2023 Interim Report

for the

Saskatchewan Pulse Crop Development Board

Lentil Response to Varying Rates and Combinations of Potassium and Sulfur Fertility

(Project #AP-2317a)

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SPG Applied Research & Demonstration – Final Report

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1. **Project Code** (as per contract): AP2317a

2. **Project Title:** Lentil (*Lens culinaris*) Response to Varying Rates and Combinations of Potassium and Sulfur Fertilizer

3. **Introduction** (background and rationale for the project – include references to original research projects where necessary):

   While the majority of past soil fertility research and demonstration activities in lentil have focused on nitrogen (N) and phosphorus (P), potassium (K) and sulphur (S) are also important nutrients which are frequently applied as fertilizer by Saskatchewan farmers. The most commonly utilized source of K is potash (0-0-60), which is readily available, soluble, and also contains approximately 45% chloride. Crop responses to potash in high K soils can sometimes be attributed to chloride. Sulfur is applied in a variety of forms which can be broadly categorized as elemental or sulfate-based products, or a combination of the two. Both types can be effective if managed appropriately; however, sulfate-based products are highly soluble and immediately available to crops. The dominant form of granular, sulfate-S is ammonium sulphate (21-0-0-24). It is estimated that lentils take up an average of 38-46 kg K_2O/Mt (2.3-2.8 lb K_2O/bu or 69-84 lb K_2O/ac for a 30 bu/ac lentil crop; i.e., https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/potassium-fertilization-in-crop-production). For sulfur, the estimated total uptake is 5 kg S/Mt (0.3 lb S/bu on average, or approximately 8-10 lb S/ac for a 30 bu/ac crop; i.e., https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/sulphur-fertilization-in-crop-production). Removal of these nutrients in the harvested grain by lentil was recently estimated (https://prairienutrientcalculator.info) at approximately 11.7 kg K_2O/Mt (0.7 lb K_2O/bu) and 2.2 kg S/Mt (0.13 lb S/bu).

   All the fertilizer forms utilized in the project are known to be effective sources of plant available K and S; however, research on lentil responses to these nutrients is limited. In a recent study with sites throughout Montana and North Dakota, Miller et al. (2022) found that the addition of 6 kg S/ha increased lentil yield at 4/20 site-years by an average of 13% at the responsive sites. At 75% of the S responsive sites, soil test results did not suggest that such a response would be likely. Sulfur fertilization increased seed protein by an average of 0.6 g/100 g (%) at 3 of the 14 sites for which data were available. Potassium fertilization (in the absence of S), increased lentil yields at 1 site, reduced yields at 1 site, and had no effect on yield at 18 sites (Miller et al., 2022). In a complementary study, Baber et al. (2022) found that, at 1 of 5 site-years, S fertilization increased the amount of N fixed by 32-38 kg N/ha. They speculated that the effect was indirect in that S fertilizer increased plant growth and, subsequently, allowed more carbon to be sent to the root nodules. The responsive location (Bozeman) was low in sulphate S (~4 ppm) and the responsive year (2020) had relatively low precipitation but good overall crop growth. The non-responsive years at this location either had much more precipitation and presumably greater mineralization of organic S (i.e., 2019) or were drought affected with poor overall crop growth (i.e., 2021). Soil exchangeable K levels were always high and N fixation responses to K were not observed in any cases. The positive effect of sulfur supply on N_2 fixation has previously been shown in field pea (Scherer et al., 2006). While not applicable to most soils in western Canada, potash application in sandy, K deficient soils of Pakistan increased lentil yields by 24% (Singh and Sharma, 2021). Similarly, Saha et al (2021) found that foliar and soil applied K fertilizer increased lentil yield by 15 and 23.5%, respectively. Work conducted in Ethiopia, looking at on lentil response to S with and without rhizobium inoculant, found increased plant biomass, S recovery, nodules per plant, and pods per plant when lentils were inoculated with rhizobium and fertilized with 20 kg S/ha compared to no additional sulphur application (Mekuria et al., 2019). Recent work in Saskatchewan focused on N, P, and S fertility in field pea showed reasonably consistent responses to P fertilization in low P soils, but responses to S were elusive (Holzapfel et al. 2020). At 1/12 sites (Yorkton 2019), a linear response to S rates from 0-15 kg S/ha was detected with a maximum yield increase exceeding 10%; however, this response was not predicted by soil test results. Under relatively low yielding conditions (due to drought) at Indian Head 2020, there was no yield response to S fertilization but a linear increase in seed protein content was detected.

Further work needs to be conducted to determine if additional K and S fertility provide beneficial responses to lentils grown in Saskatchewan. The current project is relevant to Saskatchewan lentil growers due to the importance of balanced fertility in crop production, high fertilizer costs, and the relative lack of current, regionally relevant work looking on K and S fertility in lentils. This topic was recently identified as a high priority by the directors and membership of the Saskatchewan Pulse Crop Development Board.

Literature Cited

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4. **Objective(s):**

The objectives of this project were to demonstrate, for a range of Saskatchewan environments, the yield and quality response of small red lentils to varying rates and combinations of potassium (K) and sulfur (S) fertilizer.

