2022 Final Report

for the

Saskatchewan Ministry of Agriculture's

Agricultural Demonstration of Practices & Technologies (ADOPT) Program

Project Title: Lentil Response to Fertilizer Applications and Rhizobial Inoculation

(Project #20211074)

Principal Applicants: Chris Holzapfel[1] and Allison Fletcher[2]

[1]Indian Head Agricultural Research Foundation, PO Box 156, Indian Head, SK, S0G 2K0
[2]Saskatchewan Pulse Crop Development Board, 207-116 Research Drive, Saskatoon, SK, S7N 3R3

Collaborators: Jessica Enns[3], Kayla Slind[3], Bryan Nybo[4], Don Sluth, and Amber Wall[4]

[3]Western Applied Research Corporation, PO Box 89, Scott, SK, S0K 4A0
[4]Wheatland Conservation Area, PO Box 2015, Swift Current, SK, S9H 4M7

Correspondence: cholzapfel@iharf.ca or (306) 695-7761

Project Identification

1. **Project Title:** Lentil response to fertilizer applications and rhizobial inoculation
2. **Project Number:** 20211074 (SPG-AP2206)
3. **Producer Group Sponsoring the Project:** Saskatchewan Pulse Crop Development Board
4. **Project Location(s):** Field trials were located near Indian Head (#156), Scott (#380), and Swift Current (#137), Saskatchewan
5. **Project start and end dates(s):** April-2022 to February-2023
6. **Project contact person & contact details:**

Chris Holzapfel, Research Manager (Project Manager)
Indian Head Agricultural Research Foundation
PO Box 156, Indian Head, SK, S0G 2K0
Mobile: 306-695-7761
Office: 306-695-4200
Email: cholzapfel@iharf.ca

Allison Fletcher, Research Project Manager
Saskatchewan Pulse Crop Development Board
207-116 Research Drive, Saskatoon, SK, S7N 3R3
Phone: 306-668-0591
Email: afletcher@saskpulse.com

Collaborators:
Jessica Enns, General Manager
Western Applied Research Corporation (WARC)
PO Box 89, Scott, SK, S0K 4A0
Phone: 306-247-2001
Email: Jessica.enns@warc.ca

Bryan Nybo (Manager) and Amber Wall
Wheatland Conservation Area (WCA)
PO Box 2015, Swift Current, SK, S9H 4M7
Phone: 306-773-4775
Email: wcanybo@sasktel.net

Objectives and Rationale

7. **Project Objectives:**
The objective of this project was to demonstrate the response of lentil to a wide range of fertility management treatments that focus on phosphorus rate, rhizobial inoculation, and nitrogen fertilization strategies.

8. Project Rationale:

Lentils are one of the most important pulse crop options in Saskatchewan, especially in drier regions such as the Brown and Dark Brown soil zones, but also in transitional areas of the Black soil zone. In addition to seed and crop protection products which have been the focus of recent research and demonstration activities for this crop, fertilizer and fertility related inputs comprise some of the greatest production costs for lentil and are critical for building yield potential. A 2000 kg/ha (~30 bu/ac) lentil crop requires approximately 82-101 kg N/ha, 22-27 kg P_2O_5/ha, 69-84 kg K_2O/ha, and 8-10 kg S/ha. Since both potassium and sulfur are less likely to be limiting in most Saskatchewan soils, this demonstration focussed on nitrogen (N) and phosphorus (P) management.

As a pulse crop capable of meeting most of it's N requirements through biological fixation of dinitrogen (N_2) gas through symbiotic relationships with rhizobium bacteria, it is not generally recommended to apply N fertilizer to lentils beyond what is provided by most P and/or S products. Alternatively, the recommended practice is treating the seed or soil with *Rhizobium leguminosarum* inoculants to ensure that populations of this beneficial bacteria are sufficient to colonize the lentil roots and, through biological fixation, meet the crop's N requirements. Because it can take several weeks for root nodules to form and begin supplying N to the crop, low rates of starter N are sometimes recommended, particularly in coarse textured soils with low residual N. However, biomass and nutrient accumulation is relatively slow through this early period, so crop demands prior to the late vegetative stages are low (i.e. Mahli et al. 2007). Furthermore, high levels of mineral N can inhibit nodulation and N fixation and, consequently, may even negatively impact total N availability and yield; thus, growers should be cautious with this approach. In the Brown soil zone, Yan et al. (2005) observed a 45% lentil yield increase with rhizobium inoculation and better responses with granular (versus seed-applied) products, regardless of placement; however, low rates of N fertilizer (15 kg N/ha) had inconsistent effects on yield. Their findings were consistent with work on field peas conducted by Clayton et al. (2004) where the highest yields were achieved with granular inoculant and no N fertilizer, but some benefit to N fertilization was observed when either no inoculant or a liquid inoculant was applied. Under relatively low yielding, drought conditions in Montana, Huang et al. (2016) did not increase yields with either inoculation (peat based, seed-applied) or starter N (urea or ESN), but were able to increase grain protein with both of these inputs. The fertilizer effect was much larger in the absence of inoculant. Bremer et al. (1989) observed the highest yields and N_2 fixation with inoculated lentils, but inconsistent responses to N application (i.e., increased biomass production but no effect on yield, better yield responses in the absence of inoculant). Furthermore, they also showed that higher N rates significantly reduced the amount of atmospheric N in the grain due to substitution of fixed N with fertilizer N. At five locations over a four-year period in Alberta, Bowness et al. (2019) did not observe any yield benefits to either inoculation or N fertilization, despite observing more nodules with inoculation and working in fields which had not been sown to peas, lentils, or faba beans for at least 5 years. They attributed the lack of response to adequate nodulation in all treatments, regardless of whether an inoculant was applied, even though there did anecdotally appear to be more nodules in the inoculated plots. While examples of doing so are limited in the scientific literature, it is possible that in-season applications of N could provide yield or protein benefits without some of the negative impacts on nodulation and N_2 fixation that are frequently associated with high levels of mineral N.

While, depending on yields, lentil P requirements are typically fairly modest compared to other common crops, P is one of the most commonly limiting nutrients in Saskatchewan soils, second only to N. Pulse crops such as lentil are recognized as being good scavengers of residual soil nutrients and, as such, not especially responsive to fertilizer applications; however, actual results tend to vary with environment and responses to P application occasionally occur. Gan et al. (2005) looked at both 34 kg P_2O_5/ha as fertilizer and P-solubilizing microbes (*P. bilaii*), but did not observe any effects on lentil establishment, growth, or yield. With sites in the Brown, Dark Brown, and Black soil zones, Bremer et al. (1989) only increased lentil yields with P fertilizer application (30 kg P_2O_5/ha) in the Black soil zone which had both the highest yields and lowest residual P levels. In field peas, Holzapfel et al. (2021) observed statistically significant yield increases with P fertilization at 64% (7/11) of their low P (<12 ppm Olsen-P) sites and an overall average of yield increase of 9% across 12 site-years, regardless of residual P levels or absolute yields.

This project was initiated to demonstrate some of the expected responses to rhizobial inoculation, starter N applications, and P fertilization for a range of soil climatic zones in Saskatchewan while also exploring the potential merits of deferred N applications for increasing lentil yields and grain protein concentrations.

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Methodology and Results

9. Methodology:

Field trials with small red lentils were initiated near Indian Head (thin Black soil zone), Scott (Dark Brown soil zone), and Swift Current (Brown soil zone) in 2021. Due to environmental challenges, particularly at Scott and Swift Current, along with the recognized value of additional sites for which data would be available, the demonstration was repeated at all three locations in 2022. The treatments were combinations of P fertilizer rates, granular rhizobial inoculant, and supplementary

N fertilizer applied either at the time of seeding (side-banded) or as an in-season broadcast application targeted for the bud formation stage prior to flowering. The phosphorus source was monoammonium phosphate (MAP; 11-52-0), supplemental N was provided as urea (46-0-0), and the granular inoculant product was Nodulator Duo SCG (BASF; minimum of 8 x 107 CFU/g of *Rhizobium leguminosarum* biovar *viceae* STRAIN 1435 and 2 x 108 CFU/g of *Bacillus subtilis* STRAIN BU1814) at the label recommended rate, adjusted for row spacing. Where supplemental N was applied, the total N rate was 55 kg N/ha, adjusted for N provided by the MAP. Where supplemental N was not required by protocol, N was balanced at 10 kg/ha across the P rates ranging from 0-45 kg P_2O_5/ha to ensure that any observed responses were to P and not the N provided by the MAP. In total, 12 treatments were arranged in a four replicate RCBD (Table 1).

Table 1. Fertilizer and inoculant treatments evaluated in lentil fertility demonstrations conducted at Indian Head, Scott, and Swift Current in 2021 and 2022.

