2024 Final Report

for the

Saskatchewan Pulse Crop Development Board

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

(Project #AP2406a)

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

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5. **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 (*Lens culinaris*) have focused on nitrogen (N) and phosphorus (P), potassium (K) and sulfur (S) are also important nutrients which are frequently applied as fertilizer by Saskatchewan farmers. The most utilized source of K is potash (0-0-60), which is readily available, soluble, and contains approximately 45% chloride. Crop responses to potash in high K soils can sometimes be attributed to the 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 sulfate (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 benefit 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 sulfate 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 24%, respectively. Work conducted in Ethiopia, looking at on lentil response to S with and without rhizobium inoculant, showed 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 sulfur 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 (Indian Head 2020), there was no yield response to S fertilization but a linear increase in seed protein content was detected.

Further work is required to determine if additional K and S fertility would be likely to provide beneficial responses to lentils grown in Saskatchewan. Such work would help to answer questions not addressed in recent SaskPulse/AgriARM lentil fertility research and demonstration activities. 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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Saha, M., Sarkar, A., Bandyopadhyay, P. K., Nandi, R., & Singh, K. C. 2021. Tillage and Potassium Management for Improving Yield, Physiological, and Biochemical Responses of Rainfed Lentil Under Moisture Stressed Rice-Fallow. Journal of Soil Science and Plant Nutrition, 21(1), 637–654. https://doi.org/10.1007/s42729-020-00389-6.

Scherer, H., Pacyna, S., Manthey, N., and Shulz, M. 2006. Sulphur supply to peas (*Pisum sativum* L.) influences symbiotic N_2 fixation. Plant Soil Environ. **52:** 72-77.

Singh, J. and Sharma, S. 2021. Response of lentil (*Lens culinaris* Medik.) to potassium application under deficient soils. Legume Res. **44:** 1348-1352.

6. **Objective(s) or purpose of the project:**

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

7. **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 and 2024 growing seasons. 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 extra context. One of the control treatments was intended to test for a phosphorus (P) response and 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 (Trt. #11) was to help ascertain whether responses to ammonium sulfate (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 Rhizobium 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 and 2024.

Trt #	**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 Sulfur
6	27	45	0	20	High Sulfur
7	18	45	22	10	Low Potassium – Low Sulfur
8	18	45	45	10	High Potassium – Low Sulfur
9	27	45	22	20	Low Potassium – High Sulfur
10	27	45	45	20	High Potassium – High Sulfur
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 wheat stubble and all locations used the variety CDC Proclaim CL, seeded at a target rate of 190 seeds/m^2. Weeds were controlled using registered pre-emergent and in-crop herbicide applications. A preventative foliar fungicide application was strongly recommended, regardless of disease pressure, while pre-harvest herbicides or desiccants were utilized at the discretion of individual site mangers. Insecticides were applied as required based on the specific insect pressure encountered. 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 for all sites were determined by IHARF staff using a FOSS Infratech NIR analyzer. Growing season temperatures and precipitation amounts were compiled from the nearest Environment and Climate Change Canada weather stations.

Response data were combined across locations for statistical analyses using generalized linear mixed model (GLIMMIX) in SAS® Studio. For each response variable, two separate models were used, and replicate effects (nested within site) were considered random for both. The first model excluded the control treatments (1 and 11) for a 6 x 3 x 3 factorial analysis which included site (S), potassium (K; KCl) and sulfur (S; AMS), and all possible two- and three-way interactions as fixed effects. The second model retained all 11 fertilizer treatments and simply include site, treatment, and their interactions as fixed effects. The sole purpose of the second model was to directly compare Trts. 1 and 2 (to test for a P response) and Trt. 11 to Trts. 2 and 6 (to test for an N response). For both models, we permitted and tested for heterogeneity in variance estimates (by site) for all response variables; however, the more complex model was only used when doing so significantly improved convergence. Orthogonal contrasts were not written for all possible interactions but were used to determine whether responses to K and S separately were linear, quadratic (curvilinear), or not significant for individual sites and when averaged across sites. Individual treatment means were separated using Tukey's test, which controls the experiment-wise error rate. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

8. 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 consistently 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 more neutral pH values. At 484-657 ppm, Indian Head had considerably higher K levels than the other sites (205-224 ppm); however, K levels were never low enough to be considered limiting with a high probability of yield response to K fertilizer application. 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 9-25 kg/ha which was interpreted as low to medium in terms of relative availability; however, sub-soil S levels were generally high and, when the full soil profile was considered, S was mostly considered relatively unlikely to be limiting. That said, residual soil S and S deficiencies are notoriously difficult to test for and predict due to this nutrient's high variability across the landscape and potential to move vertically 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 and 2024.

Parameter	Depth (cm)	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24
pH	0-15	8.1	7.5	5.5	5.4	6.6	6.5
Organic Matter (%)	0-15	4.7	5.9	3.3	4.0	2.6	2.5
C.E.C. (meq)	0-15	47.8	48.1	15.2	14.6	18.9	17.3
NO_3-N (kg/ha)	0-60	12	19	34	32	26	91
Olsen-P (ppm)	0-15	3	8	13	16	10	12
K (ppm)	0-15	484	657	205	219	224	211
D1-S (kg/ha)	0-15	13	9	18	25	16	9
D2-S (kg/ha)	15-30	–	–	20	–	–	–
D3-S (kg/ha)	30-60	40	20	–	114	40	20
Cl (kg/ha)	0-60	31	13	5[Z]	9	18	27

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

Mean monthly temperatures and precipitation amounts for the 2023 and 2024 growing seasons (May-August) are presented relative to the long-term (1981-2010) averages for each location in Tables 3 and 4, respectively. In 2023, 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 in 2023 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 2023 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. In 2024, temperatures at all locations were relatively cool in May and, especially, June, but well above average in July and August. Soil moisture reserves were initially low for the 2024 growing season; however, precipitation was abundant in May and June. In July, however, the high temperatures coincided with below average precipitation. The dry conditions persisted in August at Swift Current, while August precipitation was close to normal at Scott and above-average at Indian Head. The August precipitation was generally too late to benefit the lentils, but did have potential to create harvest challenges and impact grain quality. Overall, lentils are well adapted to hot, dry conditions and still fared quite well under the conditions encountered. Root disease was concern at Indian Head (2024) with the wet conditions in June; however, the plots were trimmed as necessary so that areas impacted by root disease could be excluded from the harvest area and data quality appeared to be reasonably high.