5. **Materials & Methods** (experimental design, methods used, details of growing season, materials used, sites and site design, statistical analysis used):

Field trials with small red lentils were conducted at Swift Current (Brown soil zone), Scott (Dark Brown soil zone), and Indian Head (thin Black Soil Zone) in the 2023 growing season. We will repeat the trials at all three locations in 2024. The treatments were factorial combination of three potassium (K) rates (0, 22, and 45 kg K_2O/ha) and three sulfur (S) rates (0, 11, and 22 kg S/ha) along with two additional control treatments to help explain responses and provide additional context. One of the control treatments was intended to show the potential losses that might occur when no fertilizer whatsoever is applied (Trt. #1). Since N was not balanced across treatments, the second control was to help ascertain whether responses to ammonium sulphate (AMS) were due to the S or the N that is provided by this product. For all treatments except #1, the phosphorus (P) rate was held constant at 45 kg P_2O_5/ha, provided as mono ammonium phosphate (MAP). All fertilizer was side-banded during seeding and all treatments received a label recommended rate of granular rhizobial inoculant. The treatments are described in Table 1 below.

Table 1. Lentil fertility treatments in potassium (K_2O) and sulfur (S) demonstrations conducted at Indian Head, Scott, and Swift Current in 2023.

#	Nitrogen [z] (kg N/ha)	Phosphorus (kg P_2O_5/ha)	Potassium (kg K_2O/ha)	Sulfur (kg S/ha)	Description
1	0	0	0	0	Unfertilized Control
2	10	45	0	0	Phosphorus Only
3	10	45	22	0	Low Potassium
4	10	45	45	0	High Potassium
5	18	45	0	10	Low Sulphur
6	27	45	0	20	High Sulphur
7	18	45	22	10	Low Potassium – Low Sulphur
8	18	45	45	10	High Potassium – Low Sulphur
9	27	45	22	20	Low Potassium – High Sulphur
10	27	45	45	20	High Potassium – High Sulphur
11	27	45	0	0	High Nitrogen Control

[z] Except for treatment #11 which received supplemental urea, all N was provided by MAP and AMS

Selected agronomic information and dates of operations are provided in Table 10 of the Appendices. The lentils were direct seeded into cereal stubble (wheat at all three 2023 sites) and all locations used the variety CDC Proclaim CL, seeded at a target rate of 190 seeds/m^2. Weeds were controlled with registered pre-emergent and in-crop herbicide applications and pre-harvest herbicides or desiccants were utilized at the discretion of individual site mangers. The plots were straight combined as soon as feasible after it was fit do so and outside rows were excluded from the harvest area wherever possible.

Various data were collected during the growing season and from the harvested samples. Spring plant densities were estimated by counting 2 x 1 m sections of crop row after emergence was complete and converting the averaged values to plants/m^2. Seed yields were determined from the harvested grain samples and are corrected for dockage and to 13% seed moisture content. Test weights were determined from the cleaned sub-samples using standard Canadian Grain Commission methods and are expressed as g/0.5 l. Seed weight was determined by counting and weighing a minimum of 250 seeds per plot and converting the values to g/1000 seeds. Seed protein concentrations were determined using a FOSS NIR instrument. Growing season temperatures and precipitation amounts were compiled from the nearest Environment and Climate Change Canada weather stations.

Response data were analyzed separately for each location using the generalized linear mixed model (GLIMMIX) in SAS® Studio. At this stage of the project, the analyses were kept simple with effects of all 11 individual fertilizer treatments considered fixed and replicate effects considered random. Pre-determined contrasts were used to compare the unfertilized check (1) to the combined fertilized treatments (2-11), No KCl (2,5,6) to KCl (3,4,7,8,9,10), low rates of KCl (3,7,9) to high rates of KCl (4,8,10), no AMS (2,3,4) to AMS (5,6,7,8,9,10), and low rates of AMS (5,7,8) to high rates of AMS (6,9,10). All treatment effects and differences between means were considered significant at $P \leq$

0.05; however, responses of $P \leq 0.1$ may also be highlighted if they make agronomic sense and are of potential agronomic importance.

6. **Results & Discussion** (results presented and discussed in the context of existing knowledge and relevant literature or comparison to existing recommendations. Detail any major concerns or sources of error. Provide proper statistical significance.):

Soil test results for each location are provided in Table 2. As expected, the soil at Indian Head had a higher pH, organic matter (OM) and C.E.C than Scott or Swift Current. Scott had the lowest pH and more intermediate OM while Swift Current had the lowest OM and a neutral pH. At 484 ppm, Indian Head had considerably higher K levels than the other locations (205-224 ppm); however, K levels were never low enough, regardless of location, to be considered limiting with a high probability of yield response to fertilization. Chloride levels ranged from 5-31 kg/ha and, while lentil response to Cl is not well understood, these values were interpreted as very low to low (Agvise Laboratories) for all three locations. Sulfur levels for the upper 15 cm ranged from 13-18 kg/ha which was interpreted as 'medium' in terms of relative availability; however, sub-soil S levels were generally high and, when the full soil profile was considered, S was broadly considered unlikely to be limiting. That said, S is notoriously difficult to test for due to its high variability across the landscape and potential to move up and down in the soil profile with water.