#	P rate (side-banded MAP)	Granular Inoculant (label rate)	Extra N Fertilizer (adjusted for N from MAP but not residual NO_3-N)
1	0 kg P_2O_5/ha	No	None
2	0 kg P_2O_5/ha	Yes	None
3	22 kg P_2O_5/ha	No	None
4	22 kg P_2O_5/ha	Yes	None
5	45 kg P_2O_5/ha	No	None
6	45 kg P_2O_5/ha	Yes	None
7	45 kg P_2O_5/ha	No	55 kg N/ha sideband
8	45 kg P_2O_5/ha	No	55 kg N/ha in-season broadcast
9	45 kg P_2O_5/ha	Yes	55 kg N/ha sideband
10	45 kg P_2O_5/ha	Yes	55 kg N/ha in-season broadcast
11	67 kg P_2O_5/ha	Yes	None
12	67 kg P_2O_5/ha	Yes	55 kg N/ha sideband

- N balanced at 9.5 kg N/ha for treatments 1-4 to separate P from N responses
- Both in-crop and side-band urea rates are adjusted for N provided by MAP (i.e., the total quantity of N applied in each of treatments 7, 8, 9, 10, and 12 was 55 kg N/ha

Selected agronomic information is provided in Table 5 of the Appendices. Seeding was completed within the first two weeks of May at all sites. Certified seed was used in all cases and the variety was CDC Proclaim CL at Indian Head and CDC Impulse at Scott and Swift Current. All locations used a seed rate of 190 seeds/m^2. The seed was treated with fungicides to suppress root diseases at all sites but the specific products varied. The plots were rolled after seeding but prior to emergence to break up soil lumps and push any stones down so that they would not interfere with combining. Weeds were controlled using registered pre-emergent and in-crop herbicides. Foliar fungicides were applied at the discretion of individual site managers. Pre-harvest herbicides were utilized as required to assist with crop drydown and provide late-season, perennial weed control. The lentils were straight-combined when it was fit to do so with outside crop rows excluded from the harvest area wherever possible.

Various data were collected during the growing season and from the harvested seed. Residual nutrient levels and basic soil characteristics were estimated from composite soil samples collected in the early spring. Spring plant densities were determined by counting seedlings in 2 x 1 m sections of crop row after emergence was complete and calculating plants/m^2. Seed yields were determined from the harvested grain samples and are adjusted for dockage and to a uniform seed moisture content of 13%. Test weight was determined using standard CGC methodology for two sub-samples per plot and is expressed as g/0.5 l. Seed weight was determined by counting a minimum of 250 whole seeds per plot, weighing to the nearest 0.00 g, and calculating g/1000 seeds. Seed protein was determined using a FOSS NIR analyzer for two cleaned subsamples per plot and the same instrument used for all locations. Daily temperatures and precipitation amounts were recorded from the nearest Environment and Climate Change Canada weather station for each location.

Prior to analyses, data from Scott and Swift Current in 2021 were removed due to extreme variability resulting from drought and generally unfavourable environmental conditions. Data from the remaining four sites were combined and analyzed using the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio. Site (S), fertility treatment (F), and the S x F interaction were included as fixed effects while replicate effects (within site) were considered random. Heterogeneity of variance components (by site) were tested for and permitted whenever differences between sites were significant and doing so improved the model fit. Individual treatment means were separated using the Tukey-Kramer test and means were sliced by site to produce F-tests for individual sites and prevent means comparisons of individual treatments across sites. Orthogonal contrasts were used to test whether responses to P fertilizer rate were linear, quadratic, or not significant. Predetermined contrast comparisons were used to test for differences between specific groups of treatments which were considered to be of particular interest. These were un-inoculated versus inoculated (with and without extra N) and no extra N versus extra N (with and without inoculant). All treatment effects and differences between means were considered significant at $P \leq 0.05$; however, responses at $P \leq 0.1$ were also generally highlighted if they made agronomic sense and were deemed important.

10. Results:

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

Mean monthly temperatures and precipitation amounts for May-August of each site are presented relative to the long-term (1981-2010) averages in Tables 2 and 3, respectively. At Indian Head in 2021, it was initially dry but timely precipitation events maintained a reasonable yield potential and good trial quality. While the total amount of precipitation was 121% of the long-term average, much of the rain fell in August which was too late to benefit the crop. In contrast, the 2022 growing season at Indian Head began wet, and above-average (117%) precipitation from May through August helped to support quite a high yield potential at this site. While prolonged wet conditions can be detrimental to lentils, the site was well drained and dryer weather in June allowed the crop to root well and get off to a strong start. Temperatures at Indian Head were slightly above average in 2021 (103%) and approximately average in 2022 (101%). Both Scott and Swift Current were both warmer (105-106%) and drier (83-88%) than average; however, yields were still reasonably high at these sites and the overall variability was sufficiently low that the results were considered valid.

Table 2. Mean monthly temperatures along with long-term (1981-2010) averages for the growing seasons at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022).

Location	Year	May	June	July	August	Average
		---------------------------- Mean Temperature (°C) ----------------------------				
Indian Head	2021	9.0	17.7	20.3	17.1	16.0 (103%)
	2022	10.9	16.1	18.1	18.3	15.8 (101%)
	Long-term	*10.8*	*15.8*	*18.2*	*17.4*	*15.6*
Scott	2022	10.0	15.0	18.3	18.9	15.6 (105%)
	Long-term	*10.8*	*14.8*	*17.3*	*16.3*	*14.8*
Swift Current	2022	10.8	15.7	19.7	20.9	16.8 (106%)
	Long-term	*11.0*	*15.7*	*18.4*	*17.9*	*15.8*

Table 3. Mean monthly precipitation along with long-term (1981-2010) averages for the growing seasons at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022).

Location	Year	May	June	July	August	Total
		------------------------ Cumulative Precipitation (mm) ------------------------				
Indian Head	2021	81.6	62.9	51.2	99.4	295 (121%)
	2022	97.7	27.5	114.5	45.9	286 (117%)
	Long-term	*51.7*	*77.4*	*63.8*	*51.2*	*244*
Scott	2022	11.0	57.1	86.5	32.1	187 (83%)
	Long-term	*38.9*	*69.7*	*69.4*	*48.7*	*227*
Swift Current	2022	43.2	31.2	83.5	6.7	165 (88%)
	Long-term	*42.1*	*66.1*	*44.0*	*35.4*	*188*

Selected soil test results for each site are provided in Table 4 below. The sites near Indian Head had a pH of 8.1, 4.7-4.9% organic matter, and cation exchange capacity (CEC) of 47-52 meq/100 g. Residual NO_3-N varied with 21 kg/ha (0-60 cm) in 2021 and 50 kg N/ha in 2022. Residual P was consistently very low at 2-4 ppm Olsen-P. Scott 2022 had more acidic soil (pH of 5.8) with 4.2% organic matter and much coarser soil texture with a CEC of 13 meq/100 g. Residual NO_3-N was 44 kg/ha and there were 8 ppm Olsen-P. At Swift Current 2022, the pH was 6.1, there was 2.7% organic matter, and the CEC was 19 meq/100 g. Residual NO_3-N was estimated at 33 kg/ha and Olsen-P was higher than the other sites at 15 ppm.

Table 4. Selected soil test results (AGVISE Laboratories) for lentil fertility demonstrations completed at five sites over a two-year period.

Depth	pH	SOM (%)	CEC (meq/100g)	NO_3-N (kg/ha)	Olsen-P (ppm)
---------- Indian Head 2021 ----------					
0-15	8.1	4.9	46.7	8	2
15-60	8.3	–	–	13	–
---------- Indian Head 2022 ----------					
0-15	8.1	4.7	52.0	12	4
15-60	8.3	–	–	38	–
---------- Scott 2022 ----------					
0-15	5.8	4.2	13.3	19	8
15-60	7.7	–	–	25	–
---------- Swift Current 2022 ----------					
0-15	6.1	2.7	19.2	11	15
15-60	8.1	–	–	22	–

Overall Site and Treatment Effects

Detailed results are largely deferred to the Appendices, presented in Tables 6-28, and will be referred to as necessary. Heterogeneous variance estimates (by site) improved model fit and were permitted for plant density, seed weight, and protein, but not seed yield or test weight (Table 6). Focussing on the broader F-test results (Table 7), the site effect was highly significant ($P < 0.001$) for all response variables. As expected, emergence was not affected by fertility treatment ($P = 0.568$) and there was no S x F interaction ($P = 0.492$). Yield and test weight were affected by fertility treatment ($P < 0.001$-0.031) but the the S x F interaction was not significant ($P = 0.305$-0.383). For thousand seed weight, the overall treatment effect was not significant ($P = 0.987$); however, a significant S x F interaction ($P = 0.047$) suggested that site-to-site inconsistencies for this variable ($P = 0.047$) existed. Notably, seed protein was not affected by fertility treatment and there was no S x F interaction detected ($P = 0.835$-0.940).

Emergence

All sites used a target seed rate of 190 seeds/m^2; however, emergence varied with environmental conditions ($P < 0.001$). The lowest mortality occurred both years at Indian Head, where mean plant populations were 175-177 plants/m^2 (Table 8). Stands were intermediate at Scott 2022 (148 plants/m^2) and lowest at Swift Current 2022 (98 plants/m^2). With no significant fertility treatment effects or S x F interactions detected, emergence within sites was consistent. This was largely expected since all fertilizer was side-banded or broadcast after these measurements were completed and we would not expect inoculant to affect seedling mortality. While results for all orthogonal contrasts and pre-determined group comparisons are provided in Tables 10-12 of Appendices, with no significant treatment effects or trends, they will not be discussed in detail.

