2021 Annual Report

for the

Saskatchewan Ministry of Agriculture's

Agricultural Demonstration of Practices & Technologies (ADOPT) Program

Project Title: Flax Response to Non-Traditional Nitrogen Fertilizer Management Strategies

Project #20200523 (SaskFlax 202103)

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Project Identification

1. **Project Title:** Flax response to non-traditional nitrogen fertilizer management strategies
2. **Project Number:** 20200523 (SaskFlax #202103)
3. **Producer Group Sponsoring the Project:** Saskatchewan Flax Development Commission (SaskFlax)
4. **Project Location(s):** Indian Head (#156), Melfort (#428), Redvers (#61), Swift Current (#136), Yorkton (#244), and Scott (#380) Saskatchewan
5. **Project start and end dates(s):** April-2021 to February-2022
6. **Project contact person & contact details:**

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Objectives and Rationale

7. Project Objectives:

The objectives of this project were to:

1. Demonstrate flax yield response to a range of nitrogen fertilizer rates for a variety of Saskatchewan locations
2. Demonstrate the seed-safety and potential yield benefits of polymer coated urea (ESN) relative to urea when side-banded at high rates
3. Demonstrate the potential merits of utilizing split-applications of nitrogen in flax to reduce the likelihood of seedling injury and lodging while potentially enhancing yield

8. Project Rationale:

Flax has potential to be quite a profitable crop provided that sufficiently high yields can be achieved with reasonable consistency. For most crops, increasing N fertilizer rates is one of the more effective and common means by which farmers strive for higher yields and flax is no exception. This crop has been proven to be quite responsive to N fertilization but also extremely sensitive and, even with side-banding, high rates can lead to stand reduction. This project aimed to benefit producers by demonstrating the overall response of flax to N fertilizer and different means by which growers might further enhance yields by supplying sufficient rates of N without compromising stands.

A 40 bu/ac (2.5 Mt/ha) flax crop requires a total of 120-140 kg N/ha, 30-40 kg P_2O_5/ha, 70-90 kg K_2O/ha and 20-30 kg S/ha (Canadian Fertilizer Institute, 2001). A recent Prairie-wide project evaluated flax response to varying rates of both N and phosphorus (P) at eight locations over a three-year period (Holzapfel et al. 2019). Generally consistent with previous research (i.e. May et al. 2010), flax responded reasonably well to N fertilizer with an overall average increase of 39% at 100 kg N/ha and occasional responses to even higher N rates. Importantly, flax was sensitive to side-banded urea with linear reductions in plant density with increasing N rate at 75% of the 19 site-years considered and, amongst these, an average plant loss of 28% as the rate was increased from 13 kg N/ha to 150 kg N/ha. Other studies have shown similar effects (i.e. Malhi et al. 2008; Grant et al. 2016). We hypothesized that utilizing an ESN® (Environmentally Smart Nitrogen, Agrium) blend in place of urea would greatly reduce the risk of stand reductions with high rates of side-banded N. Qin et al. (2014) found that substitution of urea with ESN® allowed 3x rates of seed-placed N in wheat and canola before seedling injury occurred.

Regarding split-applications, the Flax Council of Canada suggested that flax may be a good candidate for this practice, recognizing that it is both extremely sensitive to N fertilizer damage and can be susceptible to mid-season N deficiencies (i.e. https://flaxcouncil.ca/tips_article/fertility-requirements-for-flax/). Flax N accumulation in the leaves and capsule pericarps peaks at anthesis and early seed development at which point it declines due to translocation to the seed followed by senescence (Xie et al. 2015). Previous Prairie research with canola showed that at least 50% of the total N requirements should be applied during or before seeding and the in-crop N should be applied by the bolting stage because yield losses could occur if less than this was applied up front and/or the remainder was delayed until flowering (Lafond et al. 2008). There is anecdotal evidence of flax producers having success with in-crop applications at the budding stage; however, specific results will likely vary depending on whether there is any deficiency earlier in the season and/or sufficient precipitation is received after the application to move the N into the rooting zone before permanent yield losses can occur.

Literature cited:

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Xie, Y. Gan, Y. Li, Y., Nui, J., Gao, Y., A., Huihui, and Li A. 2015. Effect of nitrogen fertilizer on nitrogen accumulation, translocation, and use efficiency in dryland oilseed flax. Agron. J. 107: 1931-1939.

Methodology and Results

9. Methodology:

In the spring of 2021, flax field trials were initiated with locations at Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott. The treatments were selected to explore flax response to a range of N fertilizer rates (17-130 kg N/ha), contrasting fertilizer forms (urea versus ESN®) at the higher rates, and split-applications of N with the post-emergent treatments applied during either the vegetative (4-10 cm tall) or early reproductive (bud formation/first flower) stages, with and without a volatilization inhibitor (NBPT; Agrotain®). Nutrients other than N were intended to be non-limiting and, aside from the in-crop broadcast N, all fertilizer products (including any P, K, and S sources) were side-banded. For the ESN®, we utilized a 75% blend (25% untreated urea) to ensure that enough N would be available early in the season and because this is a commonly recommended industry practice with this product. Although we did not adjust the N rates for residual soil test levels, the intention was for all collaborators to secure sites with initially low residual NO_3-N, if possible. At Scott, there was an error during the early in-crop N applications in that the staff also applied N to the late in-crop treatments at that time; therefore, the late in-crop treatments (10, 11) were removed at that location. At Swift Current, for the late in-crop applications, approximately 2.5 mm of irrigation water was added after the application to dissolve the top-dressed N while, in all other cases, we relied exclusively on naturally occurring precipitation. The 11 treatments were arranged in a four replicate RCBD and are described in greater detail in Table 1.

Table 1. Treatments evaluated in ADOPT nitrogen management demonstration in flax (2021).

#	Name	kg N-P_2O_5-K_2O-S/ha	Comments
1	Check	17-40-0-11	- N from 77 kg/ha MAP and 42 kg/ha AS
2	Low N – urea	55-40-0-11	- all N side-banded as either untreated urea or a blend of 75% ESN:25% untreated urea
3	Medium N – urea	80-40-0-11	
4	High N – urea	105-40-0-11	
5	High N – 75% ESN	105-40-0-11	
6	Ultra N – urea	130-40-0-11	
7	Ultra N – 75% ESN	130-40-0-11	
8	Split – early in-crop urea	105-40-0-11	- 55 kg N/ha side-banded and 50 kg N/ha broadcast as untreated urea or Agrotain when the flax is 4-10 cm tall
9	Split – early in-crop Agrotain	105-40-0-11	
10	Split – late in-crop urea	105-40-0-11	- 55 kg N/ha side-banded and 50 kg N/ha broadcast as untreated urea or Agrotain when the flax is budding to starting to flower
11	Split – late in-crop Agrotain	105-40-0-11	

Selected agronomic information and dates of operations are provided in Table 5 of the Appendices. In all cases, the plots were established on cereal stubble (wheat, canaryseed, or barley) and seeding dates ranged from May 7-18. Seeding equipment varied across locations with row spacing ranging from 21-30 cm; however, all sites used narrow opener hoe drills with side-band capabilities. Seed rates ranged from 47-55 kg/ha and the variety was CDC Glas at all locations except for Swift Current where CDC Sorrel was grown. Weeds were controlled using registered pre-emergent and post-emergent herbicide applications. Foliar fungicides were applied at the discretion of individual site managers to reduce the potential for pasmo to develop into a yield limiting or confounding factor. The plots at Indian Head were sprayed for grasshoppers late in July but insecticides were not applied at any other locations. Pre-harvest glyphosate or diquat was applied after all treatments had reached maturity to kill weeds and/or assist with crop dry-down. The flax was straight-combined using small plot harvesters when it was fit to do so with outside rows excluded from the harvest area wherever possible.

Various data were collected during the growing season and from the harvested grain samples. Overall soil fertility and residual NO_3-N was estimated from composite soil samples submitted to AgVise Laboratories (Northwood, ND). Weather data were compiled from either Environment and Climate Change Canada or privately owned weather stations located within a few kilometers of the field trial sites. Plant densities were assessed by counting plants in 4 x 1 m sections of crop row per plot and converting the values to plants/m^2. The plots were monitored for lodging throughout the latter part of the growing season and rated on a scale of 1-9 (where 1 is perfectly upright); however, no lodging was observed in any cases so this data was not statistically analyzed or reported. Seed yields, reported in kg/ha were determined from the harvested plot areas and are adjusted for dockage and to a uniform seed moisture content of 10%.

Response data were analyzed separately for each location using the generalized linear mixed model (GLIMMIX) in SAS® Studio. Orthogonal contrasts were utilized to determine if responses to side-banded urea (Treatments 1, 2, 3, 4, and 6) were linear, quadratic (curvilinear), or not significant. For both plant densities and seed yields, additional contrasts were used to compare the control (1) to all of the plots that received additional N (2-11), side-banded urea (4, 6) to side-banded ESN® (5, 7), side-banded urea (4) to split-applications of urea (8, 10). For yield only, two additional contrasts compared early in-crop applications (8, 9) to late in-crop applications (10, 11), and in-crop urea (8, 10) to in-crop Agrotain® treated urea (9,11). All treatment effects and differences between means were considered significant at $P \leq 0.05$.