Table 2. Selected soil test analyses results for lentil potassium (K) and sulfur (S) conducted at Indian Head, Scott, and Swift Current in 2023.

Parameter	Depth (cm)	IH-23	SC-23	SW-22
pH	0-15	8.1	5.5	6.6
Organic Matter (%)	0-15	4.7	3.3	2.6
C.E.C. (meq)	0-15	47.8	15.2	18.9
NO_3-N (kg/ha) [Z]	0-60	12	34	26
Olsen-P (ppm)	0-15	3	13	10
K (ppm)	0-15	484	205	224
D1-S (kg/ha)	0-15	13	18	16
D2-S (kg/ha)	15-30	–	20	–
D3-S (kg/ha)	30-60	40	–	40
Cl (kg/ha) [Z]	0-60	31	5[Z]	18

[Z] Estimated for 0-60 cm depth by multiplying 0-30 cm values by 1.5

Mean monthly temperatures and precipitation amounts for May-August site are presented relative to the long-term (1981-2010) averages for each location in Tables 3 and 4, respectively. Temperatures were well above average at all locations, with May and June being especially hot. In contrast to any expectations based on the long-term averages, the absolute and relative precipitation totals were lowest at Indian Head (119 mm or 49% of average), intermediate at Scott (159 mm or 70% of average), and highest at Swift Current (179 m or 95% of average). Unfortunately, the plots at Swift Current were damaged during a July 22 hailstorm that resulted in an estimated 60% yield loss; however, the damage was uniform and all data from this location still appeared to be valid and usable. Overall, lentils are well adapted to hot, dry conditions and still fared quite well.

Table 3. Mean monthly temperatures along with long-term (1981-2010) averages for the 2023 and 2024 growing seasons at Indian Head, Scott, and Swift Current.

Location	Year	May	June	July	August	Average
		------ Mean Temperature (°C) ------				
Indian Head	2023	14.0	19.4	16.7	17.7	17.0 (+1.4)
	2024	–	–	–	–	–
	Long-term	*10.8*	*15.8*	*18.2*	*17.4*	*15.6*
Scott	2023	14.9	17.2	17.1	17.4	16.7 (+1.9)
	2024	–	–	–	–	–
	Long-term	*10.8*	*14.8*	*17.3*	*16.3*	*14.8*
Swift Current	2023	14.8	17.7	18.4	18.8	17.4 (+1.6)
	2024	–	–	–	–	–
	Long-term	*11.0*	*15.7*	*18.4*	*17.9*	*15.8*

Table 4. Mean monthly precipitation along with long-term (1981-2010) averages for the 2023 and 2024 growing seasons at Indian Head, Scott, and Swift Current.

Location	Year	May	June	July	August	Total
		------ Cumulative Precipitation (mm) ------				
Indian Head	2023	12.9	49.6	15.9	40.8	119 (49%)
	2024	–	–	–	–	–
	Long-term	*51.7*	*77.4*	*63.8*	*51.2*	*244*
Scott	2023	16.6	81.1	29.7	31.7	159 (70%)
	2024	–	–	–	–	–
	Long-term	*38.9*	*69.7*	*69.4*	*48.7*	*227*
Swift Current	2023	41.0	32.9	63.3*	42.1	179 (95%)
	2024	–	–	–	–	–
	Long-term	*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

Individual treatment means are presented for all response variables in Tables 5-9 below while results of the overall tests of fixed effects are in Table 11 of the Appendices. Results from all contrast comparisons and the corresponding group means are provided in Tables 12-16 of the Appendices. Highlights of the results will be discussed separately for each variable in the following paragraphs. Importantly, the statistical significance of the results presented may change in future reports when data is combined across locations and/or analyzed in a different manner.

Overall mean plant densities were higher at Indian Head (196 plants/m^2) than at Swift Current and Scott (144-155 plants/m^2). As such, with a target seeding rate of 190 seeds/m^2, seedling mortality was negligible at Indian Head and approximately 18-24% at the other two locations. The overall treatment effect (Table 11) on emergence was never significant (P = 0.105-0.962), indicating that no differences between individual treatment means (Table 5) were statistically significant. The contrast comparisons at Indian Head suggested that plant populations were higher with KCl (202 plants/m^2)

than without (188 plants/m^2). At Scott, the contrasts suggested that populations were slightly less at the high, 22 kg S/ha, rate of AMS (148 plants/m^2) compared to the low 11 kg S/ha rate (159 plants/m^2). With all fertilizer side-banded, we did not necessarily expect any treatment effects on emergence. The observed differences were too small to be of much agronomic importance and, without reason to expect such responses or any significant overall F-tests, were largely attributed to random variability.

Table 5. Mean plant densities for individual lentil K and S fertility treatments at Indian Head, Scott, and Swift Current (2023). Data were analyzed for each location individually and means within a column followed by the same letter do not significantly differ (Tukey's; P ≤ 0.05).