Seed Yield

Yields were highest at Indian Head 2022 (3722 kg/ha), intermediate at Scott 2022 (2539 kg/ha), and lowest at Indian Head 2021 and Swift Current 2022 (1882-2083 kg/ha). Individual treatment means for yield are provided in Table 13 of the Appendices. While the yield responses were consistent enough across sites that the S x F effect was not significant (*P* = 0.305), subtle variation was observed and will be discussed where considered appropriate. The overall fertility effect (across sites) was significant and the lowest yields were observed when no P fertilizer was applied (2388-2390 kg/ha). As P fertilizer and other inputs (supplemental N and granular inoculant) were added, the overall average yields ranged from 2525-2666 kg/ha. The orthogonal contrasts and group comparisons allow us to further break down these responses and detailed results for these tests are provided in Tables 14-16 in addition to being summarized in Figs. 1-3 below. Across sites, lentil yields increased linearly (*P* < 0.001) from 2390 kg/ha to 2590 kg/ha as P rates increased from 0-67 kg P_2O_5/ha. While the overall quadratic response was not significant (*P* = 0.114), the trend was for the largest increase to occur with the first 22 kg P_2O_5/ha. Inspection of the individual site data suggested that the P responses were strongest at Indian Head, where residual P was low and, particularly in 2022, yields were high. At Scott, residual P levels were higher but still considered low, yields were intermediate, and the P response was more quadratic, peaking at the lowest rate of 22 kg P_2O_5/ha. At Swift Current, with the lowest yields and highest residual P levels, neither the linear nor quadratic responses to P rate were significant (*P* = 0.764-0.956).

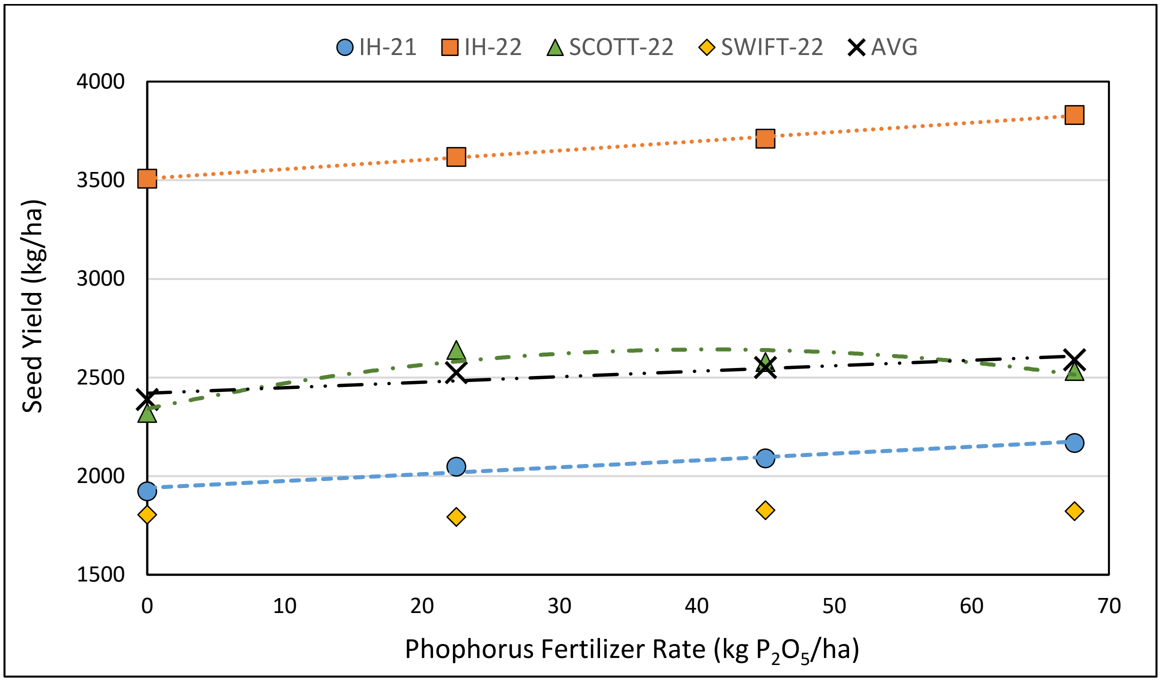

Figure 1. Lentil seed yield response to phosphorus (P) fertilizer rate at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022). Only the linear response at Indian Head was significant (*P* < 0.001).

Rather unexpectedly, yields were not affected by the addition of granular inoculant regardless of whether supplemental N was applied (Table 15; Fig. 2). This was true when averaged across sites (*P* = 0.155-0.891) and for individual sites (*P* = 0.217-0.701). While we did not specifically assess nodulation, this resulted suggests that background levels of *Rhizobium leguminosarum* in the soil were sufficient to colonize the roots and facilitate N fixation, regardless of whether an inoculant was applied. In the treatments where supplemental N was applied, we would expect the crop to be less reliant on biological fixation; however, these amounts of N would not be sufficient to support high yields on their own (i.e., in the absence of N fixation). The most recent pea, lentil, or faba bean crop for each site ranged from two years at Swift Current 2022 to four years at Scott 2022 and Indian

Head in both years. All sites had a long history of including peas and/or lentils in their rotations. Furthermore, the plots were always placed in relatively well-drained and productive areas of the fields where the soil rhizobium populations may have been more successful compared to areas within the field where conditions were less favourable for the bacteria (i.e., saline, eroded knolls, areas prone to flooding).

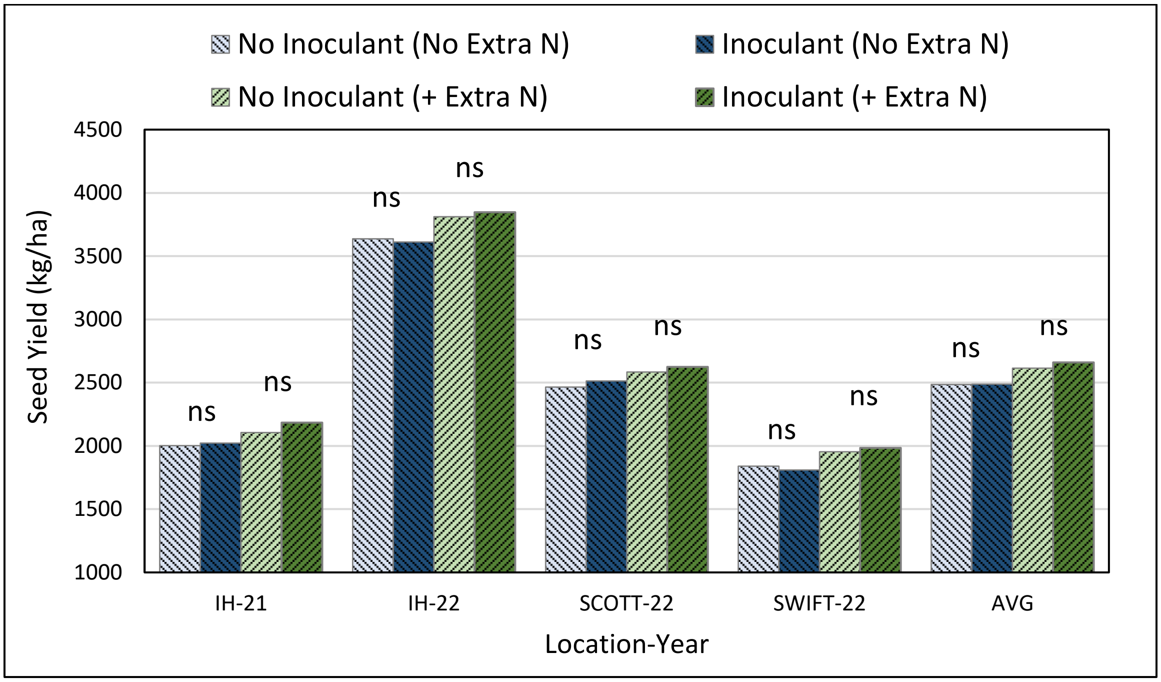

Figure 2. Predetermined contrasts comparing granular inoculant effects on lentil seed yield, with and without the addition of extra nitrogen (N) fertilizer, at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022). The comparisons are denoted by: ns – not significant, * – *P* > 0.05 ≤ 0.1, ** – *P* > 0.01 ≤ 0.05, * – *P* ≤ 0.01.**

Responses to supplemental N fertility did occasionally occur; however, they were somewhat inconsistent and difficult to predict (Table 16; Fig. 3). Averaged across sites, yields were 74 kg/ha (~3%) higher with supplemental N when combined with a granular inoculant ($P = 0.007$) while, in the absence of inoculant, the benefit was 71 kg/ha (~3%), but not quite statistically significant at the desired probability level ($P = 0.060$). The expectation was that supplemental N would be more beneficial when nodulation was poor; thus, potentially, in the absence of an inoculant. There was no clear advantage to side-band versus in-crop N; however, side-banding did appear to be slightly more beneficial than in-crop N in the absence of a granular inoculant and when averaged across sites. For individual sites, the group comparisons detected N responses at Indian Head 2022 in the absence of inoculant (~5%; $P = 0.012$) and Swift Current, when combined with granular inoculant (~8%; $P = 0.017$). At Indian Head 2022, the response was as expected in that it only occurred in the absence of inoculant, but not in the sense that this was also the site with the finest soil texture, highest organic matter, and highest residual N levels. Yields were very high at Indian Head 2022 and it is possible that biological fixation could not meet the entire N requirements, particularly in the absence of inoculant; hence the response to supplemental N. As the driest site with coarse soil and low organic matter, Swift Current is the location which we would expect supplemental N most likely to be beneficial; however, the fact that this only occurred when combined with inoculant was unexpected and difficult to explain.