10. Results:

Growing Season Weather Conditions and Residual Soil Nutrients

Mean monthly temperatures and total precipitation amounts for May through August (2021) are presented alongside the long-term averages (1981-2010) at each location in Tables 2 and 3, respectively. Overall mean temperatures for the 4-month growing season were above normal at all six locations, ranging from 103-109% of the long-term average at individual locations. The patterns were also similar for all locations in that May was cooler than average while June and July were relatively hot. Temperatures in August relative to the long-term average were more variable. With low initial soil moisture reserves and hot summer temperatures, general conditions for all locations were considered somewhat dry; however, the actual extent of the drought varied widely. At all locations, a substantial proportion of the growing season precipitation that was accounted for came in the latter half of August, too late to be of much benefit to the crop. For example, at Indian Head, the wettest of the locations in 2021, the four month precipitation total was 121% of the long-term average; however, nearly a third of this came after the 15^{th} of August. At Redvers, total precipitation was 93% of average but, again, over 25% of this came in the latter half of August. The remaining locations all received less than 150 mm of precipitation. At Swift Current, normally the driest of the locations, this was 78% of average but, again, much of it came late and, when combined with low initial soil moisture, high temperatures, and coarse textured soils, still resulted in drought conditions. Yorkton received a similar amount of absolute precipitation as Swift Current, but normally being one of the wettest locations, this was only 54% of average. At Melfort and Scott, the four-month total amount of precipitation was 61-66% of the long-term average. To help interpret responses to the in-crop N applications, the total amount of precipitation within the 14 day periods following the in-crop N applications is also provided in Table 5 of the Appendices. Overall, the dry conditions reduced yield potential and, in many cases, increased variability in emergence and yield.

Table 2. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2021 growing seasons at Indian Head (IH), Melfort (MF), Redvers (RV), Yorkton (YK), Swift Current (SW), and Scott (SCT), Saskatchewan.

Location-Year	May	June	July	August	May-Aug
	------------------------------------- Mean Temperature (°C) -------------------------------------				
IH – 2021	9.0	17.7	20.3	17.1	16.0 (103%)
IH – Long Term	10.8	15.8	18.2	17.4	15.6
MF – 2021	9.6	18.2	20.1	16.9	16.2 (106%)
MF – Long Term	10.7	15.9	17.5	16.8	15.2
RV – 2021	10.0	18.7	20.8	17.5	16.8 (105%)
RV – Long Term	11.1	16.2	18.7	18.0	16.0
YK – 2021	8.9	19.1	21	17.3	16.5 (109%)
YK – Long Term	10.4	15.5	17.9	17.1	15.2
SW – 2021	9.5	18.3	21.6	17.9	16.8 (106%)
SW – Long Term	11.0	15.7	18.4	17.9	15.8
SCT – 2021	8.9	17.3	19.6	17.2	15.8 (107%)
SCT – Long Term	10.8	14.8	17.3	16.3	14.8

Table 3. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2021 growing seasons at Indian Head (IH), Melfort (MF), Redvers (RV), Yorkton (YK), Swift Current (SW), and Scott (SCT), Saskatchewan.

Location-Year	May	June	July	August	May-Aug
	------------------------------------ Total Precipitation (mm) ------------------------------------				
IH – 2021	81.6	62.9	51.2	99.4	295 (121%)
IH – Long Term	51.8	77.4	63.8	51.2	244
MF – 2021	31.4	37.6	0.2	69.3	139 (61%)
MF – Long Term	42.9	54.3	76.7	52.4	226
RV – 2021	41.4	95.2	38.4	72.1	247 (93%)
RV – Long Term	60.0	95.2	65.5	46.6	267
YK – 2021	24.6	18.1	35.2	69.7	148 (54%)
YK – Long Term	51.3	80.1	78.2	62.2	272
SW – 2021	30.0	26.8	36.6	53.5	147 (78%)
SW – Long Term	42.1	66.1	44.0	35.4	188
SCT – 2021	43.9	43.8	10.4	51.3	149 (66%)
SCT – Long Term	38.9	69.7	69.4	48.7	227

Selected results from the composite soil sample test analyses are presented in Table 4 below. Soil pH for the upper 15 cm was generally as expected ranging from 5.5 at Scott to 8 at Indian Head and

Redvers. Cation exchange capacity (CEC) is a good indicator of soil texture with higher values being correlated with increased clay content; however, CEC is also positively correlated with organic matter and soil pH. Organic matter was also considered representative for the respective regions ranging from 2.9% at Swift Current to 11.2% at Melfort, with more intermediate values of 3.6-4.7% at the remaining four locations. Residual NO_3-N was lowest at Indian Head (19 kg/ha), intermediate at Scott and Redvers (32-45 kg/ha), and relatively high at the remaining locations (50-84 kg/ha). Residual phosphorus was considered low at all locations (9-13 ppm Olsen-P) and both K and S were unlikely to be limiting in any cases. The intent was for all nutrients other than N to be non-limiting at all locations and in all treatments.

Table 4. Selected soil test results for flax nitrogen management demonstrations at Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott, Saskatchewan in 2021.

Depth	**pH**	**SOM** (%)	**CEC** (meq/100g)	**NO_3-N** (kg/ha)	**Olsen-P** (ppm)	**K** (ppm)	**S** (kg/ha)
---- Indian Head ----							
0-15	8.0	4.6	43.9	9	9	532	7
15-60	8.3	–	–	10	–	–	34
---- Melfort[Z] ----							
0-15	6.4	11.2	–	24	9	476	16
15-30	6.1	–	–	26	–	–	13
---- Redvers ----							
0-15	8	3.6	34.6	21	6	227	134+
15-60	–	–	–	24	–	–	403+
---- Swift Current ----							
0-15	7.9	2.9	–	31	4	278	134+
15-60	8.2	–	–	37	–	–	403+
---- Yorkton ----							
0-15	7.1	4.7	22.1	30	13	253	54
15-60	8.1	–	–	54	–	–	128
---- Scott ----							
0-15	5.5	4.4	15.7	12	6	246	16
15-60	7.7	–	–	20	–	–	128

[Z]Soil samples only collected to a depth of 30 cm at Melfort; therefore, residual NO_3-N and S levels are underestimated relative to the other locations

Crop Response to Nitrogen Management Treatments

Overall F-test results and individual treatment means for each location are provided in Tables 6 and 9 of the Appendices, respectively. Detailed results from the orthogonal contrasts and predetermined contrast comparisons are also provided in the Appendices (Tables 7, 8, 10, and 11); however, for easier interpretation, these results are also illustrated in Figs 1-9 of the main body of the report.

Averaged across all treatments, plant densities were highest at Indian Head (678 plants/m^2), Redvers (561 plants/m^2), and Yorkton (529 plants/m^2), intermediate at Scott (364 plants/m^2) and Melfort (311 plants/m^2), and lowest at Swift Current (184 plants/m^2). While flax has the ability to compensate for lower plant populations through increased branching and boll formation, a minimum of 300 plants/m^2 is commonly recommended to improve the crop's ability to compete with weeds, reduce variability, and ensure optimum yields. In the current project, the overall F-test for plant density (Table 6) was not significant at Indian Head (P = 0.552), Yorkton (P = 0.504), or Scott (P = 0.175) but was at Melfort (P < 0.001), Redvers (P = 0.052), and Swift Current (P = 0.005). While significant F-tests indicate greater potential for significant differences to exist between individual means, it is still possible to detect trends or more general treatment effects with the contrasts, even in cases where this test was not significant.

The orthogonal contrasts for plant density (Fig. 1; Table 7) detected that flax emergence was reduced with increasing rates of side-banded urea at 67% of the locations; Melfort, Redvers, Swift Current, and Scott. At Redvers, the response was quadratic (P = 0.002), with a slight increase in plant density going from 17 to 55 kg N/ha followed by declining numbers with further increases in the rate of side-banded urea and the sharpest reduction at the top rate of 130 kg N/ha. At the remaining sites where negative effects were detected, plant densities declined linearly (P < 0.001-0.019) with small but consistent reductions in emergence with each incremental increase in N rate. At Scott and Swift Current, the observed effects were relatively subtle with reductions of 42 plants/m^2 (11%) at Scott and 34 plants/m^2 (17%) at Swift Current as the side-banded urea rate was increased to 130 kg N/ha. At Melfort, the response was stronger with an observed reduction of 107 plants/m^2 (31%) relative to the control at the highest rate of side-banded urea. At Scott and Swift Current, the observed response may have been due in part to the coarser soil texture and, particularly at Swift Current, low organic matter. At Melfort, with high organic matter and fine-textured soils, the risk of seedling injury from side-banded urea would normally be low; however, depending on conditions during seeding, inadequate separation between the seed and fertilizer could result in such losses.

