SPG Applied Research & Demonstration Report Format

1. **Project Code (as is in contract):**

   AP-19-06a-IHARF

2. **Project Title:**

   Enhanced fertilizer management for optimizing yield and protein in field pea

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5. **Introduction** (background and rationale for project, include references to original research projects where necessary)

   Field peas are the most widely adapted pulse crop in Saskatchewan and are important to many growers for both the rotational benefits associated with legumes and as a key option for maintaining diversity in crop rotations. Furthermore, with increasing consumer demand for plant-based protein there are emerging opportunities for growers to receive premiums for high protein pulse crops and we anticipate increased interest in exploring potential management options to more consistently achieve high protein levels. Experience with non-legume crops suggests that N fertility is one of relatively few management decisions that can consistently affect grain protein concentrations.

   Field peas can benefit from N fixation whereby symbiotic relationships with *Rhizobium leguminosarum* bacteria allow atmospheric N_2 to be converted to available forms and utilized by the crop. The maximum benefit to this process is generally achieved when mineral N (soil + fertilizer) levels are low; therefore, N fertilization in field pea production is not normally recommended unless soil residual levels are extremely low (i.e. < 11 kg NO_3-N/ha). In northwest Alberta, Clayton et al. (2004) found that, regardless of inoculant form, N fertilizer rates ranging from 0-80 kg N/ha (side-banded urea) increased vegetative growth but did not affect seed yield at 4/6 site-years and seed protein was not affected in any cases. At one site where there was a response, N fertilization increased grain yield with either no inoculant or seed-applied (peat or liquid) formulations but decreased yield when combined with granular inoculant. The highest yields, by a large margin, were achieved with no N fertilizer and granular inoculant. At the other site where there was an N fertilizer effect, increased yield with N fertilizer only occurred when no inoculant (regardless of form) was applied. Another, extensive, Alberta study showed that application of N fertilizer (20, 40, or 60 kg N/ha) increased pea yield in 24% of 58 trials by an average of 9% (McKenzie et al. 2001). When residual NO_3-N was less than 20 kg N/ha, increases occurred 33% of the time with an overall average benefit of 11%. Although protein was affected by the addition of N fertilizer at more than 36% of the sites, the response was more frequently negative than it was positive (21% versus 16%). In early work with a single site-year at Saskatoon, Sosuiski et al. (1974) were not able to measure yield but increased field pea seed protein by 2% over the control with 55 kg N/ha as ammonium-nitrate (33.5-0-0).

Focussing on P, field peas are not considered to be particularly responsive to fertilization; however, responses to modest rates have been documented in low P soils. Over a three-year period on low P soils (10-18 kg $NaHCO_3$ extractable P) near Outlook, Melfort, and Saskatoon, Henry et al. (1994) increased pea yields by approximately 15% with 35 kg P_2O_5/ha as side-banded monoammonium phosphate at one of three locations but observed negative responses to seed-placed P rates exceeding 35 kg P_2O_5/ha at the other two locations. In a series of 21 trials using Triple Super Phosphate (0-45-0) as a P source, Karamanos et al. (2003) found that field peas responded to P when modified Kelowna extractable P was less than 10 ppm and that the response was greater in loam versus clay soils and with side-banded versus seed-placed fertilizer. Many producers strive to apply P fertilizer rates that are sufficient to offset nutrients removed in the harvested grain. It is estimated that field peas removed approximately 0.6-0.8 lb P_2O_5/bu or 31-38 lb P_2O_5/ac (35-43 kg P_2O_5/ha) in a 50 bu/ac (3400 kg/ha) crop (Canadian Fertilizer Institute 1998).

Relatively few studies have evaluated field pea response to S fertilization. McKenzie et al. (2001) reported that yield increases with potassium and S fertilizer application occurred at only 3 of 44 trials in Alberta and found no correlation between the observed responses and soil test levels. Under low yielding, drought conditions at Swift Current in 2017, lentil yields were significantly increased with sulphate S fertilizer with the best results achieved using ammonium sulphate (21-0-0-24) at a rate of 20 kg S/ha (Nybo et al. 2017). While the treatments were also evaluated on field peas, yields were extremely low and no benefit was observed. A 50 bu/ac (3400 kg/ha) field pea crop will take up approximately 12-16 kg S/ha (Canadian Fertilizer Institute 1998). In general, S fertilizer responses are be more likely to occur in coarse textured soils with low organic matter and low residual S.

Literature Cited

Canadian Fertilizer Institute. 1998. Nutrient Uptake and Removal by Field Crops. Online [Available]: http://mbfc.s3.amazonaws.com/reference_manual_/5l_cfi_nutrient_uptake_for_wcanada.pdf (March 14, 2019).