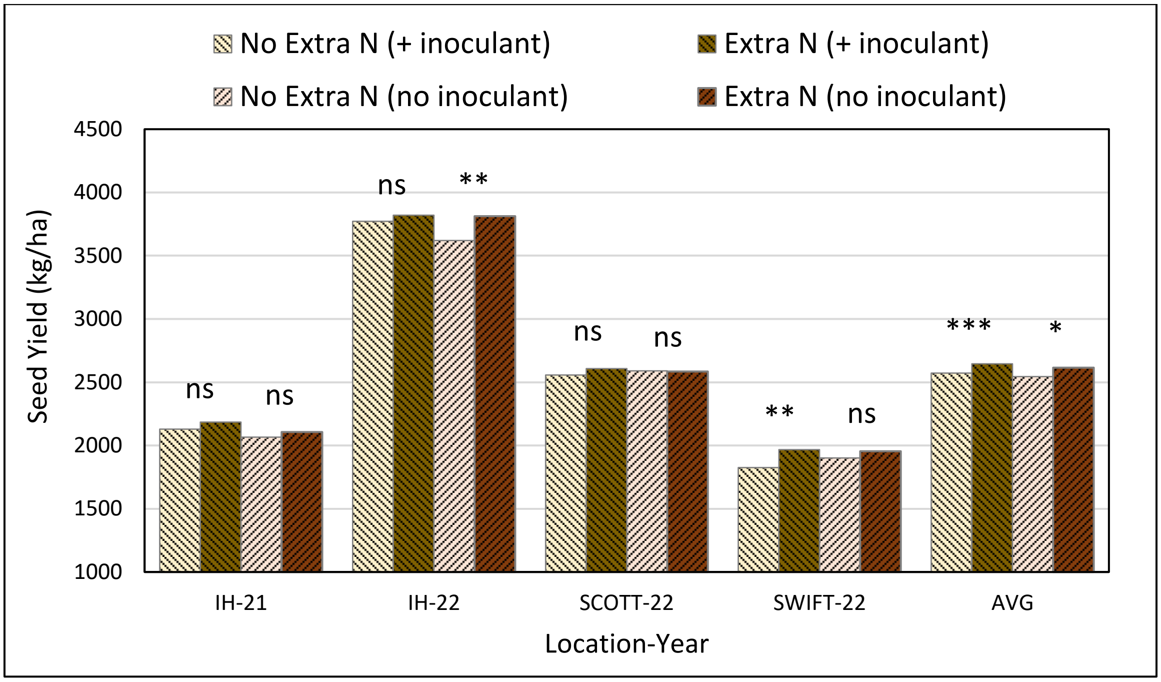

Figure 3. Predetermined contrasts comparing supplemental nitrogen fertilizer effects on lentil seed yield, with and without the addition of granular inoculant, at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022). The comparisons are denoted by: ns – not significant, * – *P* > 0.05 ≤ 0.1, ** – *P* > 0.01 ≤ 0.05, * – *P* ≤ 0.01.**

Test Weight

While test weight is not specifically a grading factor for lentils, higher values are always beneficial in that grain is sold by mass and heavier grain may be less expensive to store and handle in addition to potentially being more desirable to end users. Overall, lentil test weights were highest at Indian Head 2022 (406 g/0.5 l), followed by Indian Head 2021 (401 g/0.5 l), Scott 2022 (393 g/0.5 l), and Swift Current 2022 (389 g/0.5 l). While the overall impact of fertility on test weight was significant, the magnitude of any effects were small relative to those of environment. For example, while means across sites ranged from 389-406 g/0.5 l, the observed range across fertility treatments (averaged across sites), was only 396.6-398.0 g/0.5 l. The test weight response to P fertilizer rate was quadratic (P = 0.025) in that it was generally stable up to 45 kg P_2O_5/ha but then declined at 67 kg P_2O_5/ha (Table 18; Fig. 4). This response was most pronounced at Scott 2022 (P = 0.020); however, the lack of an S x F effect suggests a certain amount of consistency across sites. Granular inoculant did not have any impact on test weight for individual sites (P = 0.075-0.863) or when averaged across sites (P = 0.414-0.838; Table 19). At Scott 2022, there was a trend for slightly higher test weight with inoculant specifically when no supplemental N was applied (P = 0.075). Nitrogen fertilizer effects on test weight were not significant when averaged across sites (P = 0.115-0.693). The only exception amongst individual sites was Swift Current 2022 where extra N, in the absence of inoculant, resulted in a slight reduction in test weight (P = 0.027; Table 20).

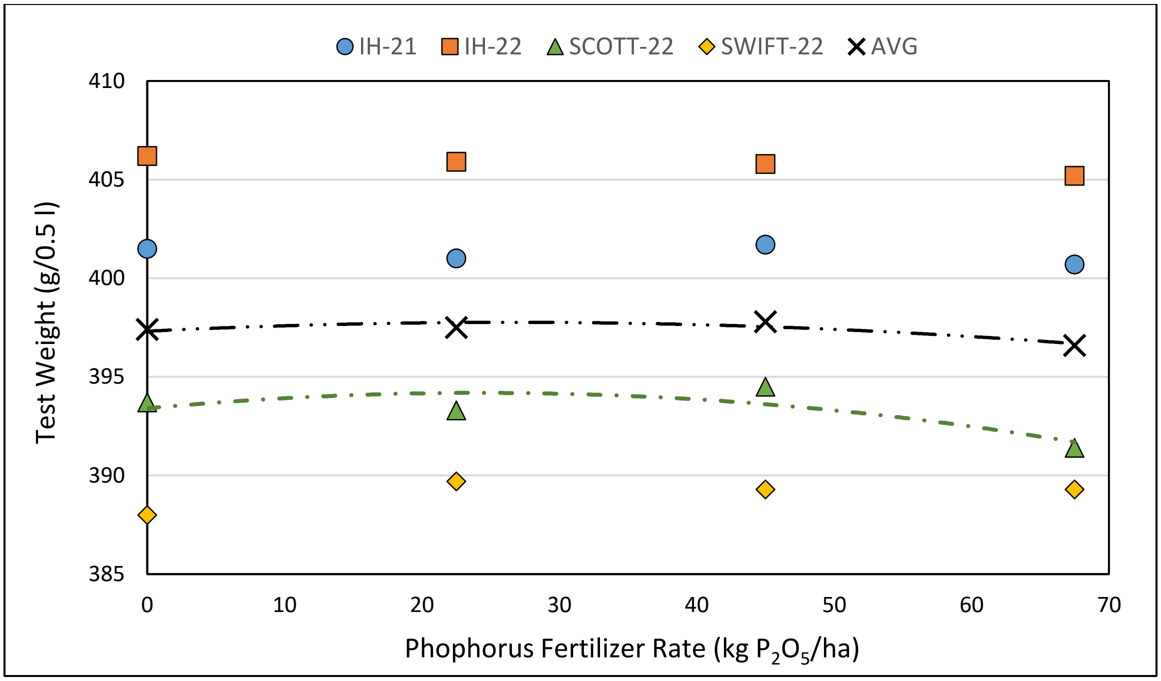

Figure 4. Lentil test weight response to phosphorus (P) fertilizer rate at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022). The quadratic response was significant at SC-22 (P = 0.020) and averaged across sites (P = 0.025).

Seed Weight

While, similar to test weight, seed weight is not a grading factor for lentils; however, it is an important yield component in that larger seeds contribute to higher yields. The overall averaged seed weight was highest at Scott 2022 (49.6 g/1000 seeds), intermediate at Swift Current 2022 (46.5 g/1000 seeds), and lowest at Indian Head in both years (42.9-43.0 g/1000 seeds). It is likely that the lower seed weights at Indian Head were partly due to genetics as, according to 2022 Saskatchewan Seed Guide, CDC Proclaim, the variety used at Indian Head, has a lower seed weight (40 g/1000 seeds) than CDC Impulse (44 g/1000 seeds). The overall fertility effect was not significant for seed weight (P = 0.987); however, an S x F interaction was detected (P = 0.047). No linear or quadratic responses to P rate were detected for this variable at any individual sites (P = 0.206-0.923), or when averaged across sites (Table 22; P = 0.788-0.879). At Swift Current, there was evidence that inoculant had a slight positive effect on seed weight when combined with extra N (P = 0.050), but not in its absence (P = 0.792); however, the effect was small and difficult to explain (Table 23). The addition of extra N slightly reduced seed weight at Scott 2022, regardless of whether the plots were inoculated (P = 0.018-0.050). The opposite occurred at Swift Current 2022, but only when combined with a granular inoculant P = 0.002). Broadly speaking, treatment effects on seed weight were too small and inconsistent to be of much practical agronomic importance.