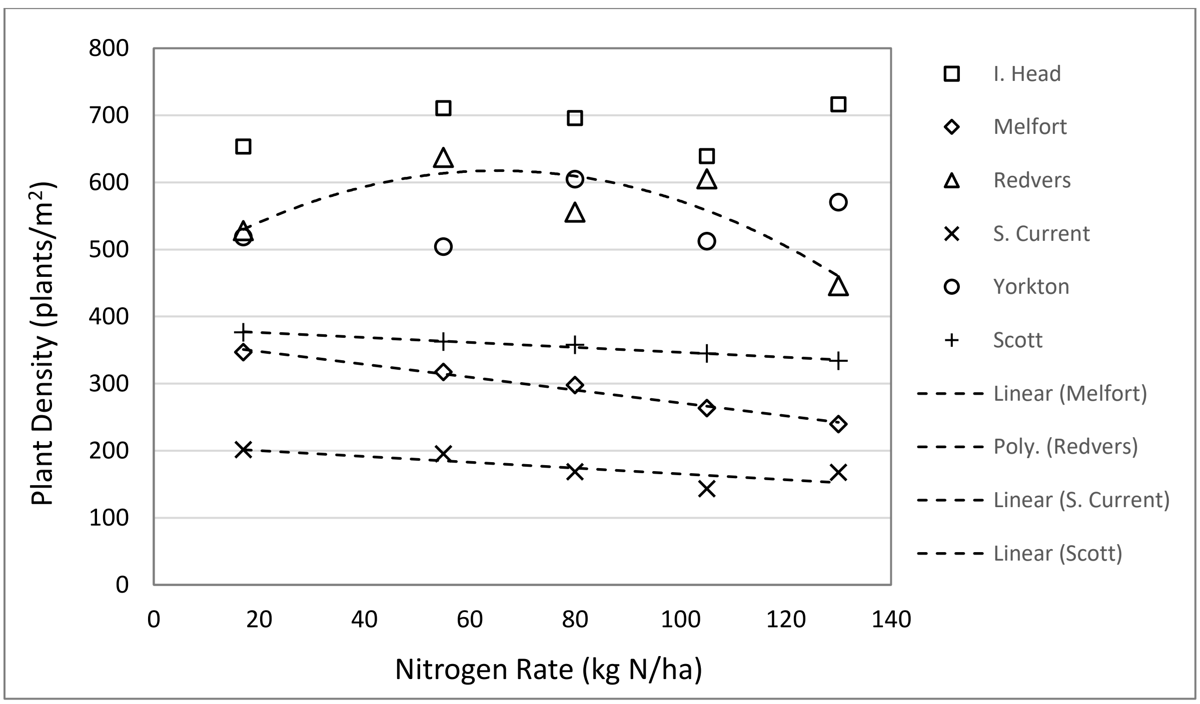

Figure 1. Nitrogen rate (side-banded urea) effects on flax plant density at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. There was no effect of side-banded urea on plant densities at Indian Head or Yorkton while the number of plants declined linearly at Melfort, Swift Current, and Scott and the quadratic response was significant at Redvers.

The observed effects of high rates of side-banded urea on flax emergence were not unexpected and, as discussed earlier, have been previously documented under Prairie conditions. We hypothesized that substituting urea with ESN®, a polymer coated urea product known to improve seed safety, would greatly alleviate these effects. To test this theory, we directly compared plant densities with side-banded urea at the highest N rates (105-130 kg N/ha) to those achieved with side-banded ESN® at the same two rates (Fig. 2; Table 8). At Melfort, Swift Current, and Scott, the locations where emergence declined linearly with increasing rates of side-banded urea, we did, in fact, see significantly higher plant populations with ESN® ($P < 0.001$-0.033). The magnitude of the increase with ESN® ranged from 9% at Scott to 34% at Swift Current. At Redvers, the difference in observed emergence between these treatments was not significant ($P = 0.282$); however, the values did trend slightly higher with ESN®.

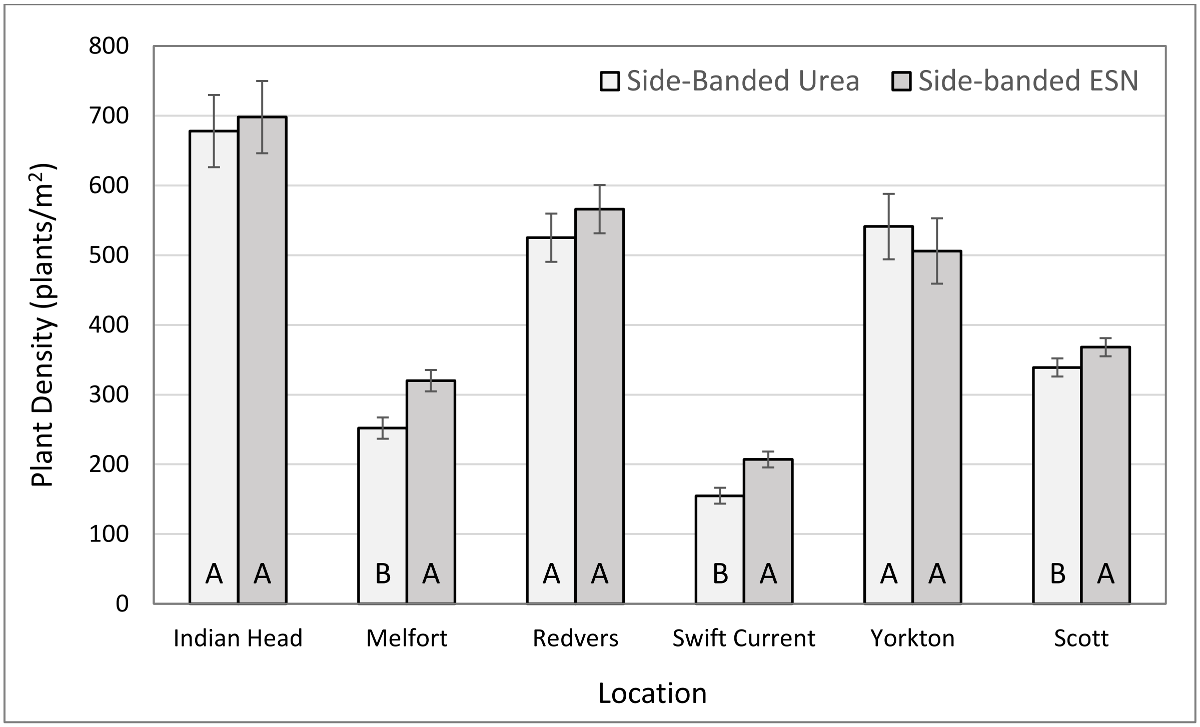

Figure 2. Predetermined contrasts comparing flax plant densities with side-banded urea (4,6) to ESN® (5,7) at the high and ultra-high application rates at six Saskatchewan locations in 2021. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ (*P* ≤ 0.05).

Another approach, which we hypothesized could alleviate concerns with flax seedling sensitivity to high rates of side-banded N, was utilizing split-applications where a reduced rate of N is side-banded and the remainder is applied in-crop, usually as a surface broadcast or, with liquid products, dribble-band application. To test this, we compared 105 kg N/ha as side-banded urea rate to split-applications where 55 kg N/ha of the urea was side-banded and the remaining 50 kg N/ha was applied as in-season surface broadcast (Fig. 3; Table 8). The results were similar to what was achieved with ESN® but slightly less pronounced and consistent, possibly due to the fact that we did not include the highest, 130 kg N/ha rate, in this comparison. At Melfort, the observed plant densities were 29% higher with the split-applications and, similarly, the advantage was 30% at Swift Current. At Scott, the response was not quite significant ($P = 0.062$) but the trend was similar with a 9% advantage to the split-applications for plant density.