Clayton, G.W., Rice, W.A., Lupwayi, N.Z., Johnston, A.M., Lafond, G.P., Grant, C.A., and Walley, F. 2004. Inoculant formulation and fertilizer nitrogen effects on field pea: Crop yield and canopy. Can. J. Plant Sci. **84:** 89-96.

Henry, J.L., Slinkard, A.E., and Hogg, T.J. 1995. The effect of phosphorus fertilizer on establishment, yield and quality of pea, lentil and faba bean. Can. J. Plant Sci. **75:** 395-398.

Karamanos, R.E., FLore, N.A., and Harapiak, J.T. 2003. Response of field peas to phosphate fertilization. Can. J. Plant Sci. **83:** 283-289.

Mckenzie, R.H., Middleton, A.B., Solberg, E.D., DeMulder, J., Flore, N., Clayton, G.W., and Bremer, E. 2001. Response of pea to rhizobia inoculation and starter nitrogen in Alberta. Can. J. Plant Sci. **81:** 637-643.

Nybo, B., Wall, A., Sluth, D. 2017. The effects of sulfur formulations on pea and lentil. Saskatchewan Pulse Crop Development Board. AP-17-07-Nybo Final Report.

Sosulski, F.W., McLean, L.A., and Austenson, H.M. 1974. Management for yield and protein of field peas in Saskatchewan. Can. J. Plant Sci. **54:** 247-251.

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

The project objectives were simply to evaluate, across a range of Saskatchewan environments, the yield and protein response of yellow field pea to various rates and combinations of nitrogen (N), phosphorus (P) and sulphur (S) fertilizer.

7. **Materials and Methods –** experimental design, methods used, details of growing the crop(s), materials used, sites, etc. Statistical analysis used

In early 2019, Agri-ARM and Saskatchewan Pulse Growers agronomists developed and initiate a comprehensive field pea fertility study at multiple Saskatchewan locations. The locations were Swift Current (dry Brown), Outlook (Brown), Scott (Dark Brown), Indian Head (thin Black), Yorkton (Black), and Melfort (moist Black). The treatments were an assortment of fertilizer applications selected to test the yield and protein responses to varying P and S rates in addition to several N fertilization strategies. To represent both extremes we also included an unfertilized control and an ultra-high fertility treatment. The P and S sources were monoammonium phosphate (11-52-0) and ammonium sulphate (21-0-0-24), respectively. With the exception of treatments 12-13 where polymer coated urea (ESN; 44-0-0) was used, the N source was urea (46-0-0). All fertilizer was side-banded with the exception of the extra urea in Treatment 11 which was applied as a surface broadcast during the late vegetative crop stages. All treatments received the full, label-recommended rate of granular inoculant. The fertilizer treatments are listed below in Table 1.

Table 1. Field pea fertilizer treatment descriptions.

#	kg N-P_2O_5-K_2O-S/ha
1	0-0-0-0 (no fertilizer)
2	17-0-0-10 (0 P)
3	17-20-0-10 (20 P)
4	17-40-0-10 (40 P / 10 S)
5	21-60-0-10 (60 P)
6	26-80-0-10 (80 P)
7	17-40-0-0 (0 S)
8	17-40-0-5 (5 S)
9	22-40-0-15 (15 S)
10	40-40-0-10 (40 N as MAP/AS/urea)
11[Z]	17.2-40-0-10 + 40 N in-crop broadcast urea
12[Y]	40-40-0-10 * (40 N as MAP/AS/ESN)
13[Y]	40-80-0-15 * (ultra high fertility / ESN)

[Z] In-crop N broadcast approximately 4-5 weeks after emergence, prior to canopy closure and 1st flowers
[Y] ESN (44-0-0) instead of urea as the supplemental N source in Trt #12 and 13
*All fertilizer side-banded except for the 40 kg N/ha as in-crop urea in Trt #11

Selected agronomic information is provided in Table 2 of the Appendices. Seeding equipment varied across locations to a certain extent but all sites utilized no-till drills with side-band capabilities and the field peas were always direct-seeded into cereal stubble. All sites used the same seed source (variety CDC Spectrum) with target seeding rates of 100 viable seeds/m^2, adjusted for seed size and percent germination. Seed treatments were used to mitigate the risk of root diseases and pea leaf weevil at all locations. Seeding dates ranged from as early as May 7 at Yorkton to May 22 at Melfort with seeding for the remaining sites completed between May 9-14. Weeds were controlled using registered pre- and post-emergent herbicide options. Insecticides were not required at any locations. Foliar fungicides were applied preventatively at all sites except for Swift Current where the risk of disease was low. Pre-harvest herbicides and/or desiccants were applied at the discretion of individual site managers and the plots were straight combined as soon as possible after it was fit to do so. Seed yields were corrected for dockage and to a uniform moisture content of 16%. Seed protein concentrations were determined for each plot using an NIR instrument. To aid in the interpretation of results, composite soil samples were collected from each location prior to seeding to be analyzed for residual nutrients and other basic qualities. Similarly, precipitation amounts and temperatures for each location were recorded at nearby Environment Canada stations.