Seed Protein

With increasing demand for plant based protein sources, higher seed protein concentrations are desirable in many pulse crops and lentils are no exception. Protein concentrations did vary with location, averaging 26.6% at Indian Head (both years), 24.2% at Swift Current 2022 and 23.8% at Scott 2022. Similar to seed weight, we cannot rule out that the observed site effects were not, at least partly, due to genetics. Regardless of the statistical tests applied or specific treatments considered, the fertility treatments had no impact on seed protein. Perhaps this result would have differed if we had observed stronger responses to either inoculant or N fertilizer; however, we must conclude that lentil protein concentrations are more likely to be impacted by environment, or potentially genetics, than fertility management.

Extension Activities

This demonstration could not be highlighted during the 2021 Indian Head Crop Management Field Day for logistic reasons; however, the plots were shown to several industry representatives and producers during smaller, informal tours throughout the season. At Swift Current in 2021, the plots were shown by WCA staff during multiple tours throughout the season and also highlighted during a CKSW radio program entitled 'Walk the Plots'. At Scott in 2021, this demonstration was highlighted through social media platforms (Facebook and Twitter) during WARC's Virtual Field Day on July 8, 2021. In 2022, The demonstration was scheduled to be shown during the 2022 Indian Head Crop Management Field Day on July 19; however, this event was rained out and moved indoors. Nonetheless, Chris Holzapfel (IHARF) and Sara Anderson (SaskPulse) presented a general overview of the trial to approximately 120 people indoors. At Swift Current in 2022, the plots were toured by approximately 80 participants during WCA's annual field tour and featured Dale Risula (Ministry of Agriculture) as a guest speaker. Highlights from the project will be presented by Chris Holzapfel during the 2022 IHARF Winter Seminar and AGM on February 1, 2023 and during the SaskPulse Winter Meetings at Assiniboia (February 9) and Elrose (February 16). This annual report will be available online through the IHARF website and results will be highlighted in other presentations and extension activities where opportunities arise. In addition Saskatchewan Pulse Growers will also incorporate results in their extension and resource materials as they see fit.

11. Conclusions and Recommendations

Although challenging conditions limited yields and also reduced data quality in some cases, this project demonstrated lentil responses to various combinations of P fertilization and N management strategies across a range of environments in Saskatchewan.

The lack of fertility effects on plant establishment indicated that side-band placement provided sufficient separation between the fertilizer and seed-row to prevent seedling toxicity and subsequent stand reduction. The strong site effects do, however, suggest that growers still should pay attention to seedbed conditions and monitor seedling mortality on their farms in order to identify issues and ensure that seeding rates are sufficient to achieve optimal plant stands.

Phosphorus application increased yields specifically at three of four locations, the exception being Swift Current 2022 where yields were lower and residual P levels were relatively high. At Scott, 22 kg P_2O_5/ha was sufficient to maximize yield but, at Indian Head, where residual P was extremely low, the response was more linear. Yields were especially high in 2022 at Indian Head and yields increased from 3509 kg/ha with no P to as high as 3832 with 67 kg P_2O_5/ha as side-banded monoammonium phosphate. In general, this is consistent with past research and supports the notion that lentils are good scavengers of residual nutrients, but can still respond to P fertilization when soil supply is limited and yields are sufficiently high. The observed responses at Indian Head, where residual P levels were extremely low, were linear and rates that would match removal (i.e., 25-40 kg/ha) were barely sufficient to ensure that yields were not limited. That being said, with only 2-4 ppm Olsen-P measured in the soil tests at this location, the higher P rates could likely be justified to ensure an adequate supply while also helping to build soil fertility over the long-term. At Scott 2022, where residual P was higher than Indian Head but still considered low, P fertilizer rates that match crop removal (~22-25 kg P_2O_5/ha) were also the most economical. At Swift Current, residual P levels were approaching sufficiency and, when this site was considered on its own, the response to P application was not significant; however, applying approximately 20-25 kg P_2O_5/ha would still be recommended to ensure that early-season availability is sufficient and to maintain soil fertility. Despite the effects on yield, P fertilization did not have any positive effects on grain quality.

Focussing on N fertility, treatment effects were less pronounced and rather inconsistent. Somewhat unexpectedly, we did not observe any significant effects of inoculation, regardless of yield potential or field history. While not formally assessed, any plants that were inspected appeared to be well nodulated, regardless of whether inoculant was applied. Despite these results, we would be hesitant to recommend not applying a rhizobial inoculant due to the high importance of biological N_2 fixation; however, lentil growers looking to reduce input costs might consider utilizing less expensive formulations (i.e., seed-applied), particularly if the field has a history of pea/lentil productions and neither nodulation failures nor N deficiencies have been observed in the past. Under such circumstances, it is unlikely that there would be any benefit to either dual inoculation (i.e., liquid plus granular) or exceeding label recommendations as we have seen with some legume crops, such as soybean, where the associated rhizobium species is not native and there is limited history of the specific crop in rotation.

Similar to recent work with field peas and much of the previously published data, limited benefits to N fertilizer applications were occasionally observed; however, their inconsistency and unpredictable nature make it difficult to recommend this practice. Traditionally, low rates of supplemental N for N fixing crops are most commonly recommended in coarse textured, low organic matter soils with low residual N. The most responsive sites were Indian Head 2022 and Swift Current 2022. While the lentils at Swift Current would generally be considered more likely to benefit from supplemental N fertilization, Indian Head 2022 had relatively high organic matter, fine textured soils, and the highest residual N levels of all the sites. That being said, the yields at Indian Head were much higher than average and it is possible that this resulted in the stronger than expected N demands and the subsequent response to fertilization. Biological N fixation and residual soil N on their own may not have been able to fully meet the demands of this high yielding crop. The N response at Indian Head 2022 was stronger in the absence of inoculant, which was expected; however, the lentils at this site did not specifically respond to inoculation. While deferring N applications into the growing season may reduce the potential for negative impacts associated with reduced N fixation to occur, where benefits in the current project did occur, they appeared to be stronger with side-band placement. If nodulation failure and subsequent N deficiencies are confirmed early enough in the growing season, in-crop 'rescue' applications of N may have merit and may be the best option to correct such deficiencies, but are still unlikely to completely mitigate yield loss. Under most conditions, the N that is provided by modest rates of P and S fertilizer products can likely fulfill much of the lentil crop's N demands before biological N_2 fixation takes over.

Supporting Information

12. Acknowledgements:

This project was financially supported by the Agricultural Demonstration of Practices and Technologies (ADOPT) initiative under the Canadian Agricultural Partnership bi-lateral agreement between the federal government and the Saskatchewan Ministry of Agriculture. The project was administrated in-kind by the Saskatchewan Pulse Crop Development Board. 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 make work like this possible.

13. Appendices:

Table 5. Selected agronomic information and dates of operations for lentil fertility demonstrations conducted at Indian Head (2021 and 2022), Scott (2022), and Swift Current (2022), Saskatchewan.

Activity	Indian Head 2021	Indian Head 2022	Scott 2022	Swift Current 2022
Previous Crop	Oat	Wheat	Wheat	Wheat
Most Recent Peas/Lentils	2007	2018	2019	2020
Pre-seed Herbicide	890 g glyphosate/ha (May 11)	890 g glyphosate/ha (May 12)	1334 g glyphosate + 21 g carfentrazone-ethyl/ha (May 12)	890 g glyphosate/ha (May 11)
Seeding	May 4	May 9	May 9	May 6
Row Spacing	30 cm	30 cm	25 cm	21 cm
Variety	CDC Proclaim CL	CDC Proclaim CL	CDC Impulse CL	CDC Impulse CL
Seed Treatment	300 ml Insure Pulse + 39 ml INTEGO Solo/100 kg seed	300 ml Insure Pulse + 39 ml INTEGO Solo/100 kg seed	100 ml Vibrance Maxx RFC/100 kg seed	100 ml Vibrance Maxx RFC/100 kg seed
In-crop Herbicide	20 g imazamox + 9 g imazapyr/ha (June 13)	15 g imazamox + 15 g imazapyr + 167 ml sethoxydim/ha (June 7)	20 g imazamox + 171 g sethoxydim/ha (June 7)	59 g clethodim/ha (June 7) 20 g imazamox/ha (June 16)
Emergence Counts	June 18	June 2	June 8	June 16
In-Crop Nitrogen	June 23 (as per protocol)	June 23 (as per protocol)	June 14 (as per protocol)	June 30 (as per protocol)
Foliar Fungicide	99 g fluxapyroxad + 99 g pryaclostrobin/ha (June 30)	99 g fluxapyroxad + 99 g pryaclostrobin/ha (June 30)	99 g fluxapyroxad + 99 g pryaclostrobin/ha (July 14)	150 g fluopyram + 150 g prothioconazole/ha (July 27)
Pre-harvest Herbicide / Desiccant	890 g glyphosate/ha (July 30) 410 g diquat/ha (August 3)	890 g glyphosate/ha (August 12) 410 g diquat/ha (August 19)	410 g diquat/ha (August 15)	297 g diquat/ha (August 8)
Harvest	August 8	August 23	August 23	August 10

Table 6. Model fit statistics and tests of common variance (between sites) for selected response variables.