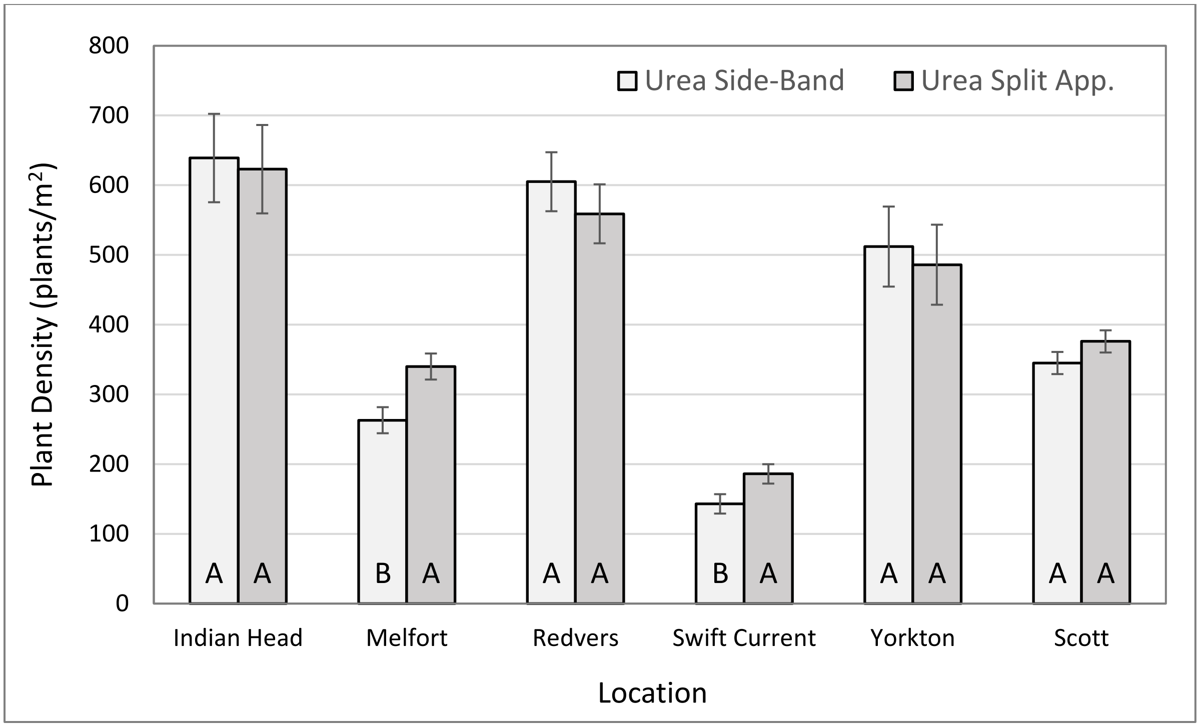

Figure 3. Predetermined contrasts comparing flax plant densities with urea applied in a side-band (4) to split applications with urea as the source (8,10) at six Saskatchewan locations in 2021. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ ($P \leq 0.05$).

A common concern reported in flax production is lodging and this is often exacerbated with high rates of N; however, as previously mentioned, no lodging was observed in any treatments at any locations in the current project. With no lodging and no variation, these results could not be statistically analyzed and, as such, are not reported. We attributed the lack of lodging primarily to the dry conditions encountered at all of the locations; however, early seeding and fungicide applications may also help to reduce lodging in flax.

The overall F-test results and individual treatment means for flax seed yield are presented in Table 9 of the Appendices. Likely attributable to the heat and drought, yields were relatively low averaging 1171 kg/ha at Indian Head, 1706 kg/ha at Melfort, 1252 kg/ha at Redvers, 849 kg/ha at Swift Current, 855 kg/ha at Yorkton, and 1131 kg/ha at Scott. Based on the overall F-tests, N fertilizer treatment significantly affected yields at Indian Head, Melfort, and Redvers (P < 0.001-0.002), but not at Swift Current (P = 0.599), Yorkton (P = 0.264), or Scott (P = 0.807).

Fig. 2 illustrates the observed flax seed yield responses to increasing rates of side-banded urea at each location and more detailed results from the orthogonal contrasts for yield are also provided in Table 10 of the Appendices. Consistent with the overall F-test results, flax yield increased quadratically with N rate at Indian Head (P = 0.030), Melfort (P = 0.043), and Redvers (P = 0.001), but neither the linear nor quadratic responses were significant at Swift Current, Yorkton, or Scott (P = 0.373-0.811). In general, these responses could be reasonably well explained by soil residual NO_3-N and the overall yield potential for each location. Maximum yields at Indian Head were relatively low but this location also had the lowest residual N levels (19 kg NO_3-N/ha); thus a response could be reasonably expected and did, in fact, occur. Maximum yields were achieved at the 105 kg N/ha rate, at which point they were 535 kg/ha, or 67%, higher than the control. Melfort had the highest yield potential but also relatively high residual N (>50 kg NO_3-N/ha) and yields at this location levelled off at a more modest rate of 80 kg N/ha where they were 342 kg/ha (24%) higher than the control. Melfort also has extremely high organic matter which can be an important source of N through mineralization but can also increase immobilization. Redvers had slightly higher overall yields compared to Indian Head but more than two times the residual N (44 kg NO_3-N/ha) and the response to applied N was weaker, peaking at only 55 kg N/ha where a gain of 397 kg/ha (44%) was observed. At both Swift Current and Yorkton, yield potential was low and residual N was high (68 kg NO_3-N at Swift Current and 84 kg NO_3-N/ha at Yorkton) and, as such, the lack of response to N fertilizer applications made sense. The results at Scott were more difficult to explain but still reasonable. This location reported the second lowest residual N levels (32 kg NO_3-N/ha) and had similar yield potential to Indian Head, yet observed no response to N fertilization. While it is possible that the soil test results did not fully reflect the actual N availability on site, it is also conceivable that that the combination of residual N and mineralization of organic matter was sufficient to meet the N requirements of the crop under the environmental conditions encountered.

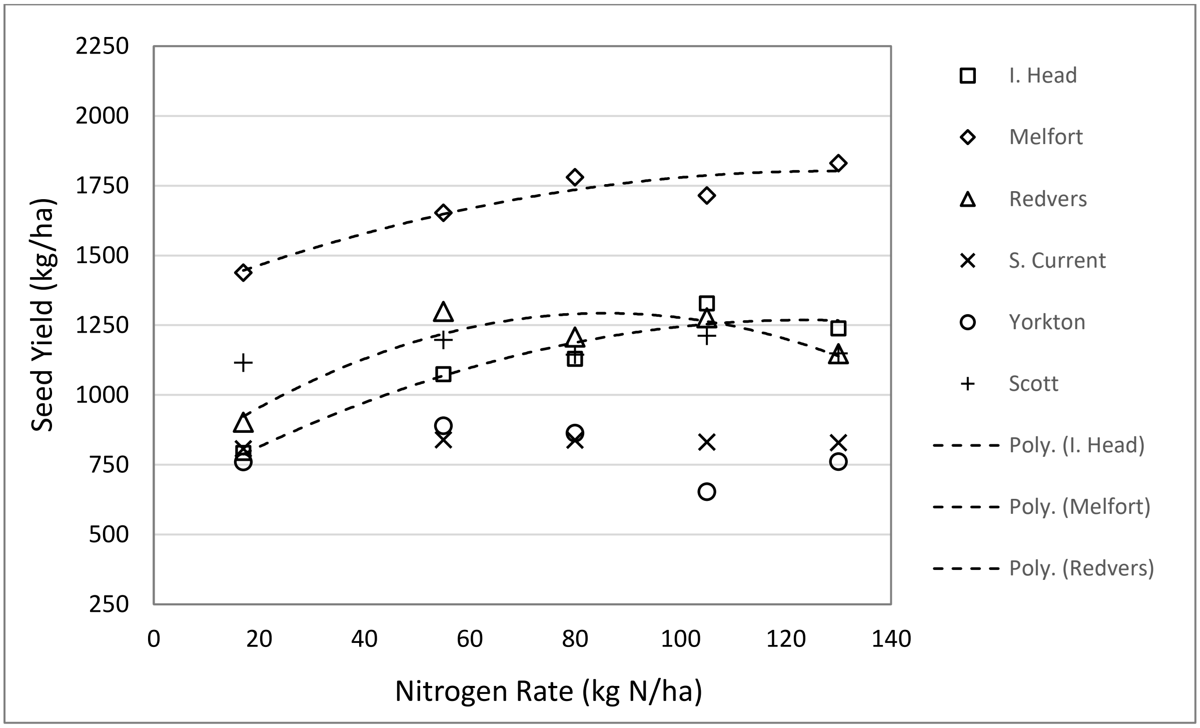

Figure 4. Nitrogen rate (side-banded urea) effects on flax seed yield at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. There was no effect of side-banded urea on yield at Swift Current, Yorkton, or Scott while yields increased quadratically at Indian Head, Melfort, and Redvers.

As a further test of the broader responses to N at each location which was more powerful than the overall F-tests, yields in the control treatment (which received up to 17 kg N/ha from P and S fertilizer products) was directly compared to all of the combined treatments where supplemental N was applied (Fig. 5; Table 11). Consistent with the previously discussed orthogonal contrasts, this comparison showed significant yield responses to N at Indian Head, Melfort, and Redvers ($P <$ 0.001), but not Swift Current ($P = 0.458$), Yorkton ($P = 0.291$), or Scott ($P = 0.864$).