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	10.6	13.6	19.5	17.9	15.4 (-0.2)
	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	9.8	13.3	18.9	17.4	14.9 (+0.1)
	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	10.6	14.3	21.3	19.4	16.4 (+0.6)
	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	63.7	74.9	37.4	71.2	248 (102%)
	Long-term	*51.7*	*77.4*	*63.8*	*51.2*	*244*
Scott	2023	16.6	81.1	29.7	31.7	159 (70%)
	2024	74.2	112.0	26.7	42.8	256 (113%)
	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	73.6	52.1	18.6	18.2	163 (87%)
	Long-term	*42.1*	*66.1*	*44.0*	*35.4*	*188*

* Hailstorm at Swift Current on July 22/2023 resulted in a substantial seed yield loss

The overall tests of fixed effects from the factorial analyses for all response variables are presented in Table 5 below; however, most of the detailed results tables are deferred to the Appendices. Significant treatment effects were relatively infrequent, and results will be discussed for each nutrient individually.

Table 5. Tests of fixed effects for site (S), potassium rate (KCl), sulfur rate (AMS), and all possible interactions for lentil emergence, yield, and quality. Data were analyzed using the Generalized Linear Mixed Model procedure of SAS Studio.

Effect	Plant Density	Grain Yield	Test Weight	Seed Weight	Grain Protein
	--- Pr > F (p-value) ---				
Site (S)	<0.001	<0.001	<0.001	<0.001	<0.001
Potassium (KCl)	0.409	0.226	0.759	0.254	0.133
S x KCL	0.052	0.951	0.730	0.037	0.841
Sulfur (AMS)	0.037	0.067	0.029	0.698	0.407
S x AMS	0.062	0.008	0.597	0.744	0.733
KCl x AMS	0.013	0.651	0.689	0.105	0.874
S X KCl X AMS	0.988	0.684	0.764	0.542	0.744

First, the site (S) effects were highly significant ($P < 0.001$) for all variables and these main effect means are presented in Table 6. Heterogeneity in variance estimates amongst sites improved model convergence for yield and seed weight, but not plant density, test weight, or protein. Across treatments, plant densities ranged from a minimum of 135 plants/m^2 at SC-24 to 198 plants/m^2 at IH-24. With a target seeding rate of 190 seeds/m^2, these numbers are indicative of mortality ranging from essentially nil to just below 30%. At IH-24, conditions for emergence were excellent, but some of the observed mortality may have been due to late spring frost events. The most recommended plant density for lentil is 130/m^2, with higher densities potentially being better able to compete against weeds but more prone to foliar disease. As such, plant densities were sufficiently high for a uniform crop at all sites and were never expected to limit yields. Yields ranged from 1315-3773 kg/ha, consistently lowest at Swift Current (1315-1339 kg/ha), more intermediate at Indian Head (2699-2852 kg/ha), and highest, especially in 2023, at Scott (3137-3773 kg/ha). Test weights ranged from 370-404 g/0.5 l across sites. The test weights from SC-23 were excluded from the analyses due to concerns about data quality. Seed weights ranged from approximately 38 g/1000 seeds at SW-24 (the driest site) to 50 g/1000 seeds at IH-23 and SC-23, with the values at IH-24, SC-24, and SW-23 being more intermediate (45-47 g/1000 seeds). Grain protein concentrations were lowest at IH-23 (23.6%), intermediate at SC-24 (24.2%), and highest at the remaining four sites (24.7-25%)

Table 6. Overall site means for lentil plant density, yield, test weight, seed weight, and grain protein. Standard errors of the treatment means are enclosed in parentheses, with heterogeneity between sites permitted when doing so improved model convergence. Values within a column followed by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

Site [Z]	Plant Density	Seed Yield	Test Weight	Seed Weight	Grain Protein
	----- plants/m^2 -----	-------- kg/ha --------	------- g/0.5 l -------	------- g/1000 -------	---------- % ----------
IH-23	198 A (2.9)	2699 C (91.0)	394.2 B (0.50)	53.0 A (0.32)	24.74 A (0.100)
IH-24	138 DE (2.9)	2852 BC (97.1)	388.4 C (0.50)	45.4 B (0.25)	23.58 C (0.100)
SC-23	156 C (2.9)	3773 A (182.5)	—	53.3 A (0.50)	24.73 A (0.100)
SC-24	135 D (2.9)	3137 B (58.8)	403.7 A (0.50)	46.2 B (0.75)	24.16 B (0.100)
SW-23	144 CD (2.9)	1315 D (29.5)	370.2 D (0.50)	46.6 B (1.67)	24.65 A (0.100)
SW-24	173 B (2.9)	1339 D (29.0)	389.2 C (0.50)	37.8 C (0.17)	24.95 A (0.100)
	-------------------- p-value --------------------				
Pr > F	<0.001	<0.001	<0.001	<0.001	<0.001

[Z] IH – Indian Head; SC – Scott; SW – Swift Current; 23 – 2023; 24 – 2024

The overall KCl effect was not significant for any response variables; however, the S x KCl interaction was at least marginally significant for plant density (P = 0.052) and seed weight (P = 0.037), indicating that the response to K varied across sites for these variables (Table 5). The S x KCl interaction for plant density was due to there being a slight improvement in establishment with KCl at IH-23, lower plant densities with 23 kg K_2O/ha at SW-24, and no response at the remaining 4/6 sites (Table 11). These responses were subtle, not considered agronomically important, and largely unexpected given that the KCl was side-banded. The S x KCl effect on thousand seed weight (TSW) was due to significant variation at IH-24 (P = 0.022) and, to a lesser extent, SW-23 (P = 0.057); however, the specific nature of the responses was inconsistent and again, the effects were small (Table 23). In both cases, TSW values in the 0 K control did not significantly differ from either treatment that received KCl, and the quadratic responses were significant (P = 0.010-0.025). In addition to the Appendices, the overall averaged responses to KCl rate are summarized in Table 7 below; however, no other significant responses or meaningful trends for K were observed.

Table 7. Overall (six site) average main effect means for potassium (K) fertilizer rate effects on lentil emergence, seed yield, test weight, seed weight, and seed protein. Overall test of fixed effects, orthogonal contrast and multiple comparison test results are also presented, whereby values within a column followed by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

Main Effect	Plant Density	Seed Yield	Test Weight	Seed Weight	Seed Protein
Potassium [Y]	---- plants/m^2 ----	------- kg/ha -------	------ g/0.5 l ------	-- g/1000 seeds --	--------- % ---------
0 kg K_2O/ha	157 a	2491 a	389.1 a	46.9 a	24.57 a
23 kg K_2O/ha	156 a	2538 a	389.2 a	47.1 a	24.44 a
45 kg K_2O/ha	159 a	2529 a	389.0 a	47.1 a	24.40 a
S.E.M.	1.8	42.9	0.28	0.33	0.067
	-------------------- Pr > F (p-value) --------------------				
Pr > F	0.409	0.226	0.759	0.254	0.133
K Rate – lin	0.339	0.193	0.008	0.115	0.056
K Rate – quad	0.351	0.253	0.607	0.619	0.543

[Z] Potassium source was side-banded muriate of potash (KCl; 0-0-60)