The specific response data evaluated were seed yield and seed protein concentrations. Data were analyzed using the Mixed procedure of SAS with the effects of location (L), fertilizer treatment (F), and the L x F interaction considered fixed and replicated effects (nested within locations) considered random. Individual treatment means were separated using Tukey's studentized range test. Heterogeneity in variance estimates amongst individual locations was permitted and improved model convergence for both response variables. Contrasts were used to compared the unfertilized (1) to fertilized (2-13) treatments and normal fertility (4) to the treatments where extra N was applied (10, 11, and 12). Orthogonal contrasts were used to test whether the specific responses to increasing P and S rates were linear, quadratic, or not significant. All responses were considered significant at $P \leq 0.05$ but values ≤ 0.10 were also generally highlighted as noteworthy trends.

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.

Weather and Soil Characteristics
Mean monthly temperatures and precipitation amounts are presented relative to the long-term (1981-2010) averages in Tables 3 and 4 of the Appendices, respectively. Overall, temperatures were below average but to a lesser extent at Swift Current and, especially, Yorkton where both June and July were warmer than average. All locations except Scott were also drier than average. The general trend was for the driest weather in May but increasing precipitation as the season progressed; however, the extent and specific timing of precipitation varied across locations. Relative to many crops, field peas do fairly well under dry conditions and the weather in 2019 was conducive to reasonably high yields at all locations.

Soil test results are provided in Table 5 of the Appendices. Soil pH ranged from 5.9-8.1 while organic matter levels ranged from 2.3-9.6% and all values were considered reasonably representative of their corresponding regions. Residual nitrate was variable, below 50 kg/ha at 5/6 locations (0-60 cm) but with a range of 21-202 kg NO_3-N/ha. The site with the higher than usual residual nitrate levels was Swift Current while the lowest N levels were at Outlook and Indian Head (21-27 kg NO_3-N/ha). Residual P levels were always low, ranging from 4-5 ppm at Indian Head and Outlook to a maximum of 11 ppm at Scott. Both potassium (K) and sulphur (S) levels were high at all locations and neither of these nutrients were expected to be limiting at any locations based on soil test results alone. Potassium responses were not evaluated in the current project.

Seed Yield
When seed yield data were averaged across all locations, the effect of fertilizer treatment and location were both highly significant ($P < 0.001$) but a significant F x L interaction ($P < 0.001$) indicated that the fertilizer effect varied with environment (Table 6). The highest yields were achieved at Scott (6022 kg/ha), followed by Yorkton and Outlook (4833-4918 kg/ha), Indian Head (4326 kg/ha), Melfort (3807 kg/ha), and Swift Current (2845 kg/ha). Looking at the averaged fertilizer responses, yields were lowest in the unfertilized control (Trt. #1) as expected while the highest yields were achieved with balanced but not excessive fertility package of 17-40-0-10 kg N-P_2O_5-K_2O-S/ha as side-banded monoammonium phosphate and ammonium sulfate (Trt. #4). Statistically, yields did not significantly differ amongst any of the

fertilized treatments where a minimum of 20 kg P_2O_5/ha was applied. The quadratic response to P rate (Table 7; *P* = 0.002) considered along with the treatment means indicated that the maximum benefit was achieved at approximately 40 kg P_2O_5/ha when averaged across locations. While there was no indication of a response to S fertilizer when averaged across locations, the contrasts did show a tendency for lower yields when additional N fertilizer (beyond what was supplied by the P and S fertilizer products) was applied (*P* = 0.062; Tables 6 and 7). The magnitude of this reduction was small at only 163 kg/ha or 3.5%.