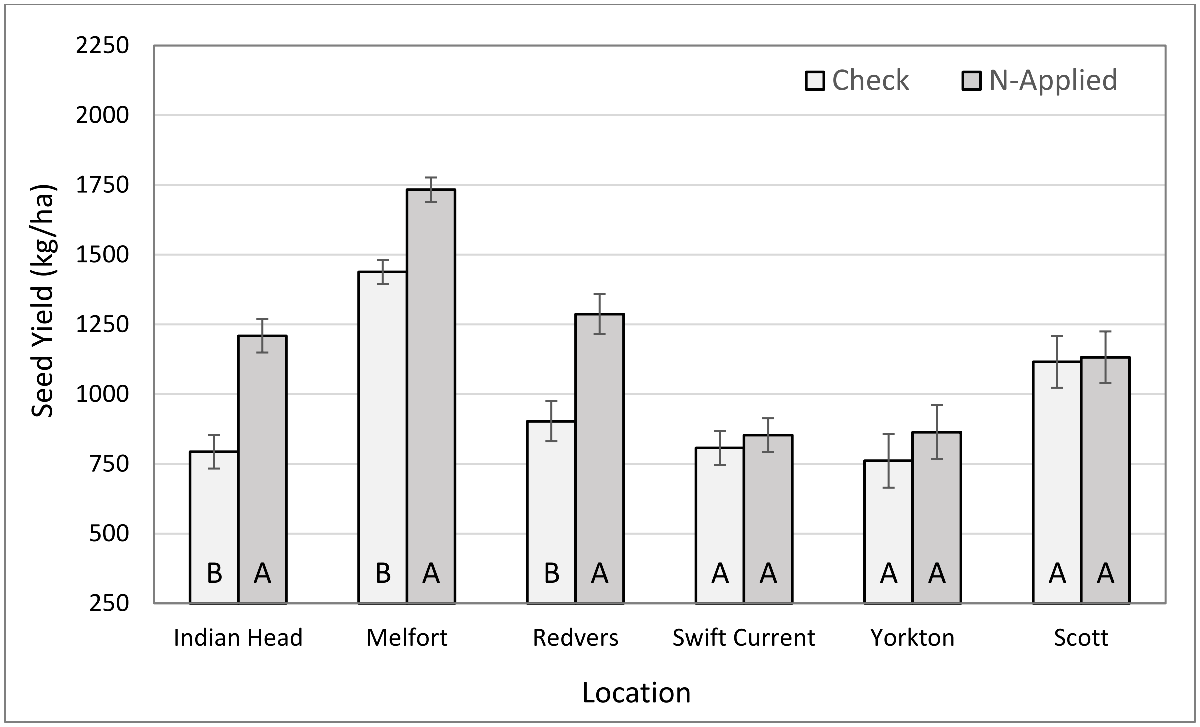

Figure 5. Predetermined contrasts comparing flax seed yields in the control (1) to all treatments where supplemental nitrogen (N) was applied (2-11) at six Saskatchewan locations in 2021. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ ($P \leq 0.05$).

Flax yields with the high rates (103-130 kg N/ha) of side-banded urea were compared to those achieved with the same rates of 75% ESN® in Fig. 6 below and Table 11 of the Appendices. Despite the advantages with regard to establishment detected at 50% of the locations, yield advantages to the ESN® blend over untreated urea were not detected in any cases (P = 0.120-0.805).

Similarly, flax seed yield comparisons between side-banded urea and split-applications with untreated urea as the source are provided in Fig. 7 and Table 11. These treatments resulted in similar yields at Indian Head, Melfort, Redvers, and Swift Current (P = 0.122-0.775); however, there was an advantage to the split-applications detected at Yorkton (P = 0.049). Despite the statistical significance, however, the response at Yorkton was likely not a true reflection of the N treatments and, rather, simply due to random variability and chance. Again, there was no response to N at this location and it just happened that the lowest mean yields at this location were observed with the 105 kg N/ha rate of side-banded N. This contrast was excluded at Scott due to the missing late in-crop application treatments; however, inspection of individual treatment means (Table 9) showed statistically similar yields with 105 kg N/ha as side-banded urea (1213 kg/ha) versus 105 kg N/ha as a split-application of urea with in-crop N applied when the flax was 4-10 cm tall (1062 kg/ha).

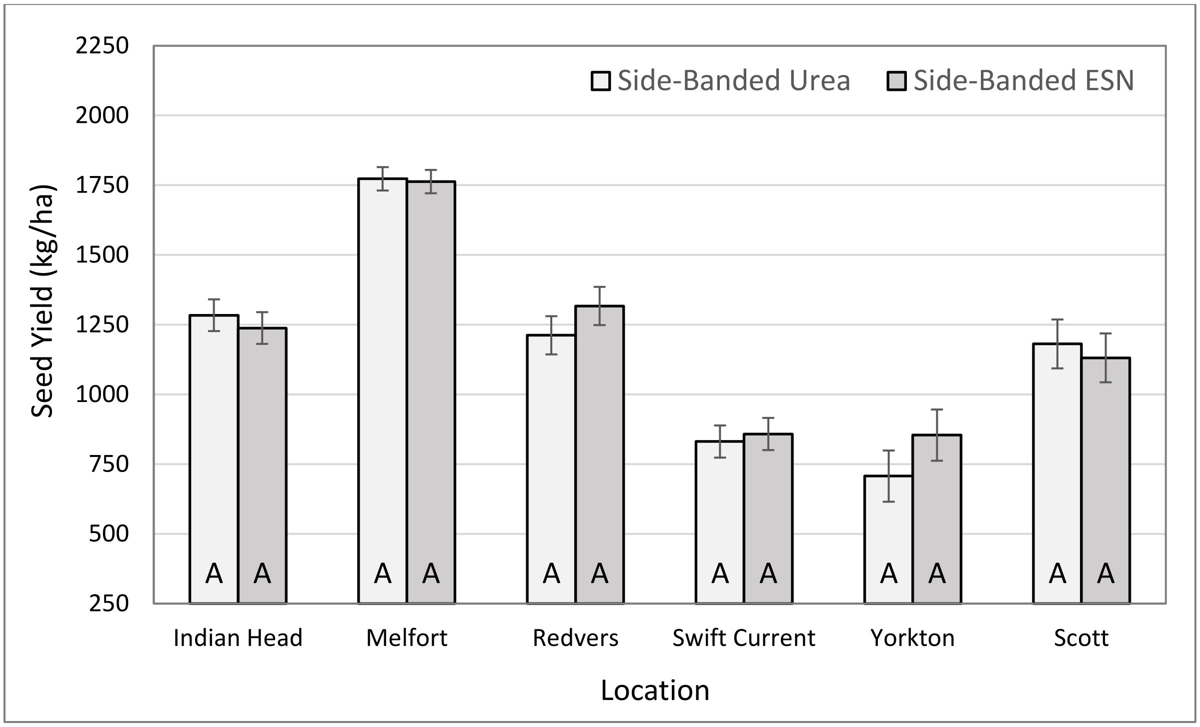

Figure 6. Predetermined contrasts comparing flax seed yields with side-banded urea (4,6) to ESN® (5,7) at the high and ultra-high application rates at six Saskatchewan locations in 2021. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ (*P* ≤ 0.05).

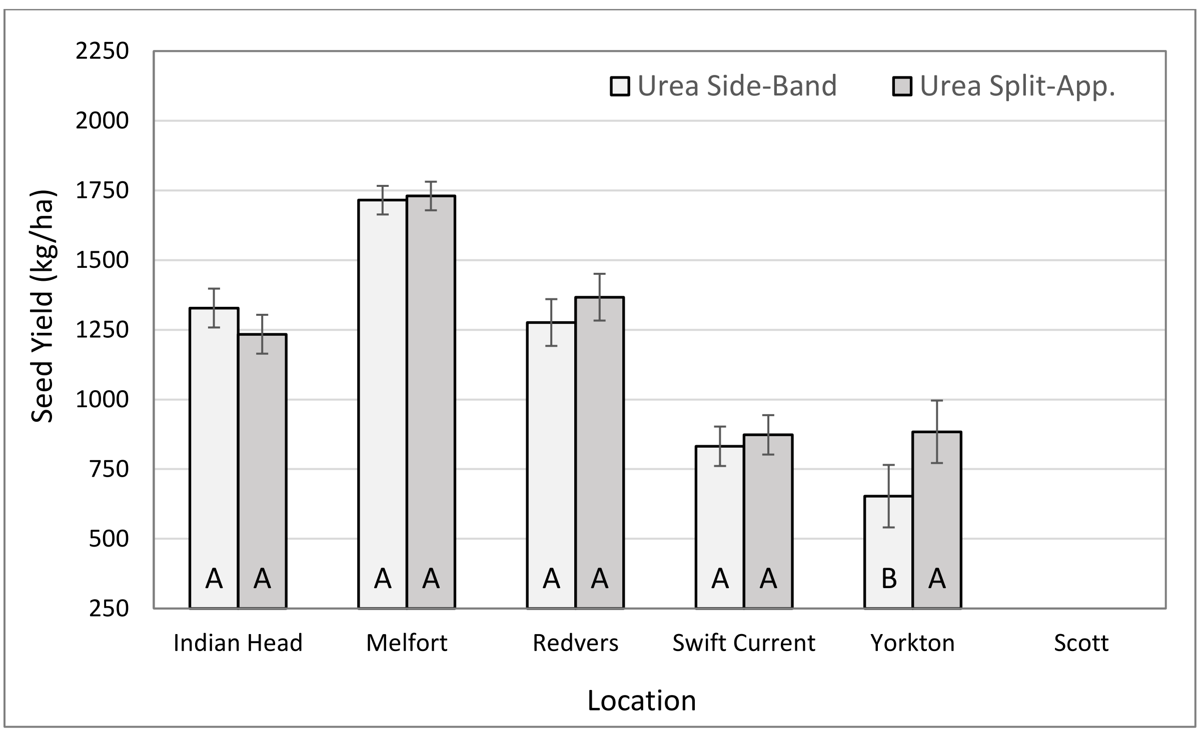

Figure 7. Predetermined contrasts comparing flax seed yields with urea applied in a side-band (4) to split-applications with urea as the sole nitrogen (N) source (8,10) at five Saskatchewan locations in 2021. Scott was excluded from this comparison due to an error during the in-crop N applications. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ (*P* ≤ 0.05).