[Y] P-value for the overall test of fixed effects for KCl rate

The overall effect of AMS, or S rate, was significant for plant density (P = 0.037) and test weight (P = 0.029), and marginally significant for seed yield (P = 0.067). The overall average plant density response to S showed a slight drop in plants/m^2 at the highest rate of side-banded AMS; however, the reduction was only 3% relative to the control (Table 8). Test weights also linearly declined (P = 0.008) with increasing S rate, albeit by a very small margin which was not considered agronomically important. The marginally significant seed yield response to S did not show any meaningful trends with no significant orthogonal contrasts (P = 0.253-0.371) and all treatments yielding within 67 kg/ha (1 bu/ac) of one another. The S x AMS interaction for plant density was marginally significant (P = 0.062), and inspection of individual site data (Table 12) showed that the response was strongest at SC-24 (P = 0.014) with at least marginally significant negative responses detected at IH-24, SC-23, and SC-24. The S x AMS response for yield was highly significant (P = 0.008) and appeared to be due to an unusual negative quadratic response to S rate (P < 0.001) at SC-23, but no other responses or trends at the remaining five sites (Table 15). Yields at SC-23 were high, but extremely variable and it appeared that this site was largely responsible for the observed trend in the in the six-site averaged results. The lack of any S x AMS interaction for any of these variables indicate that, either the trends were consistent, or any responses were too small to trigger an interaction. For test weight, the lack of any S x AMS effect (P = 0.597) despite the overall AMS effect was reenforced by the fact that the response was not significant for any sites individually (P = 0.111-0.694), but similar trends were observed for 4/5 possible sites, the biggest exception being SW-24. For seed weight and grain protein, neither the AMS nor S x AMS were even marginally significant (P = 0.407-0.744), indicating that there were no effects or trends associated with S rate whatsoever for these variables.

Table 8. Overall (six site) average main effect means for sulfur (S) fertilizer rate effects on lentil emergence, seed yield, test weight, seed weight, and seed protein. Overall test of fixed effects, orthogonal contrast and multiple comparison test results are also presented, whereby values within a column followed by the same letter do not significantly differ (Tukey's, $P \le 0.05$).

Main Effect	Plant Density	Seed Yield	Test Weight	Seed Weight	Seed Protein
Sulfur [Z]	---- plants/m^2 ----	------- kg/ha -------	------ g/0.5 l ------	-- g/1000 seeds --	--------- % ---------
0 kg S/ha	159 a	2550 a	389.5 a	47.1 a	24.44 a
11 kg S/ha	159 a	2483 a	389.0 ab	47.1 a	24.43 a
22 kg S/ha	154 a	2524 a	388.7 b	47.0 a	43.54 a
S.E.M.	1.8	42.9	0.28	0.33	0.067
	----------------------	----------------------	Pr > F (p-value)	----------------------	----------------------
Pr > F [Y]	0.037	0.067	0.029	0.698	0.407
S Rate – lin	0.023	0.371	0.008	0.502	0.261
S Rate – quad	0.351	0.253	0.607	0.619	0.543

[Z] Sulfur source was side-banded ammonium sulfate (AMS; 21-0-0-24)
[Y] P-value for the overall test of fixed effects for AMS rate

The overall averaged results for the KCl x AMS interaction are presented in Table 9, for interest's sake; however, this interaction was only significant for plant density. The KCl x AMS plant density response was due to there being a slight but significant reduction in emergence with increasing S rate, exclusively at the highest KCl rate. Looking at it another way, we see increasing establishment with KCl fertilizer when no AMS was applied, but no effect of KCl when combined with AMS. For the other variables, no KCl x AMS interactions were detected (P = 0.105-0.874) and the S x KCl x AMS interaction was never significant (P = 0.542-0.988; Table 5). Further to the lack of any interaction, the Tukey's multiple comparisons tests did not detect any differences amongst individual treatment means for seed yield, test weight, TSW, or protein.

Table 9. Overall (six site) average individual treatment means for potassium (K) by sulfur (S) fertilizer rate effects on lentil emergence, seed yield, test weight, seed weight, and seed protein. Overall test of fixed effects, orthogonal contrast and multiple comparison test results are also presented, whereby values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment	Plant Density	Seed Yield	Test Weight	Seed Weight	Seed Protein
$K^Z \times S^Y$ Rate	---- plants/m^2 ----	------- kg/ha -------	------ g/0.5 l ------	-- g/1000 seeds --	--------- % ---------
0 K – 0 S	153 b	2550 a	389.4 a	47.0 a	24.56 a
0 K – 11 S	162 ab	2456 a	388.9 a	46.8 a	24.57 a
0 K – 22 S	156 ab	2466 a	389.0 a	46.9 a	24.59 a
23 K – 0 S	158 ab	2570 a	389.6 a	46.9 a	24.44 a
23 K – 11 S	158 ab	2495 a	389.0 a	47.4 a	24.38 a
23 K – 22 S	152 b	2551 a	388.9 a	46.9 a	24.48 a
45 K – 0 S	167 a	2532 a	389.4 a	47.2 a	24.30 a
45 K – 11 S	157 ab	2498 a	389.2 a	47.0 a	24.34 a
45 K – 22 S	153 b	2557 a	388.3 a	47.1 a	24.54 a
S.E.M.	3.0	51.9	0.39	0.36	0.113
	-- Pr > F (p-value) --				
Pr > F ^{X}	0.013	0.651	0.689	0.105	0.874

^{Z} Potassium rates are kg K_2O/ha as side-banded muriate of potash (KCl; 0-0-60)
^{Y} Sulfur rates are kg S/ha as side-banded ammonium sulfate (AMS; 21-0-0-24)
^{X} P-value for the overall test of fixed effects for KCl x AMS rate

Results for the pre-determined contrast comparisons in the analyses that included the unfertilized and extra N control treatments are presented in Tables 14, 18, 22, 26, and 30 for plant density, seed yield, test weight, TSW, and protein, respectively. The results for yield showed that there was a consistent trend for higher yield with P fertilizer relative to the total control and, averaged across sites, the increase was 167 kg/ha (2.5 bu/ac; *P* = 0.001). There were no indications of yield benefit associated specifically with N (*P* = 0.949). This yield response to P was, essentially, the sole positive response to fertilizer applications observed in this project.

9. Economic & Practical Implications for Growers:

With the only evidence of positive yield responses to fertilizer being attributed to phosphorus (P), it is reasonable to assume that the applications of potassium (K) and sulfur (S), which were the focus of this project, would have reduced the short-term net economic returns. These results were not necessarily unexpected given that soil test results did not indicate a specific need for K or S while past research and experience has shown responses to these nutrients in western Canadian lentil production to be somewhat elusive. There may be longer term value to applying low rates of potash or S fertilizer products on a regular basis due to the maintenance of soil residual levels and reducing the potential for deficiencies in future years and/or crops.

