.8
Low-No-Green	171.8	2863	80.0	844	24.4
Low-Yes-Red	174.8	2828	79.3	1088	25.1
Low-Yes-Green	200.0	3174	79.5	841	24.5
Elev-No-Red	186.8	3096	79.8	1305	25.9
Elev-No-Green	203.8	3168	80.5	1011	24.7
Elev-Yes-Red	193.0	3305	79.5	1367	25.8
Elev-Yes-Green	188.8	3424	80.3	1004	25.0
Extr-No-Red	171.0	3221	79.8	1349	26.4
Extr-No-Green	173.3	3281	81.5	1015	25.7
Extr-Yes-Red	180.3	3054	79.5	1303	26.3
Extr-Yes-Green	162.8	3108	81.5	1043	26.1
S.E.M.	7.09	218.0	0.36	55.9	0.17

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.

Included in a separate document and available upon request