Response Variable	Homogeneous	Heterogeneous	Pr > Chi Square [Y]
	------------- AICc [Z] (smaller is better) -------------		-------- p-value --------
Plant Density (plants/m^2)	1259.6	1255.6	0.016
Seed Yield (kg/ha)	1900.2	1901.6	0.177
Test Weight (g/0.5 l)	530.6	536.5	0.933
Seed Weight (g/1000 seeds)	392.3	389.4	0.026
Seed Protein (%)	343.1	336.3	0.004

[Z] Akaike information criterion – used to determine the most appropriate model for each response variable
[Y] P-values greater than 0.05 indicate that variance estimates did not significantly differ across sites

Table 7. Tests of fixed effects for site (S), fertility treatment (F), and their interaction (S x F) for selected response variables in lentil fertility demonstrations conducted at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022).

Effect	Num DF	Den DF	F-Value	Pr > F
	-------------------------------- Emergence --------------------------------			
Site (S)	3	12	479.5	<0.001
Fertility (F)	11	132	0.78	0.568
S x F	33	132	1.07	0.492
	--------------------------------- Seed Yield ---------------------------------			
Site (S)	3	12	119.3	<0.001
Fertility (F)	11	132	8.80	<0.001
S x F	33	132	1.13	0.305
	-------------------------------- Test Weight --------------------------------			
Site (S)	3	12	1035.6	<0.001
Fertility (F)	11	132	2.02	0.031
S x F	33	132	1.07	0.383
	------------------------------- Seed Weight -------------------------------			
Site (S)	3	12	399.1	<0.001
Fertility (F)	11	132	0.29	0.987
S x F	33	132	1.54	0.047
	------------------------------- Seed Protein -------------------------------			
Site (S)	3	12	676.2	<0.001
Fertility (F)	11	132	0.59	0.835
S x F	33	132	0.63	0.940

Table 8. Overall site effects on lentil emergence, seed yield, test weight, seed weight, and seed protein when averaged across twelve fertility treatments. Values in parentheses are the standard error of the treatment means and means within a row followed by the same letter do not significantly differ (Tukey-Kramer; P ≤ 0.05).

Response Variable	Indian Head 2021	Indian Head 2022	Scott 2022	Swift Current 2022
Emergence (plants/m^2)	175 A (2.3)	177 A (4.9)	148 B (0.9)	98 C (1.1)
Seed Yield (kg/ha)	2083 C (75.5)	3722 A (75.5)	2539 B (75.5)	1882 C (75.5)
Test Weight (g/0.5 l)	401.2 B (0.24)	405.9 A (0.24)	393.0 C (0.24)	388.7 D (0.24)
Seed Weight (g/1000 seeds)	43.0 C (0.21)	42.9 C (0.05)	49.6 A (0.34)	46.5 B (0.11)
Seed Protein (%)	26.57 A (0.060)	26.61 A (0.112)	23.76 C (0.116)	24.17 B (0.008)

Table 9. Lentil fertility treatment effects on mean plant densities for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. P-values below 0.05 indicate that the overall fertility effect was significant. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

P_2O_5 Rate - Inoculant - Extra N	IH-21	IH-22	SC-22	SW-22	AVG
	-------------------- p-value --------------------				
Pr > *F*	0.252	0.113	0.574	0.999	0.568
	-------------------- Plant Density (plants/m^2) --------------------				
1) 0P - No - None	171 a	163 a	154 a	92 a	145 A
2) 0P - Yes - None	179 a	165 a	151 a	97 a	148 A
3) 22P - No - None	158 a	176 a	154 a	98 a	147 A
4) 22P - Yes - None	170 a	168 a	154 a	96 a	147 A
5) 45P - No - None	185 a	192 a	150 a	100 a	157 A
6) 45P - Yes - None	180 a	190 a	149 a	100 a	155 A
7) 45P - No - 55N sideband	175 a	176 a	141 a	96 a	147 A
8) 45P - No - 55N in-crop	172 a	185 a	150 a	101 a	152 A
9) 45P - Yes - 55N sideband	178 a	178 a	141 a	102 a	150 A
10) 45P - Yes - 55N in-crop	169 a	169 a	153 a	101 a	148 A
11) 67P - Yes - None	178 a	178 a	143 a	97 a	149 A
12) 67P - Yes - 55N sideband	190 a	179 a	132 a	97 a	150 A
S.E.M	7.4	8.8	7.4	7.4	3.8

Table 10. Linear and quadratic orthogonal contrast results for phosphorus (P) fertilizer rate effects on lentil plant densities for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. Only treatments with granular inoculant and no additional N fertilizer were included.

P Fertilizer Rate	IH-21	IH-22	SC-22	SW-22	AVG
	------------------ Plant Density (plants/m^2) ------------------				
0 kg P_2O_5/ha (2)	179	165	151	97	148
22 kg P_2O_5/ha (4)	170	168	154	96	147
45 kg P_2O_5/ha (6)	180	190	149	100	155
67 kg P_2O_5/ha (11)	178	178	143	97	149
<u>Orthogonal Contrast</u>	------------------ Pr > *F* (p-value) ------------------				
P Rate – Linear	0.801	0.065	0.371	0.906	0.505
P Rate – Quadratic	0.655	0.358	0.570	0.885	0.553

Table 11. Predetermined contrasts comparing un-inoculated to inoculated lentils, with and without extra nitrogen (N) fertilizer, for plant density at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	------------------ Plant Density (plants/m^2) ------------------				
No inoculant – No N (1,3,5) vs.	172 A	177	153 A	97 A	150 A
Inoculant – No N (2,4,6)	176 A	174	151 A	98 A	150 A
Pr > *F* (p-value)	0.426	0.633	0.782	0.867	0.916
No Inoculant – Extra N (7,8) vs.	173 A	181	145 A	99 A	149 A
Inoculant – Extra N (9,10)	173 A	174	147 A	101 A	149 A
Pr > *F* (p-value)	0.953	0.341	0.778	0.744	0.840

Table 12. Predetermined contrasts comparing lentils with no extra nitrogen (N) fertilizer to lentils with extra N fertilizer, with and without inoculant, for plant density at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	------------------ Plant Density (plants/m^2) ------------------				
No N + Inoculant (6,11) vs.	179	184	146	98 A	152 A
Extra N + Inoculant (9,10,12)	179	176	142	100 A	149 A
Pr > *F* (p-value)	0.889	0.140	0.514	0.920	0.278
No N – No Inoculant (5) vs.	185	192	150	100 A	157 A
Extra N – No Inoculant (7,8)	173	181	145	99 A	149 A
Pr > *F* (p-value)	0.205	0.213	0.557	0.920	0.110

Table 13. Lentil fertility treatment effects on mean seed yields for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. P-values below 0.05 indicate that the overall fertility effect was significant. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

P_2O_5 Rate - Inoculant - Extra N	IH-21	IH-22	SC-22	SW-22	AVG
	---- p-value ----				
Pr > *F*	0.003	<0.001	0.001	0.080	<0.001
	---- Seed Yield (kg/ha) ----				
1) 0P - No - None	1937 ab	3493 c	2366 bc	1756 a	2388 B
2) 0P - Yes - None	1923 b	3509 bc	2321 c	1806 a	2390 B
3) 22P - No - None	2003 ab	3794 ab	2443 abc	1861 a	2525 AB
4) 22P - Yes - None	2048 ab	3619 abc	2641 ab	1794 a	2525 AB
5) 45P - No - None	2065 ab	3620 abc	2589 abc	1901 a	2544 A
6) 45P - Yes - None	2091 ab	3711 abc	2579 abc	1828 a	2552 A
7) 45P - No - 55N sideband	2208 ab	3847 a	2531 abc	1956 a	2636 A
8) 45P - No - 55N in-crop	2007 ab	3778 abc	2640 ab	1954 a	2595 A
9) 45P - Yes - 55N sideband	2219 a	3803 a	2590 abc	1999 a	2653 A
10) 45P - Yes - 55N in-crop	2149 ab	3889 a	2657 a	1967 a	2666 A
11) 67P - Yes - None	2169 ab	3832 a	2534 abc	1823 a	2590 A
12) 67P - Yes - 55N sideband	2183 ab	3772 abc	2573 abc	1934 a	2616 A
S.E.M	95.8	95.8	95.8	95.8	47.9

Table 14. Linear and quadratic orthogonal contrast results for phosphorus (P) fertilizer rate effects on lentil seed yields for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. Only treatments with granular inoculant and no additional N fertilizer were included.