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. Assuming a fertilizer price of $650/Mt potash), the addition of KCl would have cost an estimated $24/ha and $49/ha at the 22 and 45 kg K_2O/ha rates, respectively. Using estimated small red lentil prices of $725/Mt ($37/CWT), we would only require yield gains of approximately 34 kg/ha (~0.6 bu/ac) and 67 kg/ha (~1.1 bu/ac) to pay for the potash at the utilized rates. If we assume a price of $550/Mt for ammonium sulfate, 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 justifiable not to separate the costs of N and S in this specific case. As such, we required yield gains of 35 kg/ha (~0.6 bu/ac) and 70 kg/ha (~1.2 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. Under these assumptions, the most expensive combination of KCl and AMS evaluated in this project would require a yield response of 137 kg/ha (~2.3 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 detect, even if they are genuine. Importantly, grain and fertilizer prices can vary widely; therefore, growers are encouraged to use their own prices when deciding whether to apply these nutrients. Again, 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. Additionally, other formulations of S (i.e., elemental) may provide similar benefits, if they are managed appropriately over a longer-term fertility plan, at a lower cost.

10. **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?):

Overall, this project provided valuable information regarding lentil response, or lack thereof, to potassium (K) and sulfur (S) fertilizer applications across a reasonably broad range of conditions. 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 often specifically recommended for lentil production; however, small quantities 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. While K is rarely limiting in Saskatchewan soils, responses to the chloride (Cl) in potash can occasionally occur in high K soils and, due to its mobility, Cl availability can be variable across the landscape and from year-to-year. In general, K, S, and Cl deficiencies are all more likely to occur in coarser textured, low organic matter soils. The results from this project would not specifically justify refining the current fertility recommendations for small red lentil production in Saskatchewan.

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

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. 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 suffice. 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 a 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 be a preferable approach.

12. **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 during the 2023 Scott Field Day, held on July 12 (120 participants). This project was not part of the WCA/AAFC Annual Field Day at Swift Current in 2023. In 2024, the project was shown at Indian Head during both the Crop Management Field Day (July 16, 145 participants) and a National Circle for Indigenous Agriculture and Food tour (August 7, 40 participants). At Swift Current in 2024, the trial was not a formal stop on the annual AAFC/WCA Field Day (July 18, 75 attendees) but treatment and sponsor signs were in place, and the plots were viewed in passing. The trial was also visited during a Saskatchewan Ministry of Agriculture tour (July 3, 8 participants) and Amber Wall shared project highlights during the Swift Current Winter Pulse Meeting (February 11, 2025; ~130 participants). No extension was reported for the Scott location in 2024/25. The interim technical report has been available for viewing on the websites of IHARF (https://iharf.ca/library/) and other participating organizations and this final report will also be uploaded in the near future. Results will continue to be incorporated into presentations and extension materials where appropriate opportunities arise.

13. 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. Many of the inputs and crop protection products used in this project were provided as in-kind, industry contributions. IHARF, WARC, and WCA have strong working relationships and framework agreements with Agriculture and Agri-Food Canada which should be acknowledged. Additionally, all the participating organizations have received funding for infrastructure and basic operating expenses from the Saskatchewan Ministry of Agriculture and several other producer/commodity groups, including SaskPulse, all of which helps to make work like this possible.

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

Table 10. Selected agronomic information and dates of operations for 2023 and 2024 potassium and sulfur fertilizer response lentil trials at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan.

Activity	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24
Previous Crop	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
Pre-seed Herbicide	Glyphosate (May-11)	Glyphosate (May-12) Zidua SC (May-12)	Glyphosate (May-8) AIM (May-8)	Glyphosate (May-9) AIM (May-9)	Glyphosate (May-12)	Glyphosate (Apr-24)
Seeding	May-8	May-10	May 11	May-10	May-9	May-9
Row Spacing	30 cm	30 cm	25 cm	25 cm	21 cm	21 cm
Inoculant	Nodulator Duo SCG	Nodulator Duo SCG	Nodulator Duo SCG	Nodulator Duo SCG	TagTeam BioniQ	TagTeam BioniQ
Seed Treatment	Insure Pulse + INTEGO Solo	Insure Pulse	Vibrance Maxx RFC	Vibrance Maxx RFC	Vibrance Maxx RFC	Vibrance Total
In-crop Herbicide	Odyssey NXT (Jun-6) Caziva Ultra Q (Jun-6)	Odyssey NXT (Jun-9) Caziva Ultra Q (Jun-9)	Solo ADV II (Jun-2) Caziva Ultra Q (Jun-2)	Solo ADV II (Jun-10) Caziva Ultra Q (Jun-10)	Solo ADV II (Jun-7) Poast Ultra (Jun-7)	Assure II (Jun-18) Solo ADV II (Jun-20)
Emergence Counts	Jun-5	Jun-3	Jun-5	Jun-6	Jun-6	Jun-11
Foliar Fungicide	Dyax (Jun-26)	Dyax (Jul-8)	Dyax (Jun-26)	Dyax (Jul-11)	Bravo ZNC (Jun-22)	none
Foliar Insecticide	Decis 5 EC (Jun-16) Coragen MaX (Jun-22 and Jul-11)	Coragen MaX (Jul-11) Cygon 480 (Jul-22)	Decis 5 EC (Jun-13 and Jul-7)	none	Decis 5 EC (Jul-1)	Voliam Express (Jul-23)
Pre-harvest Herbicide / Desiccant	Glyphosate (Aug-4) Reglone Ion (Aug-11)	Glyphosate (Aug-11) Reglone Ion (Aug-15)	Reglone Ion (Aug-4)	Reglone Ion (Aug-22)	Reglone Ion (Aug-11)	none
Harvest	Aug-17	Aug-27	Aug-8	Aug-26	Aug-16	Aug-2

Table 11. Main effect means and multiple comparison test results for potassium (K) fertilizer rate effects on lentil emergence at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukeys, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Potassium [Y]	------ Plant Density (plants/m^2) ------						
0 kg K_2O/ha	188 b	136 a	153 a	140 a	145 a	179 a	157 a
23 kg K_2O/ha	204 a	137 a	155 a	134 a	142 a	165 b	156 a
45 kg K_2O/ha	201 ab	142 a	160 a	131 a	144 a	176 ab	159 a
S.E.M.	4.4	4.4	4.4	4.4	4.4	4.4	1.8
	------ Pr > F (p-value) ------						
Pr > F [Y]	0.017	0.478	0.455	0.283	0.807	0.048	—
K Rate – lin	0.024	0.251	0.232	0.117	0.864	0.597	0.339
K Rate – quad	0.077	0.694	0.704	0.820	0.528	0.016	0.351

[Z] Potassium source was side-banded muriate of potash (KCl; 0-0-60)