Again, the F x L interaction tells us that the response varied across locations. Overall tests of fertility effects for individual locations suggested that yield responses occurred at Indian Head, Outlook, and Scott (*P* < 0.001) with trends observed at Swift Current and Yorkton (*P* = 0.072-0.074) and no response at Melfort. At Indian Head, P fertilizer rate had the greatest impact with a strong linear response detected (*P* < 0.001). There was a slight tendency for lower yields when supplemental N fertilizer (beyond what is provided by P and S products) was applied (*P* = 0.094). At Melfort, despite the lack of a significant F-test, the orthogonal contrasts indicated a quadratic response to P rate (*P* = 0.048) but no other impacts. At Outlook, although there was a relatively strong discrepancy between the unfertilized versus fertilized treatments (*P* < 0.001), it was difficult to attribute the response to any individual nutrients. Phosphorus appeared to have the largest and most consistent effect on yield; however, the corresponding orthogonal contrasts were marginally significant at best (P-linear, *P* = 0.095) and most of the benefit appeared to be achieved with the relatively low rate of 20 kg P_2O_5/ha. It appears that most of the yield gains with fertilization at Outlook could be attributed to the low rate (17 kg N/ha) of background N provided in all the treatments combined the first 20 kg P2O5/ha. At Scott, there was a highly significant quadratic P response (*P* = 0.007) with most of the benefit realized at the lowest rate of 20 kg P_2O_5/ha. The contrast testing the effects of extra N was also significant (*P* = 0.002) and appeared to mostly be due to a negative impact of side-banding supplemental urea. Of the N treatments evaluated, this was the most likely to increase mineral N levels early and potentially impede rhizobial colonization and subsequent N fixation; however, nodule assessments were beyond the scope of this project. At Swift Current, the quadratic orthogonal contrast for seed yield also suggested a benefit to P fertilization but, again, with most of the benefit realized at the lowest rate (20 kg P_2O_5/ha). At Yorkton, there was no evidence of a P response specifically (*P* = 0.302-0.773) but the comparison between the control and all fertilized treatments was significant (*P* = 0.011) and, somewhat unexpectedly (considering the soil test results), the linear orthogonal contrast for S rate was also significant (*P* = 0.030).

Seed Protein Concentration

When seed protein data were averaged across all locations, the effect of fertilizer treatment on its own was not significant (*P* = 0.270) but protein levels were affected by location (*P* < 0.001) and, again, the F x L interaction (*P* < 0.001) indicated that the fertilizer effect on protein varied with environment (Table 8). Average seed protein concentrations of individual locations ranged from 19.9-24.7%. Averaged across all locations, seed protein concentrations ranged from 22.2-22.9% with, as indicated by the F-tests, no significant differences amongst individual treatments. The only contrast that was significant was an overall linear increase in protein with increasing P rate (*P* = 0.046; Table 9). It is worth specifically noting that supplemental N fertilizer did not impact field pea seed protein when averaged across locations (*P* = 0.738).

Similar to seed yield, the significant F x L interaction indicated that the protein response to fertilizer was not always consistent depending on the environment. The overall F-tests for individual locations indicated that the protein responses were greatest at Indian Head and Swift Current (*P* < 0.001-0.026), followed by Outlook and Scott (*P* = 0.054-0.083) and then Melfort and Yorkton (*P* = 0.533-0.978). At Indian Head, no differences between individual treatments were significant according to the multiple comparisons test but the comparison between the control versus fertilized treatments was and appeared to be due to a slight decline in protein with fertilizer application (*P* < 0.001). At Swift Current, the opposite occurred whereby the lowest protein concentrations were observed in the unfertilized control. Protein also increased linearly with P rate at this location (*P* < 0.001). At Outlook, P rate also appeared to have a positive effect on protein; however, this appeared to be mostly due to the comparatively high values observed at the 80 kg P_2O_5/ha rate. At Scott, there was slight positive impact of extra N on protein detected; however, this mostly appeared to be associated with the side-banded urea where yields were also lowest; therefore, the effect may have been more a result of reduced yield as opposed to enhanced N uptake/availability. At Yorkton, there was evidence of a slight negative impact of extra N on grain protein ($P = 0.038$) and no significant responses or noteworthy trends were observed at Melfort.

9. **Economic and Practical Implications For growers** – is there any economic implications for growers

While it is difficult to assign a specific monetary value, the economic benefits associated with this research could conceivably arise from either enhanced yields through better fertilizer management or reduced fertilizer costs with no reduction in yield. The benefits will vary with environment and also as a function of the current practices of individual growers. For example, some growers may currently be under fertilizing their field peas, losing yield and further depleting soil reserves (i.e. phosphorus) and the results from this work may help them justify the higher costs of enhanced fertility. In contrast, other producers may be fertilizing excessively and can potentially utilize these results to reduce their fertilizer investment (i.e. starter N, S in non-limiting soils) without negatively impacting yields. Since P fertilizer provided the most consistent responses, marginal economic returns were calculated for each P rate assuming $6.25/bu for yellow peas and two monoammonium phosphate prices ($550 and 750/Mt). The results from this exercise are provided in Table 10 of the Appendices. Average across all locations, the most economical P rate was 40 kg P_2O_5/ha. This was also the most economical rate at both Indian Head and Melfort. At Outlook, Scott, and Swift Current the most economical P rate was 20 kg P_2O_5/ha while at Yorkton the P response was not significant, therefore the control was considered to be the most profitable. Notably, the most profitable P rate treatment for each individual site and on average was unchanged regardless of whether the P fertilizer price was $550/Mt or $750/Mt.