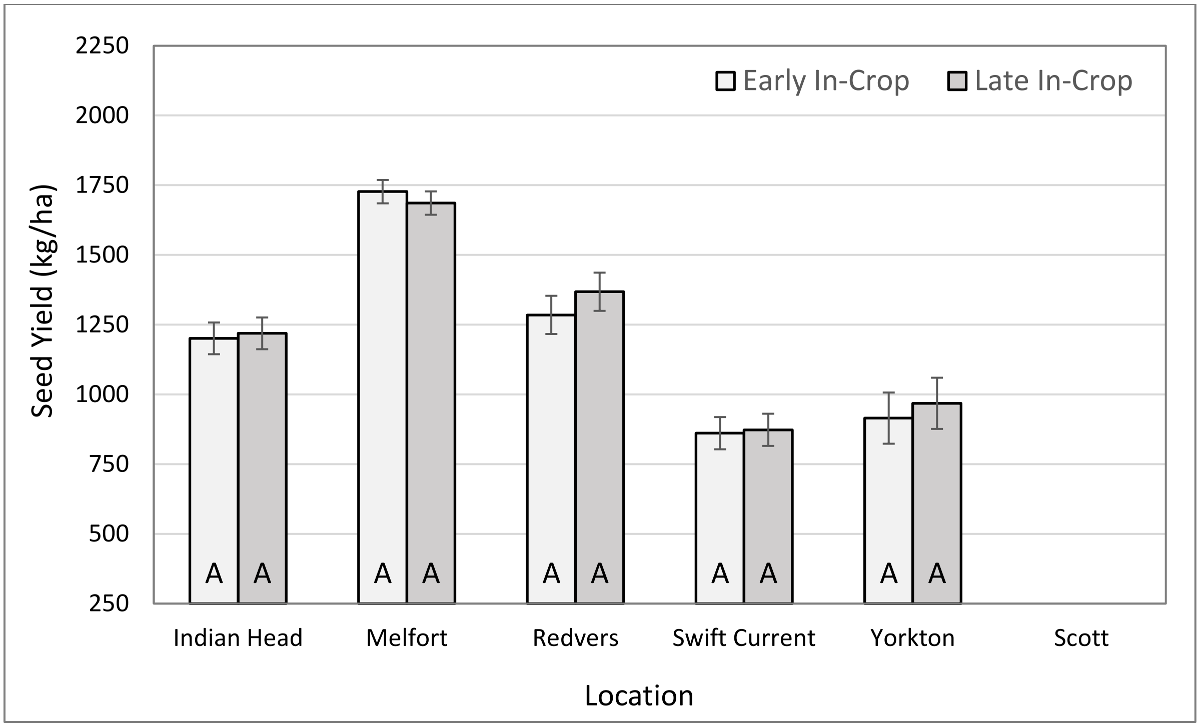

Figure 8. Predetermined contrasts comparing flax seed yields with split-applications where in-crop nitrogen (N) was applied early (4-10 cm; 8,9) to split-applications where in-crop N was applied late (budding to 1st flower) at five Saskatchewan locations in 2021. Scott was excluded from this comparison due to an error during the in-crop N applications. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ ($P \leq 0.05$).

The final set of pre-determined contrasts for flax seed yield compared in-crop applications of untreated urea to in-crop applications of Agrotain® treated urea. These comparisons did not show any benefit to the stabilized urea at Indian Head (P = 0.810), Melfort (P = 0.201), Redvers (P = 0.248), or Yorkton (P = 0.218). At Scott, yields with early in-crop N were nearly identical, regardless of the source (1031-1062 kg/ha). At Swift Current, the difference between in-crop applications of untreated urea versus Agrotain® treated urea was actually statistically significant (P = 0.015) and, despite the overall lack of N response, may have been genuine. The two treatments where in-crop N was applied as Agrotain® treated urea were the highest in the entre trial, 13% higher than those where the in-crop N source was untreated urea, and 20% higher than the equivalent rate of side-banded urea. At this location, both in-crop applications were followed by light rain (~2 mm) but then several days of hot, dry weather which may have initiated urea hydrolysis but been insufficient to move the N into the soil to be protected against volatilization before more substantial amounts of precipitation were received. The greatest risk of urea volatilization occurs when urea is applied to wet soil or there is just enough precipitation to dissolve the fertilizer but hot, dry weather follows. Surface-applied N is relatively safe if conditions are too dry to dissolve the fertilizer and initiate hydrolyses, albeit the N will not be available to the crop under such circumstances. From both a volatilization and availability perspective, sufficient rain to both dissolve the fertilizer and move it into the rooting zone before significant losses can occur is ideal.

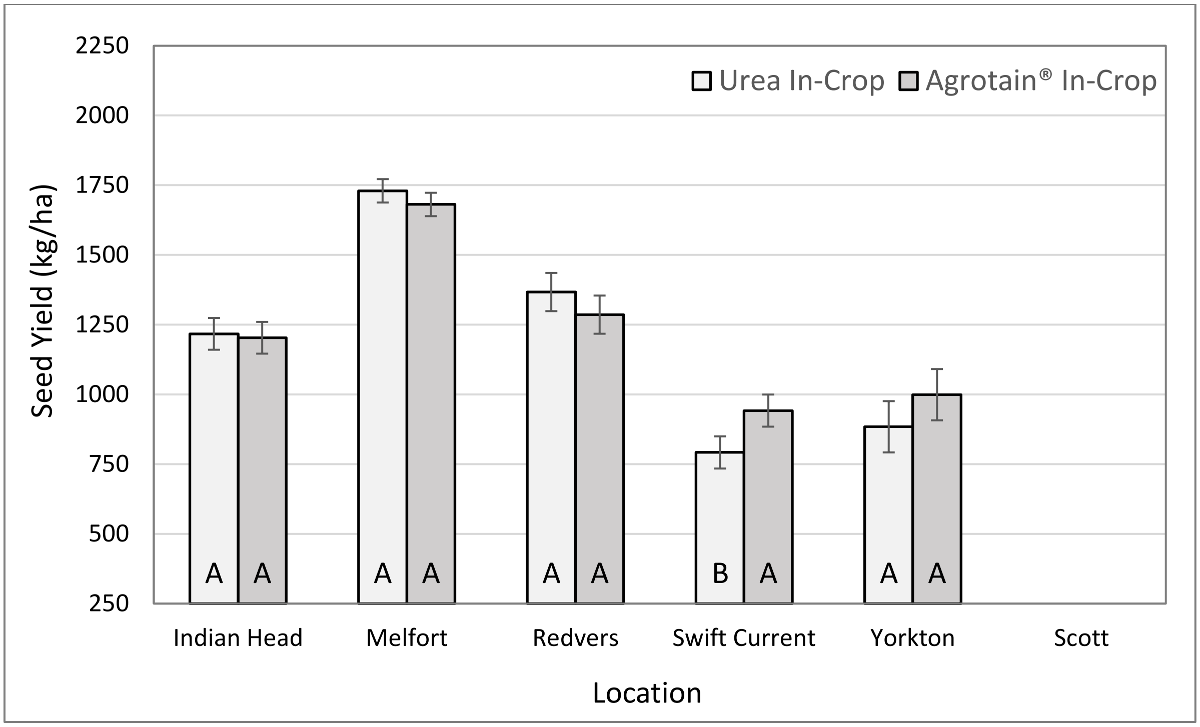

Figure 9. Predetermined contrasts comparing flax seed yields with split-applications of nitrogen (N) utilizing untreated urea as the in-crop source (8,10) to in-crop Agrotain® treated urea (9,11) at five Saskatchewan locations in 2021. Scott was excluded from this comparison due to an error during the in-crop N applications. Error bars are the standard error and means within a location denoted by the same letter do not significantly differ ($P \leq 0.05$).