[Y] Test of effect slices for SITE × K, sliced by SITE

Table 12. Main effect means and multiple comparison test results for sulfur (S) fertilizer rate effects on lentil emergence at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Sulfur [Z]	------ Plant Density (plants/m^2) ------						
0 kg S/ha	191 a	146 a	161 a	137 ab	144 a	175 a	159 a
11 kg S/ha	200 a	133 a	159 a	142 a	145 a	175 a	159 a
22 kg S/ha	201 a	135 a	148 a	126 b	142 a	170 a	154 a
S.E.M.	4.4	4.4	4.4	4.4	4.4	4.4	1.8
	------ Pr > F (p-value) ------						
Pr > F [Y]	0.168	0.060	0.062	0.014	0.887	0.628	—
S Rate – lin	0.084	0.063	0.026	0.049	0.708	0.374	0.023
S Rate – quad	0.448	0.138	0.444	0.030	0.752	0.710	0.351

[Z] Sulfur source was side-banded ammonium sulfate (AMS; 21-0-0-24)

[Y] Test of effect slices for SITE × S, sliced by SITE

Table 13. Individual potassium (K) by sulfur (S) fertilizer rate treatment effect means and multiple comparison test results for lentil plant densities at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). The six-site averaged response is also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
K[Z] × S[Y] Rate	---------- Plant Density (plants/m^2) ----------						
0 K – 0 S	176 a	139 a	152 a	130 ab	146 a	174 a	153 b
0 K – 11 S	193 a	133 a	161 a	153 a	152 a	182 a	162 ab
0 K – 22 S	196 a	135 a	147 a	136 ab	139 a	181 a	156 ab
23 K – 0 S	201 a	142 a	160 a	135 ab	141 a	168 a	158 ab
23 K – 11 S	205 a	137 a	156 a	144 ab	140 a	165 a	158 ab
23 K – 22 S	204 a	132 a	149 a	123 ab	143 a	163 a	152 b
45 K – 0 S	197 a	157 a	172 a	146 ab	146 a	184 a	167 a
45 K – 11 S	202 a	131 a	159 a	130 ab	142 a	177 a	157 ab
45 K – 22 S	204 a	139 a	149 a	117 b	144 a	167 a	153 b
S.E.M.	7.3	7.3	7.3	7.3	7.3	7.3	3.0
	---------- Pr > F (p-value) ----------						
Pr > F [X]	0.098	0.259	0.264	0.012	0.968	0.278	—

[Z] Potassium rates are kg K_2O/ha as side-banded muriate of potash (KCl; 0-0-60)
[Y] Sulfur rates are kg S/ha as side-banded ammonium sulfate (AMS; 21-0-0-24)
[X] Test of effect slices for SITE × K × S, sliced by SITE

Table 14. Pre-determined contrast comparisons to test for lentil plant density responses to phosphorus (P) and nitrogen (N). P-values ≤ 0.05 are considered significant. These results were from a separate analysis of the complete set of treatments which included 0-0-0-0 and 29-45-0-0 controls.

Treatment / Comparison	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
	---------- Plant Density (plants/m^2) ----------						
0-0-0-0 (1) vs	194 A	145 A	149 A	138 A	149 A	168 A	157 A
10-45-0-0 (2)	176 A	139 A	152 A	130 A	146 A	174 A	153 A
Pr > F (p-value)	0.066	0.574	0.755	0.472	0.749	0.540	0.304
10-45-0-0 (2) vs	176 A	139 B	152 A	130 A	146 A	174 A	153 A
29-45-0-0 (11)	183 A	160 A	154 A	137 A	143 A	161 A	156 A
Pr > F (p-value)	0.445	0.042	0.864	0.532	0.837	0.181	0.404
29-45-0-0 (11) vs	183 A	160 A	154 A	137 A	143 A	161 A	156 A
29-45-0-22 (6)	196 A	135 B	147 A	136 A	139 A	181 A	156 A
Pr > F (p-value)	0.230	0.014	0.500	0.965	0.643	0.052	0.834

Table 15. Main effect means and multiple comparison test results for potassium (K) fertilizer rate effects on lentil seed yield at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Potassium [Y]	---------- Seed Yield (kg/ha) ----------						
0 kg K_2O/ha	2678 a	2801 a	3736 a	3151 a	1253 a	1324 a	2491 a
23 kg K_2O/ha	2708 a	2910 a	3810 a	3102 a	1354 a	1346 a	2538 a
45 kg K_2O/ha	2712 a	2846 a	3771 a	3159 a	1339 a	1346 a	2529 a
S.E.M.	99.8	105.4	187.0	71.7	51.1	50.2	42.9
	---------- Pr > F (p-value) ----------						
Pr > F [Y]	0.873	0.304	0.583	0.691	0.340	0.938	—
K Rate – lin	0.636	0.531	0.623	0.917	0.242	0.758	0.193
K Rate – quad	0.827	0.159	0.361	0.394	0.356	0.855	0.253

[Z] Potassium source was side-banded muriate of potash (KCl; 0-0-60)

[Y] Test of effect slices for SITE × K, sliced by SITE

Table 16. Main effect means and multiple comparison test results for sulfur (S) fertilizer rate effects on lentil seed yield at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Sulfur [Z]	---------- Seed Yield (kg/ha) ----------						
0 kg S/ha	2728 a	2892 a	3948 a	3092 a	1313 a	1330 a	2550 a
11 kg S/ha	2681 a	2849 a	3579 b	3131 a	1309 a	1348 a	2483 a
22 kg S/ha	2689 a	2815 a	3791 a	3189 a	1323 a	1339 a	2524 a
S.E.M.	99.8	105.4	187.0	71.7	51.1	50.2	42.9
	---------- Pr > F (p-value) ----------						
Pr > F [Y]	0.779	0.552	<0.001	0.386	0.979	0.968	—
S Rate – lin	0.587	0.278	0.028	0.172	0.883	0.897	0.371
S Rate – quad	0.653	0.945	<0.001	0.870	0.888	0.826	0.253

[Z] Sulfur source was side-banded ammonium sulfate (AMS; 21-0-0-24)

[Y] Test of effect slices for SITE × S, sliced by SITE

Table 17. Individual potassium (K) by sulfur (S) fertilizer rate treatment effect means and multiple comparison test results for lentil seed yield at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). The six-site averaged response is also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
K[Z] × S[Y] Rate	---------- Seed Yield (kg/ha) ----------						
0 K – 0 S	2679 a	2868 a	4006 ab	3155 a	1300 a	1292 a	2550 a
0 K – 11 S	2774 a	2781 a	3514 c	3112 a	1207 a	1347 a	2456 a
0 K – 22 S	2581 a	2754 a	3689 abc	3187 a	1252 a	1333 a	2466 a
23 K – 0 S	2790 a	2930 a	4050 a	3005 a	1301 a	1343 a	2570 a
23 K – 11 S	2564 a	2907 a	3644 bc	3114 a	1386 a	1355 a	2495 a
23 K – 22 S	2772 a	2895 a	3738 abc	3188 a	1375 a	1340 a	2551 a
45 K – 0 S	2715 a	2879 a	3789 abc	3117 a	1338 a	1354 a	2532 a
45 K – 11 S	2705 a	2861 a	3578 bc	3165 a	1335 a	1341 a	2498 a
45 K – 22 S	2716 a	2796 a	3947 ab	3194 a	1344 a	1343 a	2557 a
S.E.M.	122.5	127.1	200.1	100.9	88.5	87.0	51.9
	---------- Pr > F (p-value) ----------						
Pr > F [X]	0.548	0.861	<0.001	0.876	0.927	1.000	—

[Z] Potassium rates are kg K_2O/ha as side-banded muriate of potash (KCl; 0-0-60)
[Y] Sulfur rates are kg S/ha as side-banded ammonium sulfate (AMS; 21-0-0-24)
[X] Test of effect slices for SITE × K × S, sliced by SITE

Table 18. Pre-determined contrast comparisons to test for lentil seed yield responses to phosphorus (P) and nitrogen (N). P-values ≤ 0.05 are considered significant. These results were from a separate analysis of the complete set of treatments which included 0-0-0-0 and 29-45-0-0 controls.