P Fertilizer Rate	IH-21	IH-22	SC-22	SW-22	AVG
	---- Seed Yield (kg/ha) ----				
0 kg P_2O_5/ha (2)	1923	3509	2321	1806	2390
22 kg P_2O_5/ha (4)	2048	3619	2641	1794	2525
45 kg P_2O_5/ha (6)	2091	3711	2579	1828	2552
67 kg P_2O_5/ha (11)	2169	3832	2534	1823	2590
Orthogonal Contrast	---- Pr > *F* (p-value) ----				
P Rate – Linear	0.005	<0.001	0.038	0.764	<0.001
P Rate – Quadratic	0.705	0.925	0.004	0.956	0.114

Table 15. Predetermined contrasts comparing un-inoculated to inoculated lentils, with and without extra nitrogen (N) fertilizer, for seed yield at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	--------------------------------		Seed Yield (kg/ha)		--------------------------------
No inoculant – No N (1,3,5) vs.	2002 A	3636 A	2466 A	1839 A	2486 A
Inoculant – No N (2,4,6)	2021 A	3613 A	2513 A	1809 A	2489 A
Pr > *F* (p-value)	0.701	0.645	0.348	0.556	0.891
No Inoculant – Extra N (7,8) vs.	2107 A	3813 A	2585 A	1955 A	2615 A
Inoculant – Extra N (9,10)	2184 A	3846 A	2624 A	1983 A	2659 A
Pr > *F* (p-value)	0.217	0.589	0.534	0.649	0.155

Table 16. Predetermined contrasts comparing lentils with no extra nitrogen (N) fertilizer to lentils with extra N fertilizer, with and without inoculant, for seed yield at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	--------------------------------		Seed Yield (kg/ha)		--------------------------------
No N + Inoculant (6,11) vs.	2130 A	3771 A	2556 A	1825 B	2571 B
Extra N + Inoculant (9,10,12)	2184 A	3821 A	2607 A	1967 A	2645 A
Pr > *F* (p-value)	0.253	0.229	0.459	0.017	0.007
No N – No Inoculant (5) vs.	2065 A	3620 B	2589 A	1901 A	2544 A
Extra N – No Inoculant (7,8)	2107 A	3813 A	2585 A	1955 A	2615 A
Pr > *F* (p-value)	0.576	0.012	0.962	0.472	0.060

Table 17. Lentil fertility treatment effects on mean test weights for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. P-values below 0.05 indicate that the overall fertility effect was significant. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

P_2O_5 Rate - Inoculant - Extra N	IH-21	IH-22	SC-22	SW-22	AVG
	---------- p-value ----------				
Pr > *F*	0.890	0.852	0.023	0.031	0.031
	---------- Test Weight (g/0.5 l) ----------				
1) 0P - No - None	401.3 a	405.9 a	392.5 ab	389.1 ab	397.2 AB
2) 0P - Yes - None	401.5 a	406.2 a	393.7 ab	388.0 ab	397.4 AB
3) 22P - No - None	401.6 a	406.8 a	393.3 ab	390.3 a	398.0 A
4) 22P - Yes - None	401.0 a	405.9 a	393.3 ab	389.7 ab	397.5 AB
5) 45P - No - None	400.5 a	405.4 a	393.2 ab	388.4 ab	396.9 AB
6) 45P - Yes - None	401.7 a	405.8 a	394.5 a	389.3 ab	397.8 AB
7) 45P - No - 55N sideband	401.4 a	406.0 a	393.0 ab	388.1 ab	397.1 AB
8) 45P - No - 55N in-crop	401.6 a	405.9 a	391.7 b	388.6 ab	396.9 AB
9) 45P - Yes - 55N sideband	401.5 a	405.5 a	392.9 ab	388.8 ab	397.2 AB
10) 45P - Yes - 55N in-crop	400.6 a	405.5 a	392.9 ab	388.0 ab	396.7 AB
11) 67P - Yes - None	400.7 a	405.2 a	391.4 b	389.3 ab	396.6 B
12) 67P - Yes - 55N sideband	401.4 a	406.0 a	393.5 ab	387.4 b	397.1 AB
S.E.M	0.61	0.61	0.61	0.61	0.30

Table 18. Linear and quadratic orthogonal contrast results for phosphorus (P) fertilizer rate effects on lentil test weight for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. Only treatments with granular inoculant and no additional N fertilizer were included.

P Fertilizer Rate	IH-21	IH-22	SC-22	SW-22	AVG
	---------- Test Weight (g/0.5 l) ----------				
0 kg P_2O_5/ha (2)	401.5	406.2	393.7	388.0	397.4
22 kg P_2O_5/ha (4)	401.0	405.9	393.3	389.7	397.5
45 kg P_2O_5/ha (6)	401.7	405.8	394.5	389.3	397.8
67 kg P_2O_5/ha (11)	400.7	405.2	391.4	389.3	396.6
Orthogonal Contrast	---------- Pr > *F* (p-value) ----------				
P Rate – Linear	0.513	0.212	0.029	0.182	0.167
P Rate – Quadratic	0.731	0.763	0.020	0.128	0.025

Table 19. Predetermined contrasts comparing un-inoculated to inoculated lentils, with and without extra nitrogen (N) fertilizer, for seed yield at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	------------------------------- Test Weight (g/0.5 l) -------------------------------				
No inoculant – No N (1,3,5) vs.	401.1 A	406.0 A	393.0 A	389.3 A	397.4 A
Inoculant – No N (2,4,6)	401.4 A	406.0 A	393.8 A	389.0 A	397.6 A
Pr > *F* (p-value)	0.611	0.916	0.075	0.574	0.414
No Inoculant – Extra N (7,8) vs.	401.5 A	406.0 A	392.3 A	388.3 A	397.0 A
Inoculant – Extra N (9,10)	401.1 A	405.5 A	392.9 A	388.4 A	397.0 A
Pr > *F* (p-value)	0.505	0.402	0.356	0.863	0.838

Table 20. Predetermined contrasts comparing lentils with no extra nitrogen (N) fertilizer to lentils with extra N fertilizer, with and without inoculant, for seed yield at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	------------------------------- Test Weight (g/0.5 l) -------------------------------				
No N + Inoculant (6,11) vs.	401.2 A	405.5 A	393.0 A	389.3 A	397.2 A
Extra N + Inoculant (9,10,12)	401.2 A	405.7 A	393.1 A	388.1 B	397.0 A
Pr > *F* (p-value)	0.761	0.927	0.475	0.027	0.115
No N – No Inoculant (5) vs.	400.5 A	405.4 A	393.2 A	388.4 A	396.9 A
Extra N – No Inoculant (7,8)	401.5 A	406.0 A	392.3 A	388.3 A	397.0 A
Pr > *F* (p-value)	0.167	0.430	0.227	0.861	0.693

Table 21. Lentil fertility treatment effects on mean thousand seed weights for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. P-values below 0.05 indicate that the overall fertility effect was significant. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

P_2O_5 Rate - Inoculant - Extra N	IH-21	IH-22	SC-22	SW-22	AVG
	---------- p-value ----------				
Pr > *F*	0.888	0.220	0.054	0.276	0.987
	---------- Seed Weight (g/0.5 l) ----------				
1) 0P - No - None	42.6 a	42.3 a	49.7 a	46.7 a	45.4 A
2) 0P - Yes - None	43.0 a	42.2 a	49.8 a	46.6 a	45.4 A
3) 22P - No - None	42.9 a	42.8 a	50.4 a	46.2 a	45.5 A
4) 22P - Yes - None	43.3 a	42.9 a	49.9 a	46.6 a	45.5 A
5) 45P - No - None	43.3 a	42.6 a	50.0 a	46.3 a	45.5 A
6) 45P - Yes - None	43.4 a	42.9 a	50.1 a	45.8 a	45.4 A
7) 45P - No - 55N sideband	42.8 a	43.6 a	48.9 a	46.4 a	45.5 A
8) 45P - No - 55N in-crop	42.9 a	43.0 a	49.1 a	46.4 a	45.4 A
9) 45P - Yes - 55N sideband	43.0 a	43.2 a	49.0 a	47.3 a	45.7 A
10) 45P - Yes - 55N in-crop	42.6 a	43.4 a	49.4 a	46.8 a	45.6 A
11) 67P - Yes - None	43.0 a	42.9 a	49.7 a	46.2 a	45.4 A
12) 67P - Yes - 55N sideband	42.9 a	43.0 a	49.6 a	46.7 a	45.6 A
S.E.M	0.40	0.34	0.47	0.35	0.20

Table 22. Linear and quadratic orthogonal contrast results for phosphorus (P) fertilizer rate effects on lentil thousand seed weight for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. Only treatments with granular inoculant and no additional N fertilizer were included.