#	$N-P_2O_5-K_2O-S$ (kg/ha)	Indian Head	Scott	Swift Current
		---------- Emergence (plants/m^2) ----------		
1	0-0-0-0	194 A	149 A	149 A
2	10-45-0-0	176 A	152 A	146 A
3	10-45-22-0	201 A	160 A	141 A
4	10-45-45-0	197 A	172 A	146 A
5	19-45-0-11	192 A	161 A	152 A
6	29-45-0-22	196 A	147 A	139 A
7	19-45-22-0	205 A	156 A	140 A
8	19-45-45-11	202 A	159 A	142 A
9	29-45-22-22	204 A	149 A	143 A
10	29-45-45-22	204 A	149 A	144 A
11	29-45-0-0	183 A	154 A	143 A
	S.E.M.	8.3	5.9	6.4

Individual treatment means for seed yield are provided in Table 6 while the group means and comparisons are in Table 13 of the Appendices. Seed yields were lowest at Swift Current (1306 kg/ha), intermediate at Indian Head (2687 kg/ha), and highest at Scott (3772 kg/ha). The low yields at Swift Current were largely attributed to the hail; however, the overall variability at this site was reasonably low despite the damage. The high yields at Scott were attributed to adequate, but not excessive precipitation; however, data were quite variable at this location. At Indian Head, where precipitation was extremely low, yields were considered approximately average to slightly above average; however, variability was also somewhat high at this location and attributed primarily to wild oats that were not completely controlled by the group 1 and 2 in-crop herbicides. The overall test of fixed effects for yield were not significant at the desired probability for any locations (P = 0.090-0.541); however, the check versus rest comparisons at Indian Head (P = 0.006) and Swift Current (P = 0.049) suggested an overall response to fertilizer applications at these two locations. At Indian Head, the unfertilized control yielded 2469 kg/ha while the fertilized treatments averaged 2709 kg/ha. At Swift Current, the values were 1170 kg/ha and 1320 kg/ha for the control and fertilized treatments, respectively. Based on soil test results, the lack of any other significant treatment comparisons, and past research results, the overall yield increases with fertilization at Indian Head was attributed primarily to phosphorus. At Swift Current, the contrast comparing the treatments with and without KCl was marginally significant (*P* = 0.088), which may have partly explained the overall response to fertilization. As the site with the lowest OM and relatively low soil test K (compared to Indian Head), Swift Current was arguably the most likely site to expect a response to KCl. The only significant contrast at Scott suggested lower yields (P = 0.017) with AMS (3685 kg/ha) than without (3948 kg/ha); however, this was attributed to the relatively high, and largely random, variability. There was no reason to expect low rates of side-banded AMS to have a negative effect on yield, even if the nutrients were not deficient and likely to increase yield. Furthermore, the low versus high AMS rate comparison showed a trend for higher yields at the higher S rate (P = 0.089), which would not be expected if there was a genuine negative response to this product.

Table 6. Mean seed yields for individual lentil K and S fertility treatments at Indian Head, Scott, and Swift Current (2023). Data were analyzed for each location individually and means within a column followed by the same letter do not significantly differ (Tukey's; P ≤ 0.05).

#	$N-P_2O_5-K_2O-S$ (kg/ha)	Indian Head	Scott	Swift Current
		---------- Seed Yield (kg/ha) ----------		
1	0-0-0-0	2469 A	3849 A	1170 A
2	10-45-0-0	2679 A	4006 A	1300 A
3	10-45-22-0	2790 A	4049 A	1301 A
4	10-45-45-0	2715 A	3789 A	1338 A
5	19-45-0-11	2774 A	3514 A	1218 A
6	29-45-0-22	2581 A	3689 A	1252 A
7	19-45-22-0	2564 A	3644 A	1386 A
8	19-45-45-11	2705 A	3578 A	1335 A
9	29-45-22-22	2772 A	3738 A	1374 A
10	29-45-45-22	2715 A	3946 A	1344 A
11	29-45-0-0	2794 A	3689 A	1348 A
	S.E.M.	121.2	213.5	73.3

The overall test of fixed effects for lentil test weight (Table 11) were not significant at any locations (*P* = 0.184-0.741). The values were lowest at Swift Current (370 g/0.5 l or 59.3 lb/bu-A), intermediate at Indian Head (394 g 0.5/l or 63.2 lb/bu-A), and extremely high at Scott (502 g/0.5 l or 80.5 lb/bu-A). The unusually high values from Scott will likely be excluded from any future combined statistical analyses; however, there were no indications of any treatment effects in either the overall F-test (*P* = 0.741) or predetermined contrast comparisons (*P* = 0.300-0.819) for this variable. Similarly, we saw no significant contrast comparisons for test weight at Swift Current (*P* = 0.143-0.829). At Indian Head, the sole significant contrast was for low versus high rates of AMS where the values were slightly (*P* = 0.045) lower at the higher rate (393.6 versus 394.8 g/0.5 l); however, relative to environmental impacts, this difference was too small to be of any concern from either an agronomic or end-use quality perspective.

Table 7. Mean test weights for individual lentil K and S fertility treatments at Indian Head, Scott, and Swift Current (2023). Data were analyzed for each location individually and means within a column followed by the same letter do not significantly differ (Tukey's; P ≤ 0.05).