From a broader agronomic perspective, our results support the use of soil tests and suggest that, of the major nutrients, phosphorus is the most likely to be limiting field pea productivity and can provide sizeable yield benefits when applied as fertilizer. Soil test results did not indicate that a response to S was likely at any individual locations and this was mostly true; however, there was some evidence of a small response to S even with high soil test levels at 1/6 sites (Yorkton). All nutrients have potential to be limiting and this result is not inconsistent with broader recommendations for S which indicate that soil test results are often variable and high residual S levels do not necessarily indicate that deficiencies cannot occur, at least on a site-specific basis. There was no benefit to additional N (beyond what is supplied with modest rates of P and S fertilizers) for either yield or protein, regardless of formulation. Any responses to N that did occur were small and/or negative.

10. **Conclusions & Recommendations –** how do results relate to origination objectives or original research that project is based on; is there a need to refine current recommendation based on the results from this project?

Overall, the locations provided a range of yield potentials and were representative of the major field pea producing regions of Saskatchewan while the observed fertilizer responses were largely consistent with past research and current recommendations for western Canada. Soil test P levels for all sites were considered low (≤ 11 ppm, Olsen) and there was evidence of a statistically significant response at 4/6 locations, or 67% of the time. For the responsive sites, the yield increase with P ranged from 11-31% and, when averaged across all six locations, yields were increased by up to 12% with P fertilization and the optimal rate was 40 kg P_2O_5/ha. While responses were occasionally linear with top yields realized at the highest P rate, yield increases beyond the 20 kg P_2O_5/ha rate were never statistically significant and it is unlikely that rates exceeding approximately 40 kg P_2O_5/ha would be justified under most conditions. An important exception could be when the objective of the producer is for long-term building of residual P levels. Some of the literature cited earlier indicated yield increases of approximately 15% at responsive sites and suggested that responses were likely when soil test levels were below 10 ppm (modified Kelowna extractable P). Sulphur responses have been elusive in past research and this was also true in the current project. Past work has also shown that responses to S are poorly correlated with soil test results.

Consequently, if deficiencies have been observed in the past for either field peas or other crops, applying a small amount of S may be justifiable; however, it is unlikely that S deficiency has been an important yield limiting factor for many field pea producers in Saskatchewan. Focussing on N, past research has found that N fertilization can frequently increase vegetative growth in field peas but positive yield responses are less likely, especially when combined with adequate rhizobial inoculation. Negative protein responses to N fertilization are at least as probable as positive responses. Our results did not show any benefits to N fertilization and, unless residual levels are extremely low or a nodulation failure is suspected, Saskatchewan field pea producers are advised to avoid applying any more N fertilizer than what is provided by any P or S fertilizer products being utilized.

11. **Future research –** did the project identify need for future research for further work?

Due to the variable nature of fertilizer responses depending on specific soil and weather conditions, especially when dealing with multiple nutrients simultaneously, it would be beneficial to repeat these field trials at all locations for a second growing seasons. Although the results to date are largely consistent with past research, there is value in generating new data with modern equipment, varieties, and overall management practices for a wide range of locations that are of practical relevance to pea producers throughout Saskatchewan.

12. **Technology transfer activities –** include presentations, extension material, field days, articles published

Extension activities to date have been limited by the fact that detailed results were not available prior to this report. Wherever possible, collaborators showed the plots and introduced the project during their annual field days and/or other formal and informal tours through the season. Wheatland Conservation Area promoted the project on a weekly CKSW radio program entitled 'Walk the Plots'. Sherrilyn Phelps (SPG) and Jessica Weber (WARC) acknowledged the project during a session entitled 'Maximizing Yield in Peas and Lentils by Optimizing Agronomy' at CropSphere (January 14, 2020, Saskatoon). Chris Holzapfel intends to share results highlights during an Independent Consulting Agronomists Network (ICAN) meeting in Regina (February 4) and the IHARF Winter Meeting/AGM in Balgonie (February 5) while Bryan Nybo will be presenting results at the Swift Current winter pulse meeting in Swift Current (February 27). We anticipate other opportunities for collaborators to utilize these results during future extension activities and this report will also be made freely available charge through IHARF (www.iharf.ca) and Agri-ARM (www.agriarm.ca) websites.