Treatment / Comparison	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
	---------- Seed Yield (kg/ha) ----------						
0-0-0-0 (1) vs	2469 A	2706 A	3849 A	2884 B	1170 A	1221 A	2383 B
10-45-0-0 (2)	2679 A	2868 A	4006 A	3154 A	1300 A	1292 A	2550 A
Pr > F (p-value)	0.086	0.184	0.199	0.027	0.287	0.558	0.001
10-45-0-0 (2) vs	2679 A	2868 A	4006 A	3154 A	1300 A	1292 A	2550 A
29-45-0-0 (11)	2794 A	2936 A	3689 B	3180 A	1348 A	1334 A	2547 A
Pr > F (p-value)	0.346	0.578	0.010	0.833	0.695	0.732	0.949
29-45-0-0 (11) vs	2794 A	2936 A	3689 A	3180 A	1348 A	1334 A	2547 A
29-45-0-22 (6)	2581 A	2754 A	3689 A	3187 A	1252 A	1333 A	2466 A
Pr > F (p-value)	0.082	1.138	1.000	0.959	0.431	0.994	0.105

Table 19. Main effect means and multiple comparison test results for potassium (K) fertilizer rate effects on lentil test weight at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Potassium [Y]	Test Weight (g/0.5 l)						
0 kg K_2O/ha	394.5 a	388.3 a	—	403.9 a	369.4 a	389.3 a	389.1 a
23 kg K_2O/ha	394.4 a	388.4 a	—	403.3 a	370.5 a	389.2 a	389.2 a
45 kg K_2O/ha	394.1 a	388.5 a	—	403.2 a	370.1 a	388.9 a	389.0 a
S.E.M.	0.62	0.62	—	0.62	0.62	0.62	0.28
	Pr > F (p-value)						
Pr > F [Y]	0.780	0.965	—	0.424	0.222	0.799	—
K Rate – lin	0.507	0.790	—	0.233	0.289	0.507	0.593
K Rate – quad	0.818	1.000	—	0.591	0.169	0.939	0.607

[Z] Potassium source was side-banded muriate of potash (KCl; 0-0-60)

[Y] Test of effect slices for SITE × K, sliced by SITE

Table 20. Main effect means and multiple comparison test results for sulfur (S) fertilizer rate effects on lentil test weight at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Sulfur [Z]	Test Weight (g/0.5 l)						
0 kg S/ha	394.8 a	389.0 a	—	404.1 a	370.6 a	388.8 a	389.5 a
11 kg S/ha	394.6 a	388.2 a	—	403.2 a	369.8 a	389.3 a	389.0 ab
22 kg S/ha	393.6 a	388.1 a	—	403.1 a	369.6 a	389.3 a	388.7 b
S.E.M.	0.62	0.62	—	0.62	0.62	0.62	0.28
	Pr > F (p-value)						
Pr > F [Y]	0.111	0.273	—	0.212	0.255	0.694	—
S Rate – lin	0.048	0.146	—	0.113	0.113	0.507	0.008
S Rate – quad	0.490	0.490	—	0.443	0.645	0.591	0.607

[Z] Sulfur source was side-banded ammonium sulfate (AMS; 21-0-0-24)

[Y] Test of effect slices for SITE × S, sliced by SITE

Table 21. Individual potassium (K) by sulfur (S) fertilizer rate treatment effect means and multiple comparison test results for lentil test weight at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). The six-site averaged response is also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
K[Z] × S[Y] Rate	---------- Test Weight (g/0.5 l) ----------						
0 K – 0 S	395.0 a	388.5 a	—	404.8 a	369.8 a	389.0 a	389.4 a
0 K – 11 S	394.8 a	388.3 a	—	403.8 a	369.3 a	388.5 a	388.9 a
0 K – 22 S	393.8 a	388.3 a	—	403.3 a	369.3 a	390.5 a	389.0 a
23 K – 0 S	395.0 a	389.5 a	—	403.8 a	370.5 a	389.3 a	389.6 a
23 K – 11 S	394.0 a	387.8 a	—	403.0 a	370.5 a	389.8 a	389.0 a
23 K – 22 S	394.3 a	388.0 a	—	403.0 a	370.5 a	388.5 a	388.9 a
45 K – 0 S	394.5 a	389.0 a	—	403.8 a	371.5 a	388.3 a	389.4 a
45 K – 11 S	395.0 a	388.5 a	—	402.8 a	369.8 a	389.8 a	389.2 a
45 K – 22 S	392.8 a	388.0 a	—	403.0 a	369.0 a	388.8 a	388.3 a
S.E.M.	0.88	0.88	—	0.88	0.88	0.88	0.39
	---------- Pr > F (p-value) ----------						
Pr > F [X]	0.472	0.850	—	0.726	0.356	0.491	—

[Z] Potassium rates are kg K_2O/ha as side-banded muriate of potash (KCl; 0-0-60)
[Y] Sulfur rates are kg S/ha as side-banded ammonium sulfate (AMS; 21-0-0-24)
[X] Test of effect slices for SITE × K × S, sliced by SITE

Table 22. Pre-determined contrast comparisons to test for lentil test weight responses to phosphorus (P) and nitrogen (N). P-values ≤ 0.05 are considered significant. These results were from a separate analysis of the complete set of treatments which included 0-0-0-0 and 29-45-0-0 controls.