#	$N\text{-}P_2O_5\text{-}K_2O\text{-}S$ (kg/ha)	Indian Head	Scott	Swift Current
		-- Test Weight (g/0.5 l)	--	--
1	0-0-0-0	394.3 A	502.1 A	369.4 A
2	10-45-0-0	394.8 A	501.8 A	369.9 A
3	10-45-22-0	395.0 A	503.7 A	370.8 A
4	10-45-45-0	394.6 A	502.5 A	371.3 A
5	19-45-0-11	395.0 A	501.9 A	369.5 A
6	29-45-0-22	393.8 A	503.5 A	369.3 A
7	19-45-22-0	394.1 A	502.2 A	370.4 A
8	19-45-45-11	395.3 A	501.4 A	369.5 A
9	29-45-22-22	394.3 A	501.9 A	370.4 A
10	29-45-45-22	392.8 A	501.0 A	369.1 A
11	29-45-0-0	393.1 A	503.6 A	372.8 A
	S.E.M.	0.70	1.19	0.89

Individual treatment means for thousand seed weight are presented in Table 8 below while the group means, and contrast comparisons are in Table 15 of the Appendices. Overall mean seed weights were similar at Indian Head and Scott (52.9-53.2 g/1000 seeds) but lower at Swift Current (46.6 g/1000 seeds). None of the overall tests of fixed effects (Table 11) were significant for this variable; however, both the check versus rest (*P* = 0.033) and no KCl versus KCl (*P* = 0.018) comparisons were significant at Scott. These responses indicated a small but significant increase in seed weight with fertilizer when combined across treatments (52.6 versus 53.3 g/1000 seeds) and more specifically with the addition of KCl (53.0 versus 53.5 g/1000 seeds). None of the pre-determined contrast comparisons for seed weight were significant at either Indian Head (*P* = 0.112-0.638) or Swift Current (*P* = 0.128-0.943).

Finally, seed protein concentrations were highly consistent across environments with an overall treatment average of 24.7% for all three locations. The overall tests of fixed effects (Table 12) were not significant in any cases (*P* = 0.320-0.839) and no contrast comparisons (Table 16) were significant at either Indian Head (*P* = 0.076-0.796) or Scott (*P* = 0.266-0.956). At Swift Current, we saw slightly higher seed protein values in the absence of KCl (25.0%) versus the combined treatments where KCl was applied (24.5%). No other contrast comparisons for seed protein at Swift Current were significant (*P* =0.307-0.370). While not statistically significant at the desired probability, there was a strong trend for higher yields with KCl at this location and, if this response was real, the observed reduction in protein may have been attributable to dilution of N in the seed.

Table 8. Mean thousand seed weights (TSW) for individual lentil K and S fertility treatments at Indian Head, Scott, and Swift Current (2023). Data were analyzed for each location individually and means within a column followed by the same letter do not significantly differ (Tukey's; $P \leq 0.05$).

#	$N-P_2O_5-K_2O-S$ (kg/ha)	Indian Head	Scott	Swift Current
		------ Seed Weight (g/1000 seeds) ------		
1	0-0-0-0	52.8 A	52.6 A	46.5 A
2	10-45-0-0	52.8 A	52.7 A	47.0 A
3	10-45-22-0	52.9 A	53.3 A	46.0 A
4	10-45-45-0	52.5 A	54.1 A	46.9 A
5	19-45-0-11	53.0 A	53.0 A	46.0 A
6	29-45-0-22	52.8 A	53.2 A	46.9 A
7	19-45-22-0	53.6 A	53.5 A	46.9 A
8	19-45-45-11	53.2 A	53.4 A	46.8 A
9	29-45-22-22	53.1 A	53.3 A	45.5 A
10	29-45-45-22	52.9 A	53.5 A	47.1 A
11	29-45-0-0	52.8 A	53.1 A	46.8 A
	S.E.M.	0.43	0.56	1.77

Table 9. Mean seed protein concentrations for individual lentil K and S fertility treatments at Indian Head, Scott, and Swift Current (2023). Data were analyzed for each location individually and means within a column followed by the same letter do not significantly differ (Tukey's; $P \leq 0.05$).

#	$N-P_2O_5-K_2O-S$ (kg/ha)	Indian Head	Scott	Swift Current
		------ Seed Protein (%) ------		
1	0-0-0-0	24.7 A	24.6 A	24.7 A
2	10-45-0-0	24.6 A	25.0 A	25.1 A
3	10-45-22-0	24.6 A	25.1 A	24.4 A
4	10-45-45-0	24.6 A	24.5 A	24.4 A
5	19-45-0-11	25.0 A	24.5 A	24.9 A
6	29-45-0-22	25.0 A	24.7 A	24.9 A
7	19-45-22-0	24.4 A	24.3 A	24.7 A
8	19-45-45-11	24.5 A	24.8 A	24.7 A
9	29-45-22-22	25.1 A	25.0 A	24.1 A
10	29-45-45-22	24.8 A	24.8 A	24.7 A
11	29-45-0-0	24.9 A	24.9 A	24.7 A
	S.E.M.	0.26	0.34	0.26

7. **Economic & Practical Implications for Growers:**

With the only evidence of positive yield responses to fertilizer at Indian Head likely being attributable to phosphorus, no positive responses to fertilizer at Scott, the additions of either K or S fertilizer at these locations would have reduced the short-term net economic returns for lentil production in 2023. At Swift Current, while there was a trend for a positive response to KCl, it was not significant at the desired probability. These results were not necessarily unexpected given that soil test results did not indicate a need for these nutrients and past research and experience has shown responses to them to be somewhat elusive for lentils in western Canada.