13. **Funding contributions –** acknowledge partners and contributors to the project

The Saskatchewan Pulse Growers Association were the sole financial supporters of this project. Many of the crop protection products utilized at the different locations were provided in-kind. Each of the participating organizations receives Agri-ARM base funding which is made available through the Canadian Agricultural Partnership bi-lateral agreement between the federal government and the Saskatchewan Ministry of Agriculture. Of the collaborating organizations, IHARF, WCA, ICDC, NARF, and WARC also have strong working relationships with Agriculture and Agri-Food Canada which should be acknowledged.

14. Appendices: detailed data tables, maps, photos, etc

Table 2. Selected agronomic information and dates of operations in 2019 for field pea fertility trials at Indian Head, Melfort, Outlook, Scott, Swift Current, and Yorkton, Saskatchewan.

Activity	Indian Head	Melfort	Outlook	Scott	Swift Current	Yorkton
Pre-seed Herbicide	890g glyphosate/ha (May 6)	667g glyphosate/ha + 18g saflufenacil/ha (May 21)	890g glyphosate/ha (May 6)	1134g glyphosate/ha + 21g carfentrazone/ha (May 19)	890g glyphosate/ha (May 4)	n/a
Seeding	May 9	May 22	May 9	May 12	May 14	May 7
Row Spacing	30 cm	30 cm	25 cm	25 cm	21 cm	30 cm
In-crop Herbicide	15g imazamox/ha + 15g imazethapyr/ha (June 12)	20g imazamox/ha + 424g bentazon/ha + 71g quizalofop/ha (July 5)	20g imazamox/ha + 424g bentazon/ha (June 5)	15g imazamox/ha + 15g imazethapyr/ha + 167g sethoxydim/ha (June 13)	20g imazamox/ha + 424g bentazon/ha (June 12)	20g imazamox/ha + 424g bentazon/ha (June 6) 89g clethodim/ha (June 6)
In-crop Nitrogen	June 28 (as per protocol)	July 11 (as per protocol)	June 27	June 10	May 14	June 27
Foliar Fungicide	74g fluxapyroxad/ha + 148g pyraclostrobin/ha (July 7)	201g picoxystrobin/ha (July 12)	74g fluxapyroxad/ha + 148g pyraclostrobin/ha (July 18)	74g fluxapyroxad/ha + 148g pyraclostrobin/ha (July 15)	n/a	201g picoxystrobin/ha (July 5)
Pre-harvest Herbicide / Desiccant	890g glyphosate/ha (August 8)	890g glyphosate/ha + 50g saflufenacil/ha (September 16)	410g diquat/ha (August 20)	410g diquat/ha (August 20)	n/a	n/a
Harvest	August 17	September 23	August 22	August 29	August 20	August 26

n/a – not applicable

Table 3. Mean monthly temperatures along with long-term (1981-2010) averages for the 2019 growing season at Indian Head, Melfort, Outlook, Scott, Swift Current, and Yorkton Saskatchewan.

Location	Year	May	June	July	August	Average
		---------------------------- Mean Temperature (°C) ----------------------------				
Indian Head	2019	8.9	15.7	17.4	15.8	14.5
	Long-term	*10.8*	*15.8*	*18.2*	*17.4*	*15.6*
Melfort	2019	8.8	15.3	16.9	14.9	14.0
	Long-term	*10.7*	*15.9*	*17.5*	*16.8*	*15.2*
Outlook	2019	9.9	16.0	18.0	16.2	15.0
	Long-term	*11.5*	*16.1*	*18.9*	*18.0*	*16.1*
Scott	2019	9.1	14.9	16.1	14.4	13.6
	Long-term	*10.8*	*14.8*	*17.3*	*16.3*	*14.8*
Swift Current	2019	9.5	15.8	17.7	16.8	15.0
	Long-term	*11*	*15.7*	*18.4*	*17.9*	*15.8*
Yorkton	2019	8.6	16.0	18.3	16.1	14.8
	Long-term	*10.4*	*15.5*	*17.9*	*17.1*	*15.2*

Table 4. Mean monthly precipitation amounts along with long-term (1981-2010) averages for the 2019 growing season at Indian Head, Melfort, Outlook, Scott, Swift Current, and Yorkton Saskatchewan.