Treatment / Comparison	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
	---------- Test Weight (g/0.5 l) ----------						
0-0-0-0 (1) vs	394.3 A	388.0 A	—	405.3 A	369.5 A	388.5 A	389.1 A
10-45-0-0 (2)	395.0 A	388.5 A	—	404.8 A	369.8 A	389.0 A	389.4 A
Pr > F (p-value)	0.476	0.635	—	0.635	0.812	0.635	0.524
10-45-0-0 (2) vs	395.0 A	388.5	—	404.8 A	369.8 B	389.0 A	389.4 A
29-45-0-0 (11)	393.3 A	389.0	—	404.5 A	372.8 A	390.0 A	389.9 A
Pr > F (p-value)	0.098	0.635	—	0.812	0.005	0.342	0.289
29-45-0-0 (11) vs	393.3 A	389.0 A	—	404.5	372.8 A	390.0 A	389.9 A
29-45-0-22 (6)	393.8 A	388.3 A	—	403.3	369.3 B	390.5 A	389.0 A
Pr > F (p-value)	0.635	0.476	—	0.236	0.001	0.635	0.057

Table 23. Main effect means and multiple comparison test results for potassium (K) fertilizer rate effects on lentil thousand seed weight (TSW) at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Potassium [Y]	Seed Weight (g/1000 seeds)						
0 kg K_2O/ha	52.9 a	45.3 ab	53.0 a	45.9 a	46.6 ab	37.8 a	46.9 a
23 kg K_2O/ha	53.2 a	45.9 a	53.4 a	46.3 a	46.1 b	37.6 a	47.1 a
45 kg K_2O/ha	52.8 a	45.0 b	53.6 a	46.4 a	46.9 a	38.0 a	47.1 a
S.E.M.	0.37	0.32	0.54	0.77	1.68	0.26	0.33
	Pr > F (p-value)						
Pr > F [Y]	0.499	0.022	0.142	0.326	0.057	0.479	—
K Rate – lin	0.941	0.292	0.051	0.149	0.390	0.461	0.115
K Rate – quad	0.240	0.010	0.777	0.702	0.025	0.335	0.619

[Z] Potassium source was side-banded muriate of potash (KCl; 0-0-60)

[Y] Test of effect slices for SITE × K, sliced by SITE

Table 24. Main effect means and multiple comparison test results for sulfur (S) fertilizer rate effects on lentil thousand seed weight (TSW) at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Sulfur [Z]	Seed Weight (g/1000 seeds)						
0 kg S/ha	52.7 a	45.6 a	53.4 a	46.3 a	46.6 a	37.7 a	47.1 a
11 kg S/ha	53.3 a	45.2 a	53.3 a	46.4 a	46.5 a	37.8 a	47.1 a
22 kg S/ha	52.9 a	45.3 a	53.4 a	45.9 a	46.5 a	37.9 a	47.0 a
S.E.M.	0.37	0.32	0.54	0.77	1.68	0.26	0.33
	Pr > F (p-value)						
Pr > F [Y]	0.293	0.456	0.973	0.245	0.874	0.873	—
S Rate – lin	0.589	0.404	0.961	0.194	0.606	0.606	0.502
S Rate – quad	0.142	0.350	0.820	0.288	0.966	0.943	0.619

[Z] Sulfur source was side-banded ammonium sulfate (AMS; 21-0-0-24)

[Y] Test of effect slices for SITE × S, sliced by SITE

Table 25. Individual potassium (K) by sulfur (S) fertilizer rate treatment effect means and multiple comparison test results for lentil thousand seed weight (TSW) at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). The six-site averaged response is also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
K[Z] × S[Y] Rate	Seed Weight (g/1000 seeds)						
0 K – 0 S	52.8 a	46.2 a	52.7 a	45.8 a	47.0 a	37.5 a	47.0 a
0 K – 11 S	53.0 a	44.4 a	53.0 a	46.3 a	46.0 a	38.0 a	46.8 a
0 K – 22 S	52.8 a	45.3 a	53.2 a	45.6 a	46.9 a	37.8 a	46.9 a
23 K – 0 S	52.9 a	45.6 a	53.3 a	46.2 a	46.0 a	37.6 a	46.9 a
23 K – 11 S	53.6 a	46.2 a	53.5 a	46.8 a	46.9 a	37.6 a	47.4 a
23 K – 22 S	53.1 a	45.9 a	53.3 a	45.8 a	45.5 a	37.7 a	46.9 a
45 K – 0 S	52.5 a	45.0 a	54.1 a	46.9 a	46.9 a	38.1 a	47.2 a
45 K – 11 S	53.2 a	45.0 a	53.4 a	46.1 a	46.8 a	37.8 a	47.0 a
45 K – 22 S	52.9 a	44.8 a	53.5 a	46.2 a	47.1 a	38.2 a	47.1 a
S.E.M.	0.50	0.47	0.63	0.84	1.72	0.43	0.36
	Pr > F (p-value)						
Pr > F [X]	0.803	0.024	0.579	0.336	0.059	0.956	—

[Z] Potassium rates are kg K_2O/ha as side-banded muriate of potash (KCl; 0-0-60)
[Y] Sulfur rates are kg S/ha as side-banded ammonium sulfate (AMS; 21-0-0-24)
[X] Test of effect slices for SITE × K × S, sliced by SITE

Table 26. Pre-determined contrast comparisons to test for lentil thousand seed weight (TSW) responses to phosphorus (P) and nitrogen (N). P-values ≤ 0.05 are considered significant. These results were from a separate analysis of the complete set of treatments which included 0-0-0-0 and 29-45-0-0 controls.

Treatment / Comparison	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
	Seed Weight (g/1000 seeds)						
0-0-0-0 (1) vs	52.8 A	45.6 A	52.6 A	47.7 A	46.5 A	37.7 A	47.2 A
10-45-0-0 (2)	52.8 A	46.2 A	52.7 A	45.8 B	47.0 A	37.5 A	47.0 A
Pr > F (p-value)	0.967	0.319	0.868	0.002	0.406	0.740	0.576
10-45-0-0 (2) vs	52.8 A	46.2 A	52.7 A	45.8 A	47.0 A	37.5 A	47.0 A
29-45-0-0 (11)	52.8 A	45.9 A	53.1 A	46.1 A	46.8 A	37.7 A	47.1 A
Pr > F (p-value)	0.967	0.533	0.506	0.648	0.678	0.771	0.892
29-45-0-0 (11) vs	52.8	45.9 A	53.1	46.1 A	46.8 A	37.7	47.1 A
29-45-0-22 (6)	52.8	45.3 A	53.2	45.6 A	46.9 A	37.8	46.9 A
Pr > F (p-value)	1.000	0.340	0.835	0.406	0.901	0.868	0.599

Table 27. Main effect means and multiple comparison test results for potassium (K) fertilizer rate effects on lentil seed protein concentration at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Potassium [Y]	Seed Protein (%)						
0 kg K_2O/ha	24.87 a	23.72 a	24.72 a	24.17 a	24.96 a	25.01 a	24.57 a
23 kg K_2O/ha	24.70 a	23.60 a	24.79 a	24.18 a	24.39 b	24.97 a	24.44 a
45 kg K_2O/ha	24.64 a	23.43 a	24.68 a	24.13 a	24.61 ab	24.88 a	24.40 a
S.E.M.	0.164	0.164	0.164	0.164	0.164	0.164	0.067
	Pr > F (p-value)						
Pr > F [Y]	0.590	0.439	0.897	0.976	0.044	0.830	—
K Rate – lin	0.325	0.202	0.865	0.873	0.129	0.548	0.056
K Rate – quad	0.771	0.910	0.666	0.879	0.046	0.911	0.543