To look more closely at the economic implications of adopting the K and S fertilizer treatments that were evaluated, we can consider the following numbers. Based on current spot fertilizer prices (Feb-28-2024; $645/Mt potash), the addition of KCl would have cost an estimated $24/ha and $48/ha at the 22 and 45 kg K_2O/ha rates, respectively. Using estimated small red lentil prices from approximately the same time frame of $750/Mt ($34/CWT), we would only require yield gains of approximately 32 kg/ha (0.5 bu/ac) and 65 kg/ha (1 bu/ac) to pay for the potash at the utilized rates. For ammonium sulfate, the spot fertilizer price from the time of writing was $545/Mt and the conclusions are similar. Normally, we would give credit for the extra N provided by this product; however, given that extra urea (or similar) is not normally recommended in lentil production, it is reasonable not to separate the costs of N and S in this specific case. As such, we required yield gains of 33 kg/ha (0.5 bu/ac) and 67 kg/ha (1 bu/ac) to cover the costs of 11 kg S/ha (46 kg AMS/ha) and 22 kg S/ha (92 kg AMS/ha), respectively. The most expensive combination of KCl and AMS evaluated in this project would have only required a yield response of 131 kg/ha (2 bu/ac) to cover the added fertilizer costs. Depending on the size of the experiment and overall variability, such small yield gains can be difficult to declare statistically significant at a 95% confidence level, even if they are genuine. An argument could be made that applying low rates of either of these nutrients may help maintain soil fertility in the long-term and doing so may be considered by some to be a relatively low-cost insurance against potential yield loss and future nutrient deficiencies.

8. **Conclusions & Recommendations** (how do results relate to original objectives or research that the project is based on? Is there a need to refine current recommendations based on the results from this project?):

   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 lentil response, or lack thereof, to K and S fertilizer applications. Given that soil tests did not indicate a high probability of response for either of these nutrients and responses in past research have been somewhat elusive and difficult to predict, the observed results were not necessarily unexpected. Currently, K and S fertilizer are not commonly specifically recommended for lentil production; however, small, or modest amounts of either nutrient may be frequently applied as part of longer-term or rotation wide nutrient management plans. This is especially the case with elemental sources of S which may not be available in the year of application but can be a cost-effective source of this nutrient over the long-term if managed appropriately. Although this project will be repeated in the 2024 growing season, our results to date would not justify refining the current fertility recommendations for small red lentil production in Saskatchewan.

9. **Future Research** (did the project identify a need for future research?):

   This project will be repeated in the 2024 growing season, therefore the current results and recommendations are only preliminary. Next year, we plan to take a different approach to looking at the data which will lend itself better to combining data across locations, more effectively isolate responses to K and S, and allow to identify any interactions between K and S, even though none are specifically expected. We plan to analyze the data using two separate models. The first will largely be used to help explain results of the second and put things in context. All 11 entries will be included; however, only select contrast comparisons will be looked at in detail. These will include, for each individual site and across sites, the 'Check versus Rest' contrast which compares the unfertilized control (1) to all fertilized treatments (2-11). This will help to establish whether there was an overall response to fertilizer applications, regardless of product or rate. A second contrast will compare the 'High N Control' (11) to treatment 6 which receives 29 kg N/ha in addition to 22 kg S/ha. This will allow us to help us establish whether any observed responses to AMS are due to S or the additional N provided by this fertilizer product. Unfortunately, treatments 9 and 10 cannot be combined with treatment 6 for this exercise because these treatments receive KCl while treatment 11 does not. For the second analysis, we intend to drop treatments 1 and 11 and analyze the data as a balanced 6 x 3 x 3 factorial with six sites, three KCl treatments, and three AMS treatments. This will improve our ability to identify and isolate responses to individual fertilizer products in addition to identifying any interactions with site or between KCl and AMS.

Due to the elusive nature of K and S responses in lentils and most other crops, a more extensive approach to exploring the potential benefits of these nutrients may be more effective. Looking at a smaller set of treatments across a much larger number of fields could provide better insights into the probability of response along with the ability of soil tests to identify responsive soils. Increased replication may be required to detect the small yield differences that might be expected (and can also be profitable) and it will likely be difficult (and of relatively little benefit) to generate rate response curves due to the spotty nature of responses and low application rates of these nutrients that are likely to be sufficient. Although small plot trials would likely be adequate for such work and potentially less expensive on a per site basis, on-farm trials may be more appropriate for evaluating a simple set of treatments (i.e., treated versus treated) across a much large number of locations. Again, increased replication would be beneficial regardless of the scale and, if this is subject that SPG sees sufficient value in, repeating the trials over multiple years would undoubtedly be ideal. To keep things manageable for farmers and reduce spatial variability, looking at K and S in separate trials would likely be preferable.