Location	Year	May	June	July	August	Total
		------------------------ Cumulative Precipitation (mm) ------------------------				
Indian Head	2019	13.3	50.4	53.1	96.0	212.8
	Long-term	*51.7*	*77.4*	*63.8*	*51.2*	*244.4*
Melfort	2019	18.8	87.4	72.7	30.7	209.6
	Long-term	*42.9*	*54.3*	*76.7*	*52.4*	*226.3*
Outlook	2019	13.2	90.2	43.8	39.6	186.8
	Long-term	*42.6*	*63.9*	*56.1*	*42.8*	*205.4*
Scott	2019	12.7	97.7	107.8	18	236.2
	Long-term	*38.9*	*69.7*	*69.4*	*48.7*	*226.7*
Swift Current	2019	13.3	156	11.1	42.6	223.0
	Long-term	*42.1*	*66.1*	*44*	*35.4*	*187.6*
Yorkton	2019	11.1	81.6	49.1	32.2	174.0
	Long-term	*51.3*	*80.1*	*78.2*	*62.2*	*271.8*

Table 5. Selected soil test results for field pea fertility trials at Indian Head, Melfort, Outlook, Scott, Swift Current, and Yorkton Saskatchewan in 2019.

Attribute/Nutrient [Z]	Indian Head	Melfort	Outlook	Scott	Swift Current	Yorkton
pH	7.9	6.0	8.1	5.9	6.5	7.0
S.O.M. (%)	4.7	9.6	2.3	3.5	2.6	6.5
NO_3-N (kg/ha)	27	37 (0-30 cm)	21	47	202	44
Olsen-P (ppm)	4	9	5	12	8	9
K ppm (ppm)	573	473	158	201	229	291
S (kg/ha)	60	85 (0-30 cm)	60 (0-30 cm)	116	47	125

[Z] NO_3-N and S are for 0-60 cm depth (unless otherwise indicated) – all other attributes are for 0-15 cm

Table 6. Tests of fixed effects and individual fertility treatment means for field pea yield at six Agri-ARM facilities in 2019. Data were analyzed using the Mixed procedure of SAS. Treatment means within a column and location means within a row followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Source / Treatment	Indian Head	Melfort	Outlook	Scott	S. Current	Yorkton	Average
Overall F-test	--- p-value ---						
Fertilizer Treatment (F)	<0.001	0.439	<0.001	<0.001	0.074	0.072	<0.001
Location (L)	–	–	–	–	–	–	<0.001
F x L	–	–	–	–	–	–	<0.001
kg N-P_2O_5-K_2O-S/ha	--- Seed Yield (kg/ha) ---						
1) 0-0-0-0 (no fertilizer)	4085 b	3763 a	3595 b	5546 bc	2701 a	4422 a	4019 C
2) 17-0-0-10 (0 P)	3994 b	3683 a	4377 ab	5625 bc	2375 a	4973 a	4171 BC
3) 17-20-0-10 (20 P)	4287 ab	3515 a	4912 ab	6202 a	3090 a	4751 a	4460 AB
4) 17-40-0-10 (40 P / 10 S)	4487 ab	4210 a	4897 ab	6137 a	3111 a	5082 a	4654 A
5) 21-60-0-10 (60 P)	4310 ab	4157 a	5004 ab	6168 a	2855 a	5269 a	4627 A
6) 26-80-0-10 (80 P)	4628 a	3484 a	5054 ab	6268 a	3078 a	5018 a	4588 A
7) 17-40-0-0 (0 S)	4437 ab	3548 a	5472 a	6181 a	2806 a	4494 a	4490 AB
8) 17-40-0-5 (5 S)	4289 ab	3742 a	4782 ab	6150 a	2908 a	4641 a	4419 AB
9) 22-40-0-15 (15 S)	4340 ab	3838 a	5218 ab	6244 a	2611 a	4952 a	4534 A
10) 40-40-0-10 (urea)	4390 ab	3923 a	5366 a	5340 c	2911 a	4932 a	4477 AB
11) 17-40-0-10 + 40 N in-crop	4186 ab	3948 a	5067 ab	5953 ab	2824 a	4978 a	4493 AB
12) 40-40-0-10 (ESN)	4374 ab	4038 a	4628 ab	6204 a	2859 a	4912 a	4502 AB
13) 40-80-0-15 (ultra high fert)	4429 ab	3644 a	5558 a	6266 a	2861 a	5049 a	4634 A
S.E.M.	127.4	253.6	288.1	124.8	181.7	207.8	84.2
Location Average	4326 C	3807 D	4918 B	6022 A	2845 E	4883 B	–
S.E.M.	95.6	113.3	119.5	95.3	102.1	105.9	–

Table 7. Group comparison and orthogonal contrast results for field pea grain yield at six Agri-ARM facilities in 2019. Data were analyzed using the Mixed procedure of SAS. P-values ≤0.05 are considered significant while P-values in the 0.05-0.10 range indicate trends.