Extension Activities

At Indian Head, this project was highlighted during the IHARF Crop Management Field Day on July 20, 2021. The event was attended by approximately 70 producers, agronomists, and industry representatives and the discussion was focussed on the current project objectives, past results with flax fertility research, and general flax agronomy considerations. In addition to this main tour, the trial was also shown to an assortment of industry representatives and producers during smaller, informal tours throughout the season. At Swift Current, the plots were shown during multiple tours throughout the season and also highlighted during a CKSW radio program entitled 'Walk the Plots' which was broadcast weekly throughout the growing season. This project was also discussed by Michelle Beaith (SFDC) during WCA's annual summer tour on July 15, 2021 which was attended by approximately 80 participants. At Redvers, the project was shown and discussed during a two-day field tour attended by approximately 35 participants. There were no extension activities for this specific project to report at Melfort, Yorkton, or Scott. Technical reports and extension materials will be available online through IHARF and/or Agri-ARM websites and results from this project will be incorporated into oral presentations as appropriate opportunities arise.

11. Conclusions and Recommendations

Although environmental conditions were not ideal, we were still successful in achieving many of the stated objectives and demonstrating flax responses to N fertilizer rates and non-traditional management practices with respect to establishment and yield. Focussing on establishment, the results were consistent with past Prairie research whereby emerged declined as the rate of side-banded urea was increased at 67% of the locations, the sole exceptions being Indian Head and

Yorkton. The magnitude of the declines in plant densities ranged from 34-107 plants/m^2, or 11-31%. As hypothesized, these losses were either greatly reduced or eliminated by substituting untreated urea with a 75:25 blend of ESN® and untreated urea or with split-applications where a portion of the N was side-banded and the remainder supplied as an in-season surface-broadcast application. The downside to these approaches is that ESN® results in higher input costs due to the premium price associated with this product relative to untreated urea and split-applications result in added costs due to the extra labour, fuel, and equipment wear-and-tear associated with in-crop applications. Furthermore, crop responses to in-crop N are less consistent to in-soil bands applied before or during seeding due to the higher risk of volatilization and need for subsequent precipitation to move the N into the rooting zone. When considering the potential negative effects of side-banded N on flax establishment, producers should consider the relative costs, benefits, and risks of simply increasing their seed rates as opposed to utilizing ESN® or split-applications.

Lodging is a concern that is frequently reported by commercial flax growers which is typically more severe with high N fertility. We had anticipated that this may be alleviated to some extent by split-applications of N; however, no lodging was observed under the specific environmental conditions encountered. Past research/demonstration activities and testimonials suggest that lodging in flax may also be reduced with early seeding and/or foliar fungicide applications.

Focussing on seed yield, responses to N fertilization were less consistent than expected, primarily due to the dry conditions and subsequently low, variable yields. Significant yield increases with N occurred at Indian Head, Melfort, and Redvers, but not at Swift Current, Scott, or Yorkton. In the cases where responses occurred, the rate where yields were maximized ranged from as low as 55 kg N/ha at Redvers to 105 kg N/ha at Indian Head. There was never any benefit to going as high as 130 kg N/ha, the top rate evaluated in this demonstration. To a large extent, this variation in responses could be explained by the combination of residual soil N and the actual yield potentials that could be realized based on environmental conditions. At Indian Head, where the strongest responses to N were achieved, yields were low but the initial potential was reasonably high and residual N was the lowest of all six locations. At Melfort, residual N was moderately high but yield potential was the highest of the locations and the yield response to N was intermediate. At Redvers, where yield potential was low (similar to Indian Head) and residual N levels were modest, 55 kg N/ha was sufficient to maximize yields. At Swift Current and Yorkton, residual N levels were high, yield potential was low, and no responses to N application were detected. Scott was somewhat more of an anomaly in that residual N was reasonably low and overall yields were similar to Indian Head (the most responsive location), but no response to N was detected. Despite the advantages with respect to establishment, there were no yield benefits to either ESN® or split-applications of N. Focussing on split-applications, yields were always similar regardless of application time; however, one location (Swift Current) did appear to benefit from utilizing Agrotain® treated urea over untreated urea as the in-crop source, despite there being essentially no response to side-banded.

It would be beneficial to evaluate these treatments under more typical growing conditions where environmental conditions are more favourable for flax productions and, ideally, residual N levels are consistently lower.

Supporting Information

12. Acknowledgements:

This project was funded through the Agricultural Demonstration of Practices and Technologies (ADOPT) initiative under the Canadian Agricultural Partnership bi-lateral agreement between the federal government and the Saskatchewan Ministry of Agriculture. IHARF, NARF, WCA, and WARC have strong working relationships and a memorandum of understanding with Agriculture and Agri-Food Canada which helps to make work like this possible and should be acknowledged. Each of the participating organizations provided the land, equipment, and infrastructure required to complete this project at their respective locations. Administration for the project was provided in-kind by SaskFlax and special thanks are extended to Michelle Beaith (formerly of SaskFlax) who aided in both development of the proposals/protocols and summer extension activities. Certain crop protection products were provided in-kind by FMC, Corteva and Bayer CropScience. Finally, this work would not have been possible without the contributions of various professional and technical staff of the collaborating organizations.

13. Appendices:

Table 5. Selected agronomic information and dates of operations for flax nitrogen management demonstrations completed at six locations in 2021.

Factor / Operation	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
Previous Crop	Canaryseed	Wheat	Wheat	Barley	Wheat	Wheat
Pre-Emergent Weed Control	894 g glyphosate/ha (Sep-28-2020)	none	none	894 g glyphosate/ha + 86 ml Aim/ha (May-3)	none	894 g glyphosate/ha + 86 ml Aim/ha (May-10)
Seeding Date	May-10	May-18	May-10	May-7	May-17	May 12
Variety	CDC Glas	CDC Glas	CDC Glas	CDC Sorrel	CDC Glas	CDC Glas
Seed Rate / Row Spacing	50 kg/ha / 30 cm	47 kg/ha / 30 cm	49 kg/ha / 25 cm	50 kg/ha / 21 cm	55 kg/ha / 30 cm	48 kg/ha / 25 cm
kg P_2O_5-K_2O-S/ha	40-0-10	40-0-11	39-0-0	40-0-10	40-0-11	40-0-10
Emergence Counts	Jun-16	Jun-14	Jun-8	Jun-7	Jun-7	Jun-14
In-Crop Herbicides	370 ml Centurion/ha (Jun-13) 2 l Curtail M/ha (Jun-19)	0.74 l Assure II/ha (Jun-14) 2.25 l Basagran Forte/ha (Jun-18)	1 l Buctril M/ha (Jun-7) 185 ml Centurion/ha (Jun-14)	470 ml Poast Ultra/ha (May 31) 247 ml Centurion/ha (Jun-16) 1 l Buctril M/ha (Jun-17)	2 l Curtail M/ha (Jun-15) 247 ml Centurion/ha (Jun-17)	1 l Buctril M/ha + 370 ml Centurion/ha (Jun-13)
In-Crop N Dates (precip. within 14 days of application)	Jun-12 (1 mm) Jun-28 (13 mm)	Jun-15 (13 mm) Jul-5 (0 mm)	Jun-7 (56 mm) Jun-30 (22 mm)	Jun-4 (14 mm) Jun-28 (34 mm)	Jun-14 (10 mm) Jun-28 (18 mm)	Jun-7 (40 mm)
Foliar Fungicide	395 ml Dyax/ha (Jul-5)	none	none	none	877 ml Acapela/ha Jun-12	395 ml Dyax/ha (Jul-5)
Foliar Insecticide	855 ml Malathion 85E/ha (Jul-27)	none	none	none	none	none
Lodging Ratings	Aug-6	Sep-8	Aug-8	Aug-29	Sep-13	Aug-9
Pre-harvest Application	894 g glyphosate/ha (Aug-27)	894 g glyphosate/ha (Aug-19)	287 g diquat/ha Sep-2	410 g diquat/ha Aug-6	410 g diquat/ha Sep-7	410 g diquat/ha Sep-2
Harvest Date	Sep-17	Sep-8	Sep-18	Aug-30	Sep-14	Aug-31

Table 6. Overall tests of fixed effects and mean flax plant densities as affected by nitrogen (N) treatment at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, P ≤ 0.05).