10. **Technology Transfer Activities** (detail any presentations delivered, extension material developed, field days, and articles published):

The project could not be shown during the 2023 Indian Head Crop Management Field Day for logistic reasons; however, the project was shown to industry representatives and farmers during several informal site visits throughout the season. The project was discussed by Kayla Slind and Meagan Reed during the 2023 Scott Field Day, held on July 12, and attended by 120 participants. This project was not part of the WCA/AAFC Annual Field Day at Swift Current in 2023. This interim technical report will be available on the websites of IHARF (www.iharf.ca) and other participating organizations and results will continue to be shared as appropriate opportunities arise.

11. **Funding Contributions** (acknowledge any partners and contributors to the project):

Financial support for this project was provided exclusively 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.

12. **Appendices** (include any additional, detailed data tables, maps, photos, etc):

Table 10. Selected agronomic information and dates of operations for 2021 and 2022 lentil trials at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan.

Activity	Indian Head	Scott	Swift Current
Previous Crop	Wheat	Wheat	Wheat
Pre-seed Herbicide	890 g glyphosate/ha (May-11)	894 g glyphosate + 21 g carfentrazon/ha (May-8)	890 g glyphosate/ha (May-12)
Seeding	May-8	May 11	May-9
Row Spacing	30 cm	25 cm	21 cm
Inoculant	3.0 kg Nodulator Duo SCG/ha	3.7 kg Nodulator Duo SCG/ha	4.6 kg TagTeam BioniQ/ha
Variety	CDC Impulse CL	CDC Impulse CL	CDC Impulse CL
Seed Treatment	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	15 g imazamox + 15 g imazapyr + 37 g quizalofop-p-ethyl/ha (Jun-6)	20 g imazamox + 37 g quizalofop-p-ethyl/ha (Jun-2)	20 g imazamox + 171 sethoxydim/ha (Jun-2)
Emergence Counts	Jun-5	Jun-5	Jun-6
Foliar Fungicide	99 g fluxapyroxad + 99 g pyraclostrobin/ha (Jun-26)	99 g fluxapyroxad + 99 g pyraclostrobin/ha (Jun-26)	1977 g chlorothalonil/ha (Jun-22)
Foliar Insecticide	7 g deltamethrin/ha (Jun-16) 50 g chlorantraniliprole/ha (Jun-22 & Jul-21)	7 g deltamethrin/ha (Jun-13 & Jul-7)	n/a
Pre-harvest Herbicide / Desiccant	894 g glyphosate/ha (Aug-4) 410 g diquat/ha (Aug-11)	410 g diquat/ha (Aug-4)	410 g diquat/ha (Aug-11)
Harvest	Aug-17	Aug-8	Aug-16

Table 11. Results from the overall tests of fixed effects for selected response variables in lentil K and S fertility demonstrations completed in 2023 at Indian Head, Scott, and Swift Current. The treatments were 11 fertility treatments which primarily focused on potassium (K) and sulfur (S). Data were analyzed individually for each location used the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio.

Response Variable	Indian Head	Scott	Swift Current
	--	p-value	--
Plant Density (plants/m^2)	0.105	0.148	0.962
Seed Yield (kg/ha)	0.090	0.231	0.541
Test Weight (g/0.5 l)	0.242	0.741	0.184
Seed Weight (g/1000 seeds)	0.559	0.109	0.736
Seed Protein (%)	0.556	0.839	0.320

[Y] P-values greater than 0.05 indicate that there were no significant differences between treatment means

Table 12. Results of the pre-determined contrast comparisons for emergence (plants/m^2) in lentil K and S fertility demonstrations at Indian Head, Scott, and Swift Current (2023). P-values ≤ 0.05 indicate that that difference between means was significant.

Contrast Comparison	Indian Head	Scott	Swift Current
Check (1) vs	194 A	149 A	149 A
Rest (2-11)	196 A	156 A	144 A
Pr > F (p-value)	0.811	0.263	0.451
No KCl (2,5,6) vs	188 B	153 A	145 A
KCl (3,4,7,8,9,10)	202 A	158 A	143 A
Pr > F (p-value)	0.007	0.314	0.611
Low KCl (3,7,9) vs	204 A	155 A	142 A
High KCl (4,8,10)	201 A	160 A	144 A
Pr > F (p-value)	0.207	0.271	0.614
No AMS (2,3,4) vs	191 A	161 A	144 A
AMS (5,6,7,8,9,10)	201 A	154 A	143 A
Pr > F (p-value)	0.065	0.068	0.855
Low AMS (5,7,8) vs	200 A	159 A	145 A
High AMS (6,9,10)	201 A	148 B	142 A
Pr > F (p-value)	0.831	0.039	0.614

Table 13. Results of the pre-determined contrast comparisons for seed yield (kg/ha) in lentil K and S fertility demonstrations at Indian Head, Scott, and Swift Current (2023). P-values ≤ 0.05 indicate that that difference between means was significant.