P Fertilizer Rate	IH-21	IH-22	SC-22	SW-22	AVG
	---------- Seed Weight (g/1000 seeds) ----------				
0 kg P_2O_5/ha (2)	43.1	42.2	49.8	46.6	45.4
22 kg P_2O_5/ha (4)	42.6	42.9	49.9	46.6	45.5
45 kg P_2O_5/ha (6)	42.9	42.9	50.1	45.8	45.4
67 kg P_2O_5/ha (11)	42.9	42.9	49.7	46.2	45.4
Orthogonal Contrast	---------- Pr > *F* (p-value) ----------				
P Rate – Linear	0.923	0.249	0.923	0.206	0.879
P Rate – Quadratic	0.519	0.316	0.519	0.641	0.788

Table 23. Predetermined contrasts comparing un-inoculated to inoculated lentils, with and without extra nitrogen (N) fertilizer, for thousand seed weight at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	------------------------- Seed Weight (g/1000 seeds) -------------------------				
No inoculant – No N (1,3,5) vs.	42.9 A	42.6 A	50.0 A	46.4 A	45.5 A
Inoculant – No N (2,4,6)	42.9 A	42.7 A	49.9 A	46.3 A	45.4 A
Pr > *F* (p-value)	0.977	0.770	0.725	0.792	0.861
No Inoculant – Extra N (7,8) vs.	43.3 A	43.3 A	49.0 A	46.4 B	45.5 A
Inoculant – Extra N (9,10)	43.1 A	43.3 A	49.2 A	47.0 A	45.6 A
Pr > *F* (p-value)	0.519	0.943	0.616	0.050	0.380

Table 24. Predetermined contrasts comparing lentils with no extra nitrogen (N) fertilizer to lentils with extra N fertilizer, with and without inoculant, for thousand seed weight at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	------------------------- Seed Weight (g/1000 seeds) -------------------------				
No N + Inoculant (6,11) vs.	42.9 A	42.9 A	49.9 A	46.0 B	45.4 A
Extra N + Inoculant (9,10,12)	43.1 A	43.2 A	49.3 B	46.9 A	45.6 A
Pr > *F* (p-value)	0.630	0.311	0.050	0.002	0.193
No N – No Inoculant (5) vs.	43.0 A	42.6 A	50.0 A	46.3 A	45.5 A
Extra N – No Inoculant (7,8)	43.3 A	43.3 A	49.0 B	46.4 A	45.5 A
Pr > *F* (p-value)	0.380	0.115	0.018	0.907	0.930

Table 25. Lentil fertility treatment effects on mean seed protein concentrations for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. P-values below 0.05 indicate that the overall fertility effect was significant. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

P_2O_5 Rate - Inoculant - Extra N	IH-21	IH-22	SC-22	SW-22	AVG
	------------- p-value -------------				
Pr > *F*	0.807	0.875	0.618	0.907	0.835
	------------- Seed Protein (%) -------------				
1) 0P - No - None	26.50 a	26.39 a	23.66 a	24.14 a	25.17 A
2) 0P - Yes - None	26.23 a	26.44 a	23.95 a	24.25 a	25.22 A
3) 22P - No - None	26.46 a	26.72 a	23.58 a	24.04 a	25.20 A
4) 22P - Yes - None	26.81 a	26.57 a	24.21 a	24.14 a	25.43 A
5) 45P - No - None	26.38 a	26.70 a	23.85 a	23.94 a	25.22 A
6) 45P - Yes - None	26.57 a	26.29 a	23.84 a	24.67 a	25.34 A
7) 45P - No - 55N sideband	26.48 a	26.72 a	23.20 a	24.08 a	25.12 A
8) 45P - No - 55N in-crop	27.11 a	26.89 a	24.04 a	24.01 a	25.51 A
9) 45P - Yes - 55N sideband	26.39 a	26.25 a	23.48 a	24.53 a	25.16 A
10) 45P - Yes - 55N in-crop	26.88 a	26.93 a	23.69 a	24.04 a	25.38 A
11) 67P - Yes - None	26.46 a	26.63 a	24.06 a	24.04 a	25.29 A
12) 67P - Yes - 55N sideband	26.60 a	26.85 a	23.61 a	24.16 a	25.30 A
S.E.M	0.306	0.320	0.321	0.300	0.156

Table 26. Linear and quadratic orthogonal contrast results for phosphorus (P) fertilizer rate effects on lentil seed protein concentrations for four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites. Only treatments with granular inoculant and no additional N fertilizer were included.

P Fertilizer Rate	IH-21	IH-22	SC-22	SW-22	AVG
	------------- Seed Protein (%) -------------				
0 kg P_2O_5/ha (2)	26.23	26.63	23.95	24.25	25.22
22 kg P_2O_5/ha (4)	26.81	26.63	24.21	24.14	25.43
45 kg P_2O_5/ha (6)	26.57	26.63	23.84	24.67	25.34
67 kg P_2O_5/ha (11)	26.46	26.63	24.06	24.04	25.29
<u>Orthogonal Contrast</u>	------------- Pr > *F* (p-value) -------------				
P Rate – Linear	0.755	0.839	0.980	0.945	0.833
P Rate – Quadratic	0.267	0.750	0.962	0.396	0.398

Table 27. Predetermined contrasts comparing un-inoculated to inoculated lentils, with and without extra nitrogen (N) fertilizer, for seed protein concentrations at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	---------- Seed Protein (%) ----------				
No inoculant – No N (1,3,5) vs.	26.44 A	26.60 A	23.70 A	24.04 A	25.20 A
Inoculant – No N (2,4,6)	26.54 A	26.43 A	24.00 A	24.35 A	25.33 A
Pr > *F* (p-value)	0.711	0.507	0.238	0.221	0.291
No Inoculant – Extra N (7,8) vs.	26.80 A	26.81 A	23.62 A	24.05 A	25.32 A
Inoculant – Extra N (9,10)	26.64 A	26.59 A	23.58 A	24.28 A	25.27 A
Pr > *F* (p-value)	0.613	0.491	0.914	0.447	0.786

Table 28. Predetermined contrasts comparing lentils with no extra nitrogen (N) fertilizer to lentils with extra N fertilizer, with and without inoculant, for seed protein concentrations at four sites (Indian Head 2021 and 2022, Scott 2022, and Swift Current 2022) and averaged across sites.

Inoculant Comparisons	IH-21	IH-22	SC-22	SW-22	AVG
	---------- Seed Protein (%) ----------				
No N + Inoculant (6,11) vs.	26.51 A	26.46 A	23.95 A	24.35 A	25.32 A
Extra N + Inoculant (9,10,12)	26.62 A	26.68 A	23.59 A	24.24 A	25.28 A
Pr > *F* (p-value)	0.761	0.356	0.276	0.462	0.765
No N – No Inoculant (5) vs.	26.38 A	26.70 A	23.85 A	23.94 A	25.22 A
Extra N – No Inoculant (7,8)	26.80 A	26.81 A	23.62 A	24.05 A	25.32 A
Pr > *F* (p-value)	0.275	0.782	0.541	0.774	0.601

Abstract

14. Abstract/Summary

Field trials were conducted at Indian Head, Scott, and Swift Current in 2021 and 2022 to demonstrate lentil response to phosphorus rate and nitrogen management strategies which encompassed combinations of rhizobial inoculant, starter N, and in-crop N. The locations were representative of Saskatchewan's Brown, Dark Brown, and thin Black soil zones. Data from Scott and Swift Current in 2021 were removed due to poor environmental conditions and high variability. Data collection included residual soil nutrients, emergence, seed yield, test weight, seed weight, and seed protein. Emergence was not affected by the treatments in any cases; thus, indicating that side-banding provided adequate separation between the seed and fertilizer. Yields increased with P fertilizer at 3 of 4 sites, with the strongest responses observed at Indian Head, a modest response at Scott, and no response at Swift Current. Residual P was extremely low at Indian Head (both years), slightly higher but still deficient at Scott, and approaching sufficiency at Swift Current. No yield benefits to rhizobial inoculation were detected at any locations. Responses to extra N were inconsistent and small, but detected at Swift Current and Indian Head in 2022. With low organic matter, coarse soil texture, and low residual N, Swift Current was the best candidate for supplemental N to be beneficial. These conditions were not met at Indian Head; however, yields were well above-average and the N provided by biological fixation may not have been sufficient to achieve the maximum yield potential at this site. In conclusion, we recommend P fertilizer rates that meet or exceed expected removal, depending on soil test levels and objectives, to achieve optimum yields without depleting soil fertility. An exception would be soils that are already high in P, in which case low rates of starter P are likely adequate. We hesitate to suggest that growers may not need to inoculate, as biological N fixation is critical for profitable lentil production and naturally occurring populations of *Rhizobium leguminosarum* may vary across the landscape and from year-to-year. We would not broadly recommend applying N fertilizer beyond what is supplied by modest rates of P and sulfur products; however, responses could occur in coarse textured soils low in both organic matter and residual N and, potentially, when yield potential is especially high; however, the latter can be difficult to predict.