Source / Nitrogen Treatment	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
	---------- Pr > *F* (p-values) ----------					
Entry	0.512	<0.001	0.052	0.005	0.504	0.175
	---------- Plant Density (plants/m^2) ----------					
1. Check	653 a	347 a	528 ab	201 a	519 a	376 a
2. Low N – urea	711 a	317 ab	637 a	195 ab	504 a	362 a
3. Med N – urea	696 a	298 abc	555 ab	169 ab	605 a	358 a
4. High N – urea	639 a	263 bc	605 ab	143 b	512 a	345 a
5. High N – 75% ESN®	780 a	306 abc	531 ab	216 a	516 a	377 a
6. Ultra N – urea	716 a	240 c	446 b	167 ab	570 a	334 a
7. Ultra N – 75% ESN®	616 a	335 ab	601 ab	198 ab	497 a	360 a
8. Split – early urea	619 a	344 a	541 ab	174 ab	488 a	392 a
9. Split – early Agrotain®	680 a	296 abc	578 ab	191 ab	615 a	359 a
10. Split – late urea	627 a	337 ab	576 ab	198 ab	484 a	360 a
11. Split – late Agrotain®	665 a	344 a	570 ab	171 ab	516 a	376 a
S.E.M.	50.9	25.5	38.0	15.8	90.6	13.9

Table 7. Orthogonal contrasts for N fertilizer rate (side-banded urea) effects on plant densities for flax at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. P-values of ≤ 0.05 indicate that the corresponding response (i.e. linear, quadratic) was significant.

Nitrogen Rate / Orthogonal Contrast	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
	---------- Plant Density (plants/m^2) ----------					
17 kg N/ha	653	347	528	201	519	376
55 kg N/ha	711	317	637	195	504	362
80 kg N/ha	696	298	555	169	605	358
105 kg N/ha	639	263	605	143	512	345
130 kg N/ha	716	240	446	167	570	334
	---------- Pr > *F* (p-value) ----------					
N-Rate – linear	0.703	<0.001	0.144	0.002	0.459	0.019
N-Rate – quadratic	0.899	0.613	0.002	0.377	0.880	0.811

Table 8. Pre-determined contrast comparisons exploring N management effects on plant densities for flax at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. P-values of ≤ 0.05 indicate that mean densities for the treatments groups significantly differed.

Pre-determined Contrast Comparisons	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
	------------------------------- Plant Density (plants/m^2) -------------------------------					
Check (1) vs.	653 A	347 A	528 A	201 A	519 A	376 A
N Applied (2-11)	675 A	308 B	564 A	182 A	531 A	362 A
Pr > *F* (p-value)	0.695	0.022	0.325	0.121	0.809	0.311
Side-Band Urea (4,6) vs.	678 A	252 B	525 A	155 B	541 A	339 B
Side-Band ESN® (5,7)	698 A	320 A	566 A	207 A	506 A	368 A
Pr > *F* (p-value)	0.695	<0.001	0.250	<0.001	0.462	0.033
Urea Side-Band (4) vs.	639 A	263 B	605 A	143 B	512 A	345 A
Urea Split Apps. (8,10)	623 A	340 A	559 A	186 A	486 A	376 A
Pr > *F* (p-value)	0.801	<0.001	0.282	0.005	0.656	0.062

Table 9. Mean flax seed yield as affected by nitrogen (N) treatment at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, P ≤ 0.05).

Source / Nitrogen Treatment	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
	------------------------------------ Pr > *F* (p-values) ------------------------------------					
Entry	<0.001	<0.001	0.002	0.599	0.264	0.807
	----------------------------------- Seed Yield (kg/ha) -----------------------------------					
1. Check	793 b	1438 b	903 b	807 a	761 a	1116 a
2. Low N – urea	1075 a	1654 a	1300 a	840 a	891 a	1198 a
3. Med N – urea	1130 a	1780 a	1208 ab	839 a	864 a	1145 a
4. High N – urea	1328 a	1715 a	1276 ab	832 a	653 a	1213 a
5. High N – 75% ESN®	1243 a	1731 a	1278 a	883 a	864 a	1190 a
6. Ultra N – urea	1239 a	1831 a	1148 ab	830 a	761 a	1150 a
7. Ultra N – 75% ESN®	1233 a	1794 a	1355 a	834 a	845 a	1071 a
8. Split – early urea	1209 a	1749 a	1336 a	783 a	894 a	1062 a
9. Split – early Agrotain®	1194 a	1705 a	1234 ab	939 a	937 a	1031 a
10. Split – late urea	1226 a	1712 a	1397 a	802 a	874 a	–
11. Split – late Agrotain®	1213 a	1658 a	1338 a	945 a	1062 a	–
S.E.M.	107.6	44.9	145.5	94.2	114.4	91.8

Table 10. Orthogonal contrasts for N fertilizer rate (side-banded urea) effects on seed yield for flax at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. P-values of ≤ 0.05 indicate that the corresponding response (i.e. linear, quadratic) was significant.

Nitrogen Rate / Orthogonal Contrast	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
	------ Seed Yield (kg/ha) ------					
17 kg N/ha	793	1438	903	807	761	1116
55 kg N/ha	1075	1654	1300	840	891	1198
80 kg N/ha	1130	1780	1208	839	864	1145
105 kg N/ha	1328	1715	1276	832	653	1213
130 kg N/ha	1239	1831	1148	830	761	1150
	------ Pr > *F* (p-value) ------					
N-Rate – linear	<0.001	<0.001	0.018	0.811	0.493	0.731
N-Rate – quadratic	0.030	0.043	0.001	0.724	0.373	0.609

Table 11. Pre-determined contrast comparisons exploring N management effects on seed yield for flax at six Saskatchewan locations (Indian Head, Melfort, Redvers, Swift Current, Yorkton, and Scott) in 2021. P-values of ≤ 0.05 indicate that mean densities for the treatments groups significantly differed.

Pre-determined Contrast Comparisons	Indian Head	Melfort	Redvers	Swift Current	Yorkton	Scott
	------ Seed Yield (kg/ha) ------					
Check (1) vs.	793 B	1438 B	903 B	807 A	761 A	1116 A
N Applied (2-11)	1209 A	1733 A	1287 A	853 A	864 A	1132 A
Pr > *F* (p-value)	<0.001	<0.001	<0.001	0.458	0.291	0.864
Side-Band Urea (4,6) vs.	1284 A	1773 A	1212 A	831 A	707 A	1181 A
Side-Band ESN® (5,7)	1238 A	1763 A	1317 A	858 A	854 A	1131 A
Pr > *F* (p-value)	0.425	0.805	0.139	0.638	0.120	0.569
Urea Side-Band (4) vs.	1328 A	1715 A	1276 A	832 A	653 B	–
Urea Split Apps. (8,10)	1234 A	1730 A	1367 A	792 A	884 A	–
Pr > *F* (p-value)	0.122	0.775	0.292	0.583	0.049	–
Early In-Crop (8,9) vs.	1201 A	1727 A	1285 A	861 A	915 A	–
Late In-Crop (10,11)	1219 A	1686 A	1368 A	873 A	968 A	–
Pr > *F* (p-value)	0.757	0.324	0.235	0.838	0.569	–
Urea In-Crop (8,10) vs.	1217 A	1730 A	1367 A	792 B	884 A	–
Agrotain® In-Crop (9,11)	1203 A	1681 A	1286 A	942 A	999 A	–
Pr > *F* (p-value)	0.810	0.251	0.248	0.015	0.218	–

Abstract

14. Abstract/Summary

In the spring of 2021 at multiple Saskatchewan locations, field trials with flax were initiated to demonstrate crop response to a range of side-banded urea rates and non-traditional nitrogen (N) management practices. The locations were Indian Head, Melfort, Yorkton, and Redvers in the Black soil zone, Scott in the Dark Brown soil zone, and Swift Current in the Brown soil zone. The treatments included a range (17-130 kg N/ha) of side-banded urea rates, high rates of a side-banded ESN® blend, and split-applications where both the timing and sources of in-crop N were varied. In addition to residual soil nutrient levels, data collection included plant density, lodging, and seed yield. The 2021 growing season was considered dry at all locations and, as such, yields were relatively low and variable. High rates of side-banded urea negatively impacted emergence at 67% of the locations, the exceptions being Indian Head and Yorkton. Where they occurred, the magnitude of these reductions ranged from 11-31%. As hypothesized, substituting side-banded urea with the ESN® blend greatly reduced or eliminated the stand reductions associated with side-banded urea and utilizing split-applications also helped in this regard. Lodging was not observed in any treatments, regardless of location. When averaged across treatments, yields ranged from 849-1706 kg/ha and responses to N fertilization occurred at Indian Head, Melfort, and Redvers, but not Swift Current, Scott or Yorkton. Where responses occurred, maximum yields were achieved with 55-105 kg N/ha. In most cases, the observed yield responses could be reasonably explained by the combination of residual soil N levels and the actual yield potentials that could be achieved under the conditions encountered. Yield benefits were never realized by substituting side-banded urea with the ESN® blend or with split-applications where the in-crop source of N was untreated urea. No differences between the early or late in-crop applications were detected for yield. At Swift Current, there appeared to be a benefit to substituting untreated urea with Agrotain® treated urea; however, our confidence in this result was limited by the overall lack of N response. There would be benefit to repeating this demonstration under more typical and higher yielding conditions.