[Z] Potassium source was side-banded muriate of potash (KCl; 0-0-60)

[Y] Test of effect slices for SITE × K, sliced by SITE

Table 28. Main effect means and multiple comparison test results for sulfur (S) fertilizer rate effects on lentil seed protein concentration at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). Orthogonal contrast results and the six-site averaged results are also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Main Effect	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
Sulfur [Z]	Seed Protein (%)						
0 kg S/ha	24.61 a	23.47 a	24.86 a	24.09 a	24.64 a	24.95 a	24.44 a
11 kg S/ha	24.61 a	23.62 a	24.51 a	24.17 a	24.76 a	24.92 a	24.43 a
22 kg S/ha	24.99 a	23.66 a	24.82 a	24.22 a	24.57 a	24.99 a	43.54 a
S.E.M.	0.164	0.164	0.164	0.164	0.164	0.164	0.067
	Pr > F (p-value)						
Pr > F [Y]	0.152	0.681	0.231	0.853	0.689	0.956	—
S Rate – lin	0.095	0.405	0.882	0.578	0.739	0.862	0.261
S Rate – quad	0.323	0.789	0.089	0.925	0.427	0.809	0.543

[Z] Sulfur source was side-banded ammonium sulfate (AMS; 21-0-0-24)

[Y] Test of effect slices for SITE × S, sliced by SITE

Table 29. Individual potassium (K) by sulfur (S) fertilizer rate treatment effect means and multiple comparison test results for lentil seed protein concentration at Indian Head (IH), Scott (SC), and Swift Current (SW), Saskatchewan, over a two-year period (2023-24). The six-site averaged response is also presented. Values within a column followed by the same letter do not significantly differ (Tukey's, *P* ≤ 0.05).

Treatment	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
K[Z] × S[Y] Rate	---- Seed Protein (%) ----						
0 K – 0 S	24.61 a	23.62 a	24.96 a	24.27 a	25.11 a	24.81 a	24.56 a
0 K – 11 S	24.96 a	23.83 a	24.46 a	24.16 a	24.85 a	25.13 a	24.57 a
0 K – 22 S	25.03 a	23.72 a	24.75 a	24.08 a	24.90 a	25.10 a	24.59 a
23 K – 0 S	24.58 a	23.52 a	25.12 a	24.04 a	24.43 a	24.98 a	24.44 a
23 K – 11 S	24.38 a	23.50 a	24.28 a	24.37 a	24.71 a	25.05 a	24.38 a
23 K – 22 S	25.14 a	23.78 a	24.95 a	24.13 a	24.05 a	24.86 a	24.48 a
45 K – 0 S	24.65 a	23.28 a	24.49 a	23.97 a	24.38 a	25.05 a	24.30 a
45 K – 11 S	24.48 a	23.53 a	24.78 a	23.99 a	24.72 a	24.58 a	24.34 a
45 K – 22 S	24.80 a	23.49 a	24.77 a	24.44 a	24.74 a	25.00 a	24.54 a
S.E.M.	0.278	0.278	0.278	0.278	0.278	0.278	0.113
	---- Pr > F (p-value) ----						
Pr > F [X]	0.516	0.930	0.457	0.935	0.223	0.915	—

[Z] Potassium rates are kg K_2O/ha as side-banded muriate of potash (KCl; 0-0-60)
[Y] Sulfur rates are kg S/ha as side-banded ammonium sulfate (AMS; 21-0-0-24)
[X] Test of effect slices for SITE × K × S, sliced by SITE

Table 30. Pre-determined contrast comparisons to test for lentil seed protein concentration responses to phosphorus (P) and nitrogen (N). P-values ≤ 0.05 are considered significant. These results were from a separate analysis of the complete set of treatments which included 0-0-0-0 and 29-45-0-0 controls.

Treatment / Comparison	IH-23	IH-24	SC-23	SC-24	SW-23	SW-24	Average
	---- Seed Protein (%) ----						
0-0-0-0 (1) vs	24.65 A	24.10 A	24.62 A	24.32 A	24.66 A	24.79 A	24.52 A
10-45-0-0 (2)	24.61 A	23.62 A	24.96 A	24.27 A	25.11 A	24.81 A	24.56 A
Pr > F (p-value)	0.900	0.206	0.377	0.879	0.233	0.953	0.808
10-45-0-0 (2) vs	24.61 A	23.62 A	24.96 A	24.27 A	25.11 A	24.81 B	24.56 A
29-45-0-0 (11)	24.89 A	23.48 A	24.94 A	23.83 A	24.68 A	25.60 A	24.57 A
Pr > F (p-value)	0.460	0.716	0.968	0.254	0.249	0.037	0.957
29-45-0-0 (11) vs	24.89 A	23.48	24.94 A	23.83 A	24.68 A	25.60 A	24.57 A
29-45-0-22 (6)	25.03 A	23.72	24.75 A	24.08 A	24.90 A	25.10 A	24.59 A
Pr > F (p-value)	0.707	0.531	0.607	0.513	0.548	0.183	0.867

15. Abstract / Non-confidential Summary (in lay language, detailing Project objectives, results and conclusions, suitable for use in publications and on the SPG website):

Field trials with small red lentil (*Lens culinaris*) were conducted at three Saskatchewan locations in 2023 and 2024 with the objective of evaluating crop response to varying rates of potassium (K) and sulfur (S) fertilizer. The locations were selected to represent the diverse lentil growing regions of the province and included Indian Head (thin-Black soil zone), Scott (Dark Brown soil zone), and Swift Current (dry Brown Soil zone). The treatments were a factorial combination of three K rates (0, 22.5, and 45 kg K_2O/ha as side-banded potash), three S rates (0, 11, and 22 kg S/ha as side-banded ammonium sulfate), and two control treatments to test for responses to phosphorus and nitrogen. Data collection included measurements of emergence, yield, test weight, thousand seed weight, and protein. Soil test results did not indicate any specific need for K, but chloride levels were potentially limiting. Residual S levels were reasonably low for the top soil, but considerably higher when the sub-soil was considered. The 2023 growing season was hot and dry while 2024 was initially cool and wet but became hot and dry in July. Overall, significant treatment effects were relatively infrequent. We saw a minor reduction in emergence with increasing S rate when combined with the highest rate of potash. There were never any yield responses to K detected. At Scott in 2023 there was a slight negative response to S; however, yields at this site were variable overall and this did not occur at any other sites. Impacts on seed quality were infrequent and, if they did occur, either minor or inconsistent. Despite the lack of responses in the current project, relatively small yield gains can be sufficient to cover the cost of small amounts of K and S fertilizer. Furthermore, regular applications of these nutrients at low rates could help to maintain soil fertility over the long-term and reduce the risk of deficiencies in future crops and/or years. As such, some growers may see value in including K and S in their lentil fertility program; however, the likelihood of yield loss or reduced profits if they refrain from doing so is low.