Contrast	Indian Head	Melfort	Outlook	Scott	S. Current	Yorkton	Average
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1) No fertilizer (1) vs. rest (2-13)	0.005	0.847	<0.001	<0.001	0.339	0.011	<0.001
2) P rate – linear	<0.001	0.743	0.095	<0.001	0.019	0.302	<0.001
3) P rate – quadratic	0.319	0.048	0.408	0.007	0.032	0.773	0.002
4) S rate – linear	0.815	0.206	0.597	0.640	0.586	0.030	0.275
5) S rate – quadratic	0.994	0.232	0.066	0.414	0.056	0.458	0.743
6) No extra N (4) vs extra N (10-12)	0.094	0.379	0.697	0.002	0.173	0.512	0.062

Table 8. Tests of fixed effects and individual fertility treatment means for field pea protein concentrations at six Agri-ARM facilities in 2019. Data were analyzed using the Mixed procedure of SAS. Treatment means within a column and location means within a row followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Source / Treatment	Indian Head	Melfort	Outlook	Scott	S. Current	Yorkton	Average
Overall F-test	p-value						
Fertilizer Treatment (F)	0.026	0.978	0.054	0.083	<0.001	0.533	0.270
Location (L)	–	–	–	–	–	–	<0.001
F x L	–	–	–	–	–	–	<0.001
kg N-P_2O_5-K_2O-S/ha	Seed Protein (%)						
1) 0-0-0-0 (no fertilizer)	24.4 a	20.9 a	19.7 a	23.6 a	24.0 b	22.0 a	22.4 A
2) 17-0-0-10 (0 P)	23.8 a	21.2 a	19.7 a	23.9 a	24.1 b	22.0 a	22.4 A
3) 17-20-0-10 (20 P)	24.1 a	21.1 a	19.5 a	23.4 a	24.9 ab	21.8 a	22.5 A
4) 17-40-0-10 (40 P / 10 S)	24.0 a	20.7 a	19.3 a	23.4 a	24.7 ab	22.7 a	22.5 A
5) 21-60-0-10 (60 P)	24.0 a	20.9 a	19.9 a	23.8 a	24.6 ab	22.1 a	22.5 A
6) 26-80-0-10 (80 P)	24.1 a	20.9 a	22.1 a	23.6 a	25.1 a	21.5 a	22.9 A
7) 17-40-0-0 (0 S)	24.0 a	21.1 a	20.1 a	23.8 a	24.8 ab	21.2 a	22.5 A
8) 17-40-0-5 (5 S)	24.0 a	20.7 a	20.9 a	23.6 a	24.9 ab	21.4 a	22.6 A
9) 22-40-0-15 (15 S)	24.0 a	21.0 a	19.5 a	23.8 a	24.7 ab	21.8 a	22.5 A
10) 40-40-0-10 (urea)	23.8 a	21.2 a	18.8 a	24.1 a	24.8 ab	21.7 a	22.4 A
11) 17-40-0-10 + 40 N in-crop	24.1 a	21.2 a	20.5 a	23.8 a	24.6 ab	22.0 a	22.7 A
12) 40-40-0-10 (ESN)	23.9 a	20.8 a	18.7 a	23.6 a	24.9 ab	21.3 a	22.2 A
13) 40-80-0-15 (ultra high fert)	24.1 a	21.1 a	19.6 a	23.6 a	25.2 a	21.8 a	22.6 A
S.E.M.	0.16	0.34	0.68	0.19	0.19	0.43	0.16
Location Average	24.0 B	21.0 D	19.9 E	23.7 B	24.7 A	21.8 C	–
S.E.M.	0.12	0.15	0.22	0.13	0.13	0.17	–

Table 9. Group comparison and orthogonal contrast results for field pea grain protein at six Agri-ARM facilities in 2019. Data were analyzed using the Mixed procedure of SAS. P-values ≤0.05 are considered significant while P-values in the 0.05-0.10 range indicate trends.

Contrast	Indian Head	Melfort	Outlook	Scott	S. Current	Yorkton	Average
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7) No fertilizer (1) vs. rest (2-13)	<0.001	0.838	0.780	0.453	<0.001	0.630	0.532
8) P rate – linear	0.252	0.392	0.015	0.835	<0.001	0.607	0.046
9) P rate – quadratic	0.401	0.469	0.031	0.136	0.274	0.144	0.233
10) S rate – linear	0.705	0.929	0.270	0.713	0.420	0.101	0.728
11) S rate – quadratic	0.904	0.282	0.642	0.049	0.623	0.206	0.745
12) No extra N (4) vs extra N (10-12)	0.485	0.370	0.991	0.023	0.962	0.038	0.738