Contrast Comparison	Indian Head	Scott	Swift Current
Check (1) vs	2469 B	3849 A	1170 B
Rest (2-11)	2709 A	3764 A	1320 A
Pr > F (p-value)	0.006	0.587	0.049
No KCl (2,5,6) vs	2678 A	3736 A	1257 A
KCl (3,4,7,8,9,10)	2710 A	3791 A	1346 A
Pr > F (p-value)	0.563	0.607	0.088
Low KCl (3,7,9) vs	2709 A	3810 A	1354 A
High KCl (4,8,10)	2712 A	3771 A	1339 A
Pr > F (p-value)	0.962	0.749	0.796
No AMS (2,3,4) vs	2728 A	3948 A	1313 A
AMS (5,6,7,8,9,10)	2685 A	3685 B	1318 A
Pr > F (p-value)	0.439	0.017	0.916
Low AMS (5,7,8) vs	2681 A	3579 A	1313 A
High AMS (6,9,10)	2689 A	3791 A	1323 A
Pr > F (p-value)	0.896	0.089	0.858

Table 14. Results of the pre-determined contrast comparisons for test weight (g/0.5 l) in lentil K and S fertility demonstrations at Indian Head, Scott, and Swift Current (2023). P-values ≤ 0.05 indicate that that difference between means was significant.

Contrast Comparison	Indian Head	Scott	Swift Current
Check (1) vs	394.3 A	502.1 A	369.4 A
Rest (2-11)	394.2 A	502.3 A	370.3 A
Pr > F (p-value)	0.936	0.819	0.361
No KCl (2,5,6) vs	394.5 A	502.4 A	369.6 A
KCl (3,4,7,8,9,10)	394.3 A	502.1 A	370.2 A
Pr > F (p-value)	0.713	0.714	0.289
Low KCl (3,7,9) vs	394.4 A	502.6 A	370.5 A
High KCl (4,8,10)	394.2 A	501.6 A	370.0 A
Pr > F (p-value)	0.667	0.300	0.462
No AMS (2,3,4) vs	394.8 A	502.7 A	370.6 A
AMS (5,6,7,8,9,10)	394.2 A	502.0 A	369.7 A
Pr > F (p-value)	0.229	0.380	0.143
Low AMS (5,7,8) vs	394.8 A	501.8 A	369.8 A
High AMS (6,9,10)	393.6 B	502.1 A	369.6 A
Pr > F (p-value)	0.045	0.780	0.829

Table 15. Results of the pre-determined contrast comparisons for seed weight (g/1000 seeds) in lentil K and S fertility demonstrations at Indian Head, Scott, and Swift Current (2023). P-values ≤ 0.05 indicate that that difference between means was significant.

Contrast Comparison	Indian Head	Scott	Swift Current
Check (1) vs	52.8 A	52.6 B	46.5 A
Rest (2-11)	53.0 A	53.3 A	46.6 A
Pr > F (p-value)	0.638	0.033	0.943
No KCl (2,5,6) vs	52.9 A	53.0 B	46.6 A
KCl (3,4,7,8,9,10)	53.0 A	53.5 A	46.5 A
Pr > F (p-value)	0.482	0.018	0.803
Low KCl (3,7,9) vs	53.2 A	53.4 A	46.1 A
High KCl (4,8,10)	52.8 A	53.6 A	46.9 A
Pr > F (p-value)	0.162	0.323	0.128
No AMS (2,3,4) vs	52.7 A	53.4 A	46.6 A
AMS (5,6,7,8,9,10)	53.1 A	53.3 A	46.5 A
Pr > F (p-value)	0.112	0.833	0.761
Low AMS (5,7,8) vs	53.3 A	53.3 A	46.5 A
High AMS (6,9,10)	52.9 A	53.4 A	46.5 A
Pr > F (p-value)	0.182	0.816	0.886

Table 16. Results of the pre-determined contrast comparisons for seed protein concentrations (%) in lentil K and S fertility demonstrations at Indian Head, Scott, and Swift Current (2023). P-values ≤ 0.05 indicate that that difference between means was significant.

Contrast Comparison	Indian Head	Scott	Swift Current
Check (1) vs	24.7 A	24.6 A	24.7 A
Rest (2-11)	24.8 A	24.8 A	24.7 A
Pr > F (p-value)	0.716	0.724	0.989
No KCl (2,5,6) vs	24.9 A	24.7 A	25.0 A
KCl (3,4,7,8,9,10)	24.7 A	24.7 A	24.5 B
Pr > F (p-value)	0.287	0.956	0.019
Low KCl (3,7,9) vs	24.7 A	24.8 A	24.4 A
High KCl (4,8,10)	24.6 A	24.7 A	24.6 A
Pr > F (p-value)	0.796	0.714	0.307
No AMS (2,3,4) vs	24.6 A	24.9 A	24.6 A
AMS (5,6,7,8,9,10)	24.8 A	24.7 A	24.7 A
Pr > F (p-value)	0.309	0.434	0.908
Low AMS (5,7,8) vs	24.6 A	24.5 A	24.8 A
High AMS (6,9,10)	25.0 A	24.8 A	24.6 A
Pr > F (p-value)	0.076	0.266	0.370