ADF Project Final Report

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for the

Saskatchewan Ministry of Agriculture (ADF Program), Saskatchewan Flax Development Commission (SFDC) & Western Grains Research Foundation (WGRF)

Project Title: Flax Response to a Wide Range of Nitrogen & Phosphorus Fertilizer Rates in Western Canada

(Project #20150105)

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1. **Project title and ADF file number.**
   Flax (*Linum usitatissimum)* response to a wide range of nitrogen and phosphorus fertilizer rates in western Canada (ADF #20150105)

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4. **Abstract/ Summary**: *An outline on overall project objectives, methods, key findings and conclusions for use in publications and in the Ministry database (Maximum of 500 words or one page in lay language).*

Flax fertility trials were conducted over a three-year period at eight locations, primarily in Saskatchewan but also in Alberta and Manitoba. All fertilizer was side-banded, and the treatments were a factorial combination of four nitrogen (N) fertilizer rates (13, 50, 100, and 150 kg N/ha) and four phosphorus (P) fertilizer rates (0, 20, 40, and 60 kg P_2O_5/ha) arranged in an RCBD with four replicates. The response variables measured were plant density, days to maturity, seed yield, and test weight. Residual NO3-N was rather variable across locations; however, P levels were relatively low with a maximum of 24 ppm (Olsen P) and less than 10 ppm at 63% of the sites. Flax emergence was somewhat sensitive to side-banded urea whereby stand reductions associated with increasing N rate were observed at 74% of the sites. Amongst the affected sites, the response was linear with a 28% reduction in plant densities when the N rate was increased from 13 kg N/ha to 150 kg N/ha. Side-banded monoammonium phosphate did not affect plant density, regardless of rate. Increasing N rate delayed maturity 71% of the time; however, averaging 2.4 days amongst the affected sites this is not expected be of practical concern under normal conditions. Phosphorus rate did not have a noticeable effect on flax maturity. Flax yields were increased with both N and P fertilizer. Focussing on N, there was a site by N

rate interaction whereby the response was relatively strong at 83% of the sites, increasing yields by 39% on average with maximum yields achieved at approximately 100 kg N/ha. At the remaining sites, the response was weak with an 11% yield increase on average and optimal rates closer to 50 kg N/ha. For phosphorus, although there was variation, no site by phosphorus interaction was detected. The average response was linear but relatively shallow (7%); therefore, more modest rates of 20-40 kg P_2O_5/ha are likely to be most economical and enough to maintain soil fertility under most circumstances. At 50% of the sites, the maximum yield increase with P was 5-10% while the response was below 5% at 28% of the sites and greater than 10% at 22% of the sites. Test weight was not affected by P fertilizer rate but there was a very slight linear increase at 41% of the sites. In conclusion, these results show that adequate N and P fertility are both important for achieving higher flax yields; however, the responses were modest with respect to both magnitude of the yield increase and the rates at which maximum yield was achieved. Although this in not necessarily unexpected with any crops, site-to-site variability was much higher than the variability within sites due to N and P fertilizer rate. This potentially suggests that fertility is not likely the most limiting factor for majority of western Canadian flax acres; however, this will vary on a farm-to-farm basis.

5. Extension Messages: *key outcomes and their importance for producers/industry (3-5 bullet points* *<u>in lay language).</u>*

- Flax emergence was sensitive to side-banded urea whereby there were linear reductions in plant density with increasing N rate at approximately three-quarters of the site-years and, amongst these, an average plant loss of 28% as the rate was increased from 13 kg N/ha to 150 kg N/ha. Side-banded monoammonium phosphate did not affect flax emergence.
- Increasing N rate led to slight but significant delays in maturity approximately 70% of time. The average delay amongst the affected site-years was 2.4 days when the N rate was increased from 13 kg N/ha to 150 kg N/ha – this would not be expected to be of any agronomic concern under most circumstances. Phosphorus fertilization did not have any noteworthy effects on maturity.
- Flax yield increased with N fertilization in essentially all cases; however, the response was weak at 17% of the site-years where either residual N was high, or yields were more limited by other environmental factors. Amongst the more responsive sites, yields plateaued at approximately 100 kg N/ha and the magnitude of the yield increase averaged 39%. At the less responsive sites the average magnitude of response was 11% and there was little benefit to fertilizer rates exceeding 50 kg N/ha.
- At 7% when averaged across site-years, the magnitude of the flax yield response to P fertilizer was smaller than that observed for N; however, it did appear to be reasonably consistent. The response was linear, but the slope was likely too shallow to justify rates exceeding 20-40 kg P_2O_5/ha. Amongst individual sites, the magnitude of the individual responses to P ranged from nil to nearly 40% with responses between 5-10% at half the sites, below 5% at 28% of the sites, and greater than 10% at 22% of the sites.
- Flax test weight was affected by N rate at 41% of the site-years where there was a slight linear increase in test weight with N rate. The effect was small with, specifically amongst the responsive sites, only a 2% increase in test weight at the 150 kg N/ha rate relative to the 13 kg N/ha rate.

6. Introduction: *Brief project background and rationale.*

Many growers in Saskatchewan are interested in flax (*Linum usitatissimum*) as a rotational alternative to canola and potentially profitable crop; however, flax yields have been variable and have not increased over time to the same extent as other crops like wheat and canola. While flax varieties have improved in many respects, the yield gains that have been achieved with genetics have also been somewhat modest and, perhaps more importantly, there is often a large gap in commercial yields and genetic potential. Consequently, many growers seek agronomic solutions to increase the overall productivity and yield stability for this crop. While there are many agronomic factors to consider, for most crops, including flax, fertilizer comprises one of the largest input costs and typically provides a strong return on investment when used appropriately. With flax, every bushel (25 kg) of seed produced, there is a requirement of 1.2-1.4 kg N, 0.3-0.4 kg P_2O_5, 0.7-0.9 kg

K_2O and 0.2-0.3 kg S; therefore a 40 bu/ac (2.5 Mt/ha) 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). While there have been numerous high quality and relevant flax fertility studies conducted in western Canada over the past 10-15 years, there are specific gaps which have been identified. Furthermore, with significant advancements in seeding technology and potential soil improvement through long-term no-till and continuous cropping (i.e. Lafond et al. 2011), flax response to fertilizer applications in Saskatchewan and the Prairies in general is worth revisiting.

Flax often responds well to nitrogen (N) fertilizer application and, depending on residual N and soil moisture, rates of 35-80 kg N/ha are commonly applied. Numerous studies have evaluated different aspects of N management for flax production in western Canada. Nitrogen source, placement, timing of application, and rate have all been the subject of regionally relevant research projects over the years (i.e. Nuttall and Malhi 1991; Lafond et al. 2003; Malhi et al. 2007). Nitrogen fertilizer rate interactions with factors such as row spacing and seeding rate (Lafond 1992), seeding date (Lafond et al. 2008), P fertilization (Grant et al. 1999) and fungicide application (Vera et al. 2014) have also been explored. However, in many of these cases, the number of rates evaluated was small and the rates rarely (with exceptions) exceeded 100 kg ha^{-1}. Most of these studies have indeed shown that flax response to N can be inconsistent and yields typically level off at relatively modest rates (i.e. 100-125 kg/ha fertilizer plus residual N); however, responses to higher rates have occasionally been documented. Averaged across 15 site-years in Saskatchewan, one more recent study showed that maximum flax yield was achieved at 169 kg/ha with the strongest increase between 10-90 kg N/ha (May et al. 2010). That said, while yields peaked at relatively high rates in this case, marginal economic returns were optimized at rates below 110 kg N/ha except when high grain prices were combined with low N fertilizer prices. While we do not necessarily expect higher N rates than have traditionally been recommended to be economical under most circumstances, this is one of the first factors that flax growers who wish to increase productivity through agronomic practices tend to look at.

Relative to N, flax response to phosphorus (P) fertilizer can be less consistent and often is not as pronounced as for crops like spring wheat or canola. Still, many producers recognize applying at least enough P fertilizer to replace what the crop removes as an important strategy for maintaining soil fertility and productivity over the long-term. As with N, several western Canadian studies have evaluated various aspects of P fertility management for flax production. Several of these have focussed on P fertilizer placement methods as opposed to rates and have generally showed that flax can be sensitive to seed-placed P rates exceeding 15-20 kg P_2O_5/ha; therefore, side-banding is usually a preferred placement option (i.e Bailey and Grant, 1989; Malhi et al. 2008). Other research has investigated potential implications for P fertilization of factors such as soil residual P, previous crop (mycorrhizal versus non-mycorrhizal crops), previous season applications of P fertilizer, and P solubilizing microbial inoculants (i.e. Bailey et al. 1977; Grant et al. 1999; Grant et al. 2009). Flax yields and P uptake have been consistently higher following mycorrhizal crops and in soils with high residual P levels (Bailey et al. 1977; Grant et al. 2009); however, in cases where residual P is low, fertilizer is the most effective method of increasing yields and correcting nutrient deficiencies. While a substantial number of western Canadian P studies with flax have been conducted, relatively few have looked at multiple rates of P or rates exceeding 20-25 kg P_2O_5/ha. Fewer still have combined multiple rates of P fertilizer with other nutrient applications such as N when attempting to target high flax yields.

While still important for crop growth with potential to limit yields when not sufficiently available, potassium (K) and sulphur (S) are generally much less likely to limit flax yields in western Canada than N or P.

This project aimed to evaluate the flax yield response to applications of varying rates of side-banded N and P fertilizer under a broad range of environmental conditions and to investigate potential interactions amongst these nutrients. For example, are there circumstances where P only becomes limiting when N rates reach a certain level? Similarly, flax could conceivably respond to higher rates of N when applied in combination with P fertilizer, particularly in deficient soils. While past studies have evaluated many aspects of fertility for flax, the current study hopes to address some of the existing gaps and validate existing recommendations with research conducted using modern seeding equipment and genetics.

7. **Objectives and the progress towards meeting each objective.**

Objectives **(Please list the original objectives and/or revised objectives if Ministry-approved revisions have been made to original objective. A justification is needed for any deviation from original objectives)**	**Progress** **(e.g. completed/not completed)**
a) To evaluate the yield response of flax to various rates and combinations of nitrogen and phosphorus fertilizer	Completed
b) The evaluate the potential yield response to higher N and P rates than are typically recommended or utilized for flax	Completed

Please add additional lines as required.

8. **Methodology:** *Specify project activities undertaken during entire project period. Include approaches, experimental design, methodology, materials, sites, etc.*

Following consultations with the Saskatchewan Flax Development Commission (SFDC), an extensive field study to revaluate flax (Linum usitatissimum) fertility requirements was initiated in time for the 2016 growing season. The project aimed to investigate flax response to nitrogen (N) and phosphorus (P) fertilizer applications under a broad range of western Canadian environments using modern varieties and seeding equipment. Field trials for the three-year project were initiated at eight locations with six in Saskatchewan (Indian Head, Melfort, Redvers, Scott, Swift Current and Yorkton), one in Alberta (Vegreville), and one in Manitoba (Brandon). The treatments were a factorial combination of four N rates (13, 50, 100 and 150 kg N/ha) and four P rates (0, 20, 40 and 60 kg P_2O_5/ha) arranged in Randomized Complete Block Design (RCBD) with four replicates. While certain aspects of the specific seeding equipment varied (i.e. row spacing, opener type), plots at all locations, except Vegreville, were direct-seeded into cereal stubble and all fertilizer was side-banded during seeding. At Vegreville, the plots were tilled prior to seeding and all fertilizer was mid-row banded. The fertilizer products utilized in the treatments were commercial grade urea (46-0-0) and monoammonium phosphate (11-52-0).

Selected agronomic information for all location-year combinations (site-years) is provided in Table A-1 of the Appendices. Specific management practices and decisions were largely left to individual site managers and tailored to regional practices, available equipment, and specific pests encountered; however, all controllable factors other than fertility were intended to be non-limiting. Seeding dates ranged from May 5 to June 7 with most sites seeded in the second or third week of May. Except at Melfort in 2017 where the plots were not sprayed but were hand-weeded throughout the season, weeds were managed using registered pre-emergent and in-crop herbicides. Foliar fungicide applications were utilized at most sites to minimize any potential for disease (pasmo) and insecticides were not required in any cases. Pre-harvest herbicides or desiccants were used in many cases and were applied at the time of or after the latest maturing plots reached physiological maturity (75% boll colour change). The plots were straight-combined when fit to do so (with respect to crop stage and environmental conditions) and, wherever possible, outside rows were excluded from the harvest area to minimize edge effects.

A composite soil sample (targeted depth intervals of 0-15 cm and 15-60 cm) was collected from each trial location in the late fall or early spring and submitted to AgVise laboratories for various analyses. There was some variation in the specific sampling depths amongst sites whereby Melfort was only sampled to 30 cm in all three years and Redvers was only sampled to 46 cm in 2016 and 2017. The crop response data collected included plant density, days to maturity, seed yield and test weight. Plant density was measured by counting the number of emerged plants in two separate 1 m sections of crop row per plot and calculating the average plants/m2 for each plot. These counts were targeted for approximately 3-4 weeks after planting but the specific dates varied amongst individual sites (Table 1 and 2). Physiological maturity, defined as when approximately 75% of the bolls had turned brown, was recorded for each plot with values expressed as days from planting to maturity. Days to maturity was not recorded at Melfort or Redvers in 2016. At Melfort and Swift Current in 2017 there was no variation in maturity recorded across treatments or replicates therefore this data was not statistically analyzed or discussed. Seed yield was determined from the harvested grain samples and is corrected for dockage and to a uniform moisture content of 10%. Test weights were measured at each location except Swift Current where the samples were too small. Mean monthly temperatures and precipitation amounts were estimated from the nearest weather station for each site.

Not unexpectedly given the large number of sites, there were cases where the field trials were compromised by extreme weather or establishment issues and, in some cases, data were excluded from any combined analyses. Due to heavy and widespread snowfall in early October and extremely wet conditions through that entire month, the 2016 harvest was delayed late into the fall at Melfort, Swift Current, and Vegreville. The prolonged exposure to severe environmental conditions led to reduced yields and seed quality (test weight) while increasing variability at affected sites. Data from Melfort in this year, the most severely impacted site, was discarded prior to the final combined analyses. In 2017, the plots at Swift Current were affected by drought and then further impacted by wildlife damage prior to harvest. Maturity, yield and test weight data from this site-year were excluded from the combined analyses; however, the emergence data were retained. In 2018 at Melfort, establishment was very poor with an overall average of less than 50 plants/m^2 established; all data from this location was also excluded from the final analyses. All fertilizer was midrow banded as opposed to side-banded at Vegreville. Due to this fundamental difference in both the timing and placement of fertilizer, data from this site was analyzed on its own.

Response data were analyzed in several distinct steps. First, all data (other than what was discarded as discussed in the previous paragraph) was analyzed using the Mixed procedure of SAS with site (location-year) included as fixed effect along with N rate, P rate, and all possible interactions. This allowed us to evaluate the overall impacts of the various fixed effects and identify responsive versus non-responsive sites in cases where interactions with site were significant. Next, for each variable and as appropriate, the specific groups identified were reanalyzed with site effects considered random and N rate, P rate, and their interaction considered fixed. In all cases, orthogonal contrasts were used to describe any observed responses to N rate and P rate both on average and at individual N/P rates. Individual treatment means were separated using Fisher's protected LSD test. Individual site means or non-significant interactions are only presented for yield due to the large volume of data. Data from Vegreville were analyzed separately with site included as a fixed effect along with N rate, P rate, and all possible interactions. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

9. **Results and discussion:** *Describe results accomplished during the entire project period under each objective listed under section 6. The results need to be accompanied with tables, graphs and/or other illustrations. Provide discussion necessary to the full understanding of results. Where applicable, results should be discussed in the context of existing knowledge and relevant literature. Detail any major concerns or project setbacks.*

Mean monthly temperature and precipitation data over the four-month growing season (May-August) for each location over the three-year study period are provided in Tables A-2 and A-3 of the Appendices, respectively. With field trials at eight geographic locations spanning all the major soil zones over three consecutive growing seasons, the results of this project should be applicable under a broad range of conditions. At locations, 2016 was the wettest of the three years while 2017 and 2018 were generally much drier. Over the four-month growing season (May through August), precipitation amounts ranged from less than 100 mm at Swift Current 2017 and 2018 to as high as 375 mm, ironically, at the same location (Swift Current) in 2016.

The locations were predominantly in the Black soil zone (Indian Head, Yorkton, Redvers, and Brandon) with moderate organic matter levels but also reached into the brown (Swift Current, Dark Brown (Scott), Grey (Vegreville), and high organic matter moist Black (Melfort) zones. Selected soil test results are provided in Table 1 below. The pH of the 0-15 cm soil profile ranged from approximately 5-8 with Scott being the most consistently acidic location and pH at most of the locations falling in the 7-8 range. Soil organic matter ranged from below 3% at Swift Current to over 9% at Melfort with more than half of site-years falling between 4-7% organic matter. While there was some variation in the sampling depths, residual soil nitrate varied widely from less than 10 kg NO_3-N/ha to more than 100 kg NO_3-N/ha. Residual (Olsen) P levels were more consistently low with a maximum of 24 ppm, 79% of the sites below 15 ppm, 63% of sites below 10 ppm, and 25% of the sites below 5 ppm.

Table 1. Selected soil test results for flax nitrogen and phosphorus trial at eight western Canadian locations over a three-year period (2016-2018).

Location	Year	pH (0-15 cm)	SOM (0-15 cm)	NO_3-N (0-60 cm)	Olsen-P (0-15 cm)
		–	%	kg/ha	ppm
Indian Head	2016	7.6	4.0	25	10
	2017	7.7	5.3	25	10
	2018	7.6	5.8	19	3
Melfort	2016	7.1	9.5	55 [Z]	22
	2017	6.1	9.0	56 [Z]	16
	2018	5.7	6.6	19 [Z]	12
Scott	2016	4.9	4.1	37	24
	2017	5.9	4.7	29	19
	2018	5.7	3.5	22	17
Swift Current	2016	7.4	2.7	46	7
	2017	7.1	2.3	31	3
	2018	8.1	2.1	88	4
Redvers	2016	7.7	–	104 [Y]	4
	2017	7.0	3.2	28 [Y]	4
	2018	7.8	3.4	58	7
Yorkton	2016	7.8	5.7	36	6
	2017	6.5	6.3	43	11
	2018	7.8	7.4	104	5
Brandon	2016	7.9	5.1	37	6
	2017	7.9	5.0	55	7
	2018	8.1	4.5	8	3
Vegreville	2016	7.5	8.2	26	11
	2017	6.6	6.3	34	14
	2018	7.6	4.4	43	8

[Z] Soil only sampled to 30 cm depth at Melfort [Y] 0-46 cm sample depth

Treatment Effects on Flax Emergence

The initial analyses which included the entire dataset showed differences in emergence between site-years (S; $P < 0.001$), an overall nitrogen rate (NR) effect ($P < 0.001$), and a strong S × NR interaction ($P = 0.030$; Table 2). Overall mean plant populations at the individual site-years ranged from 146-617 plants/m^2 and were generally lowest at Swift Current and highest at Indian Head and Yorkton. Closer inspection of the S × NR interaction revealed that the N effect occurred at 74% (14/19) of the individual sites (Table A-4) and the data were subsequently divided into two sub-groups, responsive to N rate (n=14) and non-responsive (n=5) with respect to emergence. Amongst the responsive site-years (with site effects considered random), emergence was affected by N rate (<0.001) but not P rate ($P = 0.333$) and there was no NR × PR interaction ($P = 0.518$). The NR effect was such that flax plant populations declined linearly from an overall mean of 424 plants/m^2 at 13 kg

N/ha to 306 plants/m^2 at 150 kg N/ha, with significantly higher reductions occurring with each subsequent increase in N. For the smaller sub-set of non-N responsive sites, the NR effect was again, somewhat unexpectedly, significant ($P = 0.002$) with no P rate effect ($P = 0.825$) but a significant NR × PR interaction ($P = 0.039$). Amongst the non-N responsive sites, there was still a linear ($P < 0.001$) decline in plant populations; however, the range was much smaller at 377-415 plants/m^2. The NR × PR interaction appeared to be due to inconsistencies in the N response amongst P rates and a slight reduction in plant populations with increasing P rate at the lowest N level but no PR effect at the 50-150 kg N/ha rates.

Fertilizer applied near the seed can reduce emergence through direct ammonia toxicity, desiccation under dry conditions due to the high osmotic potential of the fertilizer, or a combination of these two factors (Dowling 1996) and our results are generally consistent with previous research. In western Manitoba Grant et al. (2016) evaluated various forms and placement options for N and found that side-banded N reduced emergence at 5/6 sites. While actual treatment means were not presented, the authors suggested that the effects were minor and of little agronomic concern; however, the maximum rate used in this study was 90 kg N/ha compared to 150 kg N/ha in the current project. Across multiple oilseed species (including flax) and with N rates up to 200 kg N/ha, May et al. (2010) observed a linear reduction in plant densities with an average reduction of 10% at the highest rate. The slightly lower reductions in this study may be attributed to some species being less sensitive than flax and the fact that growing conditions were better overall during this period (2004-2006) than in the current project (2016-2018). With rates of up to 120 kg N/ha, Lafond et al. (2008b) observed reduced plant populations with side-banded urea 25% of the time and 33% of the time with side-banded anhydrous ammonia; however, the authors concluded that the effect was too small to have a negative impact on overall productivity. In contrast, Lafond et al. (2008a) observed approximately 13% lower plant populations for side-banded urea and Agrotain® treated urea compared to side-banded ammonium-nitrate when applied at a rate of 70 kg N/ha. Focussing on P (monoammonium phosphate), Bailey and Grant (1989) did not report any impact on emergence to rates as high of 57 kg P_2O_5/ha when the fertilizer was either directly below or beside and below the seed-row. There is considerable research showing reduced stands with seed-placed mono-ammonium relative to banding P away from the seed but, it seems, relatively little showing the effects (on emergence) of higher side-banded monoammonium rates relative to an unfertilized control.

Table 2. Overall tests of fixed effects for plant density. The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Flax Plant Density		
	All Sites [Z] (n=19)	**N Responsive Sites (n=14)[Y]**	**Non-N Responsive Sites (n=5)[Y]**
Effect	---------- p-values ----------		
Site-Year (S)	<0.001	–	–
N Rate (NR)	<0.001	<0.001	0.002
P Rate (PR)	0.286	0.333	0.825
NR × PR	0.030	0.518	0.039
S × NR	<0.001	–	–
S × PR	0.762	–	–
S × NR × PR	0.779	–	–

[Z] Site effects considered fixed for initial combined analyses

[Y] Site effects considered random for combined analyses of responsive versus non-responsive sub-sets

Table 3. Main effect means for flax emergence when averaged across all sites (n=19), sites where a significant N effect was detected (n=14), and sites where there was no N effect (n=5). Main effect means within a column followed by the same letter do not significantly differ. Orthogonal contrast results to describe N responses are also presented.

Treatment/ Main Effect	**All Sites (n=19) [Z]**	**N Responsive Sites (n=14) [Y]**	**Non-N Responsive Sites (n=5) [Y]**
Nitrogen Rate		------ plants/m^2 ------	
13 kg N/ha	422 a	424 a	415 a
50 kg N/ha	392 b	390 b	403 a
100 kg N/ha	366 c	353 c	398 a
150 kg N/ha	325 d	306 d	377 b
S.E.M. (L.S.D.)	33.8 (14.1)	33.9 (14.1)	64.8 (19.4)
		------ p-values ------	
NR – linear	<0.001	<0.001	<0.001
NR - quadratic	0.644	0.824	0.576
Phosphorus Rate		------ plants/m^2 ------	
0 kg P_2O_5/ha	374 a	367 a	393 a
20 kg P_2O_5/ha	376 a	367 a	402 a
40 kg P_2O_5/ha	372 a	364 a	397 a
60 kg P_2O_5/ha	382 a	376 a	400 a
S.E.M. (L.S.D.)	4.8 (11.0)	33.9 (14.1)	64.8 (19.4)
		------ p-values ------	
PR – linear	0.201	0.259	0.591
PR - quadratic	0.320	0.217	0.713

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

Table 4. Individual treatment means for the N rate by P rate interaction detected amongst non-N responsive sites (n=5) for flax emergence. Means followed by the same letter do not significantly differ (L.S.D. = 38.8).

	Phosphorus Rate				Orthogonal Contrasts	
Nitrogen Rate	0 kg P_2O_5/ha	20 kg P_2O_5/ha	40 kg P_2O_5/ha	60 kg P_2O_5/ha	PR – linear	PR – quadratic
	---------- plants/m^2 ----------				---------- p-values ----------	
13 kg N/ha	439 a	423 abc	393 b-e	406 a-d	0.042	0.297
50 kg N/ha	381 de	396 b-e	407 a-d	408 a-d	0.144	0.632
100 kg N/ha	382 de	395 b-e	431 ab	402 a-d	0.129	0.130
150 kg N/ha	371 de	393 b-e	358 e	386 cde	0.896	0.826
Orthogonal Contrasts	---------- p-values ----------				–	–
NR – linear	0.002	0.184	0.146	0.273	–	–
NR - quadratic	0.084	0.355	0.002	0.568	–	–

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

Treatment Effects on Flax Maturity

In the initial analyses, flax maturity varied amongst site years (n=17) as expected and was also affected by N rate ($P < 0.001$) with a S × NR interaction ($P < 0.001$) indicating that the N effect varied across site-years (Table 5). Closer evaluation of the S × NR interaction suggested that an N response occurred at 13/17 site-years, or 71% of the time (Table A-5). The overall effect of environment on maturity was strong with site averages ranging 86-111 days from seeding with earlier maturity primarily attributed to drier conditions and the more southern locations. Amongst the N responsive sites (n=13), the NR effect was significant while the PR and NR × PR interactions were not (P = 0.320-0.950). The NR effect was due to maturity being delayed by an overall average of 2.4 days as the rate of N was increased from 13 kg N/ha to 150 kg/ha (Table 6). This response was quadratic ($P = 0.007$) with no difference between the 13-50 kg N/ha rates but small yet significant incremental delays as the N rate was further increased to 100-150 kg N/ha. When the four non-N responsive sites were analyzed, the NR effect again turned out to be significant with an NR × PR interaction ($P = 0.048$) but no PR effect ($P = 0.337$). While statistically significant, the NR effect amongst the non-responsive sites was negligible with only 0.7 days between the earliest and latest maturing treatments. The response in this case was also quadratic with similar values for 13-100 kg N/ha rates but slightly delayed maturity at the highest N rate. The explanation for the NR × PR interaction is unclear and may have been due to random variability to a certain extent but there appeared to be a more consistent N effect at the two higher P levels (Table 7).

Most the literature pertaining to N and P fertility in flax does not specifically report any effects on maturity; however, it is generally accepted that increasing N rates can delay maturity to some extent under certain conditions (i.e. cool/wet). Within a range of 67-133% of soil test recommended N rates, Lafond et al. (2008b) did not observe any impacts on flax maturity. Based on past experiences with other crops, mainly cereals, P fertilizer management can potentially impact maturity but, unless perhaps due to substantial impacts on establishment (i.e. with high rates of seed-placed P) they are very small. Because phosphorus is important for both vigorous vegetative growth and the development of reproductive parts, severe P deficiency can substantially delay maturity; however, this is not frequently observed under normal field conditions.

Table 5. Overall tests of fixed effects for days to maturity. The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Flax Maturity		
	All Sites [Z] (n=17)	**N Responsive Sites (n=13)[Y]**	**Non-N Responsive Sites (n=4) [Y]**
Effect	---	p-values	---
Site-Year (S)	<0.001	–	–
N Rate (NR)	<0.001	<0.001	<0.001
P Rate (PR)	0.803	0.950	0.337
NR × PR	0.276	0.320	0.048
S × NR	<0.001	–	–
S × PR	0.984	–	–
S × NR × PR	0.955	–	–

[Z] Site effects considered fixed for initial combined analyses

[Y] Site effects considered random for combined analyses of responsive versus non-responsive sub-sets

Table 6. Main effect means for flax maturity when averaged across all sites (n=19), sites where a significant N effect was detected (n=14), and sites where there was no N effect (n=5). Main effect means within a column followed by the same letter do not significantly differ. Orthogonal contrast results to describe N responses are also presented.

Treatment/ Main Effect	**All Sites (n=17)** [Z]	**N Responsive Sites (n=13)** [Y]	**Non-N Responsive Sites (n=4)** [Y]
Nitrogen Rate		---------- days from seeding ----------	
13 kg N/ha	98.6 c	99.2 c	96.4 bc
50 kg N/ha	98.7 c	99.4 c	96.1 c
100 kg N/ha	99.6 b	100.5 b	96.4 b
150 kg N/ha	100.5 a	101.6 a	96.8 a
S.E.M. (L.S.D.)	0.11 (0.24)	2.20 (0.30)	3.19 (0.36)
		---------- p-values ----------	
NR – linear	<0.001	<0.001	0.004
NR - quadratic	0.002	0.007	0.013
Phosphorus Rate		---------- days from seeding ----------	
0 kg P_2O_5/ha	99.4 a	100.2 a	96.5 a
20 kg P_2O_5/ha	99.3 a	100.2 a	96.2 a
40 kg P_2O_5/ha	99.3 a	100.2 a	96.5 a
60 kg P_2O_5/ha	99.4 a	100.2 a	96.4 a
S.E.M. (L.S.D.)	0.11 (0.24)	2.20 (0.30)	3.19 (0.36)
		---------- p-values ----------	
PR – linear	0.677	0.831	0.827
PR - quadratic	0.385	0.587	0.392

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

Table 7. Individual treatment means for the N rate by P rate interaction detected in the non-N responsive sites (n=4) for flax maturity. Means followed by the same letter do not significantly differ (L.S.D. = 0.71).

	Phosphorus Rate				Orthogonal Contrasts	
Nitrogen Rate	0 kg P_2O_5/ha	20 kg P_2O_5/ha	40 kg P_2O_5/ha	60 kg P_2O_5/ha	PR – linear	PR – quadratic
	------------------------- days from seeding -------------------------				------------ p-values ------------	
13 kg N/ha	96.4 cde	96.3 de	96.3 cde	96.6 a-d	0.566	0.427
50 kg N/ha	96.1 de	96.3 de	96.1 de	95.8 e	0.287	0.427
100 kg N/ha	97.0 abc	96.1 de	96.4 cde	96.2 de	0.081	0.179
150 kg N/ha	96.5 bcd	96.3 de	97.3 a	97.2 ab	0.008	0.714
Orthogonal Contrasts	-------------------------------- p-values --------------------------------				–	–
NR – linear	0.309	0.918	0.006	0.031	–	–
NR - quadratic	0.513	0.776	0.038	0.001	–	–

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

Treatment Effects on Flax Seed Yield

Yield data from 18 site-years were included in the initial combined analyses (Table 8) which showed that yield varied with site-year ($P < 0.001$), N rate ($P < 0.001$), P rate ($P < 0.001$). This analyses also indicated significant NR × PR ($P = 0.050$) and S × NR ($P < 0.001$) interactions. In contrast, the S × PR interaction was not significant ($P = 0.499$).

Focussing on the N response, the S × NR interaction showed that the flax yield was affected by N rate at 15/18 sites (83%) while mean yields ranged from 968-3360 kg/ha. The non-responsive sites either had high residual NO_3-N (i.e. Melfort 2017) or yields were severely limited by other environmental factors (i.e. Brandon 2018 and Swift Current 2018); however, there were other sites where these conditions were also met but the N response was still significant. When N responsive sites were analyzed on their own, mean flax yields increased from 1669 kg/ha at 13 kg N/ha to 2313 kg/ha at the highest N rate, an increase of 39% (Table 9). The response was quadratic ($P < 0.001$) with no statistically significant further yield gains when the N rate was increased from 100 kg N/ha to 150 kg N/ha. When the three non-N responsive sites were analyzed on their own, once again the N response turned out to be significant ($P = 0.011$). However, the range was much smaller (1526-1690 kg N/ha) and the response was again quadratic ($P = 0.039$) with, on average, maximum yields achieved at a modest 50 kg N/ha. For individual sites, the magnitude of the observed responses to N fertilization ranged from as low as 8% at Melfort in 2017 to as high as 115% at Swift Current in 2016. At 50% of the site-years, the observed yield increases with N fell within the more typical range of 30-60% with weaker responses at 28% of the sites and stronger responses at 22% of the sites (Tables A-7 through A-14).

Since there was no S × PR interaction detected in the initial analyses ($P = 0.499$), the entire dataset was reanalyzed with site effects considered random to describe the response to P; however, the P response was highly significant regardless of how the data was analyzed ($P < 0.001$; Table 8). While significant, the flax yield response to P rate was modest relative to N rate with yields ranging from 1929 kg/ha in the control to 2064 kg/ha at the highest P fertilizer rate, an average increase of 7% (Table 9). Despite the modest yield response to P, it was more linear ($P < 0.001$) than quadratic ($P = 0.069$) with small yield increases occurring right up to the 60 kg P_2O_5/ha rate when averaged across all locations. As a matter of interest, the magnitude of the P response was largest in the small sub-set of sites identified as non-responsive to N (14% versus 6-7%). Notably, in these non-N responsive sites, the magnitude of response was larger for P (14%) than for N (11%).

Although there was no interaction between P rate and site-year for flax yield, the magnitude of the individual responses to P fertilizer ranged from nil to nearly 40% with half the sites included in the combined analyses showing responses between 5-10%. Responses at 28% of the sites were below 5% while the response was stronger than 10% at 22% of individual sites.

Although the only indication of an NR × PR interaction was detected in the initial combined analyses where site effects were considered fixed ($P = 0.050$), there was also evidence of this in the orthogonal contrasts. The results from these tests indicated that the responses to P only occurred when N fertilizer was also applied (Table 10). These results showed a linear yield increase with increasing to P rates when 50-150 kg N/ha was also applied ($P < 0.001$-0.017) but not at the lowest, 13 kg N/ha, rate ($P = 0.134$).

The observed effects of N rate on flax yield are generally consistent with previous research, although most of the cited previous studies did not evaluate rates this high. As referenced in the introduction, May et al. (2010) looked at rates as high as 200 kg N/ha and report that the maximum flax yield was achieved at 169 kg/ha (averaged across 15 site-years) with the strongest increases occurring between 10-90 kg N/ha. (May et al. 2010) and economic optimums generally below 110 kg/ha. With rates ranging from 0-90 kg N/ha, Grant et al. (2016) reported modest yield increases with N at all but one of five sites where residual N was high. Although the responses were mostly linear, the authors did not test for quadratic responses and it was not uncommon for yields to be similar at 60-90 kg N/ha. Although the placement differed (broadcast as opposed to side-band), Nuttall and Mahli (1991) reported maximum yields with greater than 120 kg N/ha when averaged over a three-year period at Melfort; however, there were diminishing returns associated with rates exceeding 100 kg N/ha. Grant et al. (1999) found that yields were optimized at 40-80 kg N/ha and added that that the observed responses could be explained ,to some extent by residual NO_3-N; however, the relationship was not particularly strong. Mahli et al. (2008) evaluated rates ranging from 0-120 kg N/ha at four Saskatchewan locations and found that, with some exceptions, yield increases going from 40 kg N/ha to 80 kg N/ha were small and frequently not significant. As with most crops, documented yield increases with P fertilization in flax have been less consistent but are not necessarily uncommon. On relatively low P soils (<15 ppm $NaHCO_3$ extractable P), Bailey and Grant (1989) reported average yield increases (over 10 site-years) of 121% when P was banded away from the seed at rates of 23-57 kg P_2O_5/ha and yields were maximized at approximately 34 kg P_2O_5/ha. While this response was much larger than anything observed in the current project, intensive tillage and negative impacts on arbuscular mycorrhizal fungi (AMF) may have contributed to the strong response to P fertilizer. In contrast, in comparatively high P soils (approximately 15-30 ppm), Grant et al. (1999) only observed a flax yield benefit to P fertilization at 1/9 site years. In addition to environmental conditions, it is possible that some of the observed poor responses to P fertilization might be attributed to the specific placement. In early growth chamber studies, which may or may not be applicable to field conditions, Sadler and Bailey (1981), found the P uptake and yield response was highest when P was banded 2 cm directly below the seed row followed by deep, side-placement (2 cm below and 1.5 cm to the side), and finally shallow side-placement (0.5 cm below and 1.5 cm to the side) where the rates required to maximize yields were 2-3 times higher those required with the deeper placement options.

Table 8. Overall tests of fixed effects for flax yield. The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. In subsequent analyses, site effects were considered random. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Flax Seed Yield			
	All Sites [Z] (n=18)	**All Sites (n=18) [Y]**	**N Responsive Sites (n=15)[Y]**	**Non-N Responsive Sites (n=3) [Y]**
Effect	---------- p-values ----------			
Site-Year (S)	<0.001	–	–	–
N Rate (NR)	<0.001	<0.001	<0.001	0.011
P Rate (PR)	<0.001	<0.001	<0.001	<0.001
NR × PR	0.050	0.134	0.427	0.208
S × NR	<0.001	–	–	–
S × PR	0.499	–	–	–
S × NR × PR	0.768	–	–	–

[Z] Site effects considered fixed for initial combined analyses

[Y] Site effects considered random for combined analyses of responsive versus non-responsive sub-sets

Table 9. Main effect means for flax seed yield when averaged across all sites (n=18), for sites where a significant N effect was detected (n=14), and for sites where there was no N effect (n=5). Main effect means within a column followed by the same letter do not significantly differ. Orthogonal contrast results to describe N responses are also presented.

Treatment/ Main Effect	All Sites (n=18) [Z]	All Sites (n=18) [Y]	N Responsive Sites (n=15) [Y]	Non-N Responsive Sites (n=3) [Y]
Nitrogen Rate	---------- kg/ha ----------			
13 kg N/ha	1682 c	1679 c	1669 c	1526 b
50 kg N/ha	2073 b	2073 b	2094 b	1638 a
100 kg N/ha	2249 a	2251 a	2288 a	1661 a
150 kg N/ha	2271 a	2271 a	2313 a	1690 a
S.E.M. (L.S.D.)	30.8 (41.8)	156.7 (43.7)	168.9 (44.5)	460.5 (102.8)
	---------- p-values ----------			
NR – linear	<0.001	<0.001	<0.001	0.009
NR - quadratic	<0.001	<0.001	<0.001	0.039
Phosphorus Rate	---------- kg/ha ----------			
0 kg P_2O_5/ha	1984 c	1929 c	2017 c	1500 b
20 kg P_2O_5/ha	2067 b	2006 b	2080 b	1667 a
40 kg P_2O_5/ha	2099 ab	2039 ab	2124 a	1645 a
60 kg P_2O_5/ha	2125 a	2064 a	2143 a	1704 a
S.E.M. (L.S.D.)	30.8 (41.8)	156.7 (43.7)	168.9 (44.4)	460.5 (102.8)
	---------- p-values ----------			
PR – linear	<0.001	<0.001	<0.001	<0.001
PR - quadratic	0.056	0.069	0.176	0.144

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

Table 10. Individual treatment means for the N rate by P rate (not statistically significant) interaction averaged across all sites (n=18) for flax seed yield. Means followed by the same letter do not significantly differ (L.S.D. = 89.0).

	Phosphorus Rate				**Orthogonal Contrasts**	
Nitrogen Rate	0 kg P_2O_5/ha	20 kg P_2O_5/ha	40 kg P_2O_5/ha	60 kg P_2O_5/ha	PR – linear	PR – quadratic
	---------- kg/ha ----------				------ p-values ------	
13 kg N/ha	1627 g	1697 g	1686 g	1707 g	0.103	0.438
50 kg N/ha	1993 f	2113 de	2063 ef	2122 de	0.017	0.329
100 kg N/ha	2129 de	2235 bc	2325 a	2317 ab	<0.001	0.068
150 kg N/ha	2188 cd	2219 c	2326 a	2352 a	<0.001	0.946
Orthogonal Contrasts	---------- p-values ----------				–	–
NR – linear	<0.001	<0.001	<0.001	<0.001	–	–
NR - quadratic	<0.001	<0.001	<0.001	<0.001	–	–

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

Treatment Effects on Flax Test Weight

The initial combined analyses for test weight indicated that this variable was affected by site-year (P < 0.001) and N rate (P < 0.001) with a significant S × NR interaction (P < 0.001; Table 11). Overall, mean test weights ranged from 271-352 kg/ha and the S × NR interaction indicated that the NR effect was significant at 7/17 site-years, or 41% of the time (Table A-7). When the seven N responsive sites were analyzed on their own, again only the NR effect was significant (P < 0.001). The effect was such that test weight increased with N rate from an average of 313 g/0.5 l at the lowest N rate to 319 g/0.5 l at 150 kg N/ha (Table 12). Although the means separations suggested that the effect on test weight diminished with increasing N rates, the orthogonal contrasts suggested that the response was linear (P < 0.001) but not quadratic at the desired probability level (P = 0.077). Like the other variables, separate analyses of the ten 'non-N responsive' sites found that the N response was, in fact, significant (P < 0.001); however, again, the magnitude of the response was much smaller. Amongst these sites, test weight values only ranged from 343 g/0.5 l at 13 kg N/ha to 345 g/0.5 l at 150 kg N/ha; however, both differences amongst individual N rates and the linear orthogonal contrast (P < 0.001) were significant. Again, there were no effects of P rate or interactions including this factor detected regardless of how the sites were grouped or which statistical test was used.

To receive the top grade, flax test weight must meet or exceed 305 g/0.5 l while for No. 2 flax the requirement is 290 g/0.5 l, and there is no minimum for No. 3 flax. There is little documentation of N and P fertility effects on flax test weight in the peer-reviewed literature. Averaged across oilseed crop types (canola, mustard, flax, and sunflower) and site-years, May et al. (2010) reported a significant increase in test weight with increasing N rate. Similar to the current study, the magnitude was small, only 1.2% across a similar range of N rates, and of little agronomic importance.

Table 11. Overall tests of fixed effects for flax test weight. The initial combined analyses with all sites was used to assess the overall average response, determine frequency of response, and identify individually responsive site-years. In subsequent analyses, site effects were considered random. Data were analysed using the Mixed procedure of SAS.

	Overall Tests of Fixed Effects for Flax Test Weight		
	All Sites [Z] (n=17)	**N Responsive Sites (n=7)[Y]**	**Non-N Responsive Sites (n=10) [Y]**
Effect	p-values		
Site-Year (S)	<0.001	–	–
N Rate (NR)	<0.001	<0.001	<0.001
P Rate (PR)	0.467	0.371	0.740
NR × PR	0.527	0.226	0.453
S × NR	<0.001	–	–
S × PR	0.999	–	–
S × NR × PR	0.277	–	–

[Z] Site effects considered fixed for initial combined analyses

[Y] Site effects considered random for combined analyses of responsive versus non-responsive sub-sets

Table 12. Main effect means for flax test weight when averaged across all sites (n=17), sites where a significant N effect was detected (n=7, and sites where there was no N effect (n=10). Main effect means within a column followed by the same letter do not significantly differ. Orthogonal contrast results to describe N responses are also presented.

Treatment/ Main Effect	All Sites (n=17) [Z]	N Responsive Sites (n=7) [Y]	Non-N Responsive Sites (n=10) [Y]
Nitrogen Rate		---------- g/0.5 L ----------	
13 kg N/ha	330.5 c	312.8 c	342.9 b
50 kg N/ha	331.8 b	315.2 b	343.4 b
100 kg N/ha	333.7 a	318.5 a	344.4 a
150 kg N/ha	334.1 a	319.4 a	344.5 a
S.E.M. (L.S.D.)	0.31 (0.76)	8.59 (1.73)	3.26 (0.50)
		---------- p-values ----------	
NR – linear	<0.001	<0.001	<0.001
NR - quadratic	0.022	0.077	0.108
Phosphorus Rate		---------- g/0.5 L ----------	
0 kg P_2O_5/ha	332.5 a	316.0 a	344.0 a
20 kg P_2O_5/ha	332.3 a	316.1 a	343.7 a
40 kg P_2O_5/ha	332.5 a	316.4 a	343.7 a
60 kg P_2O_5/ha	332.9 a	317.4 a	343.8
S.E.M. (L.S.D.)	0.31 (0.76)	8.59 (1.73)	3.26 (0.50)
		---------- p-values ----------	
PR – linear	0.225	0.107	0.481
PR - quadratic	0.305	0.470	0.393

[Z] The entire dataset was initially analyzed using Proc Mixed with site effects considered fixed

[Y] Sub-sets of responsive versus non-responsive sites analyzed using Proc Mixed with site considered random

10. **Conclusions and Recommendations:** Highlight significant conclusions based on the findings of this project, with emphasis on the project objectives specified above. Provide recommendations for the application and adoption of the project findings.

Flax emergence was variable from site to site indicating that establishment of this crop is sensitive to environment; however, side-banded N fertilizer also frequently affected emergence in a negative manner. This is not necessarily a cause for great concern but does indicate that flax growers should take care to ensure adequate separation between seed and fertilizer and also ensure that seeding rates are sufficient to allow for some seedling loss if side-banding high rates of urea or similar N fertilizer formulations. The response was linear; therefore, it was most severe at higher N rates but also occurred at modest rates (i.e. 50 kg N/ha), albeit to a lesser extent. Side-banded mono-ammonium phosphate did not affect emergence; however, past work has shown flax can be sensitive to seed-placed P fertilizer.

The project showed benefits to both nitrogen and phosphorus fertilization. The majority of locations had a relatively strong response to N with an average yield increase of 39% and maximum yields achieved at approximately 100 kg N/ha. At the less responsive sites, yields increased by only 11% with N fertilization and levelled off at 50 kg N/ha or even lower. The lack of response at these sites was attributed to either high residual soil NO_3-N or other major yield limiting factors; however, stronger responses did occasionally occur with high residual N or low yield potential. The response to P was smaller than for N but reasonably consistent with no interactions between site and P rate detected. Averaged across sites, the response was linear (i.e. yields continued to increase right up to the highest rate) but relatively shallow with an average yield increase of 7% at the 60 kg P_2O_5/ha rate. There was substantial variation in the magnitude of response with a 5-10% yield increase at 50% of the sites, less than 5% at 28% of the sites, and greater than 10% at 22% of the sites. Despite the linear response to P, more modest rates of 20-40 kg P_2O_5 will likely be enough to prevent significant yield loss and maintain soil fertility. Interactions between N and P were subtle at best with evidence that the response to P was weaker at the lowest N rate where N was essentially always limiting to yield.

Soil tests can be useful to determine whether a response to N and P is likely along with the magnitude of response that might be expected, but the relationship is not always strong. Soil tests are also useful for aiding growers in decisions as to whether they want to consider building, maintaining, or drawing down soil P over the long-term. While fall or early spring NO_3-N levels should be considered in anticipated total N requirements to a certain extent, growers should exercise some caution in doing so recognizing that soil NO_3-N is highly variable across the landscape and does not account for mineralization (which can also be both spatially and temporally variable). Soil test values alone did not consistently explain the observed responses to either N or P fertilizer. Although responses to higher rates of N and P fertilizer than are typically recommended or applied were occasionally observed, the gains associated with doing so were modest at best. When considered along with the overall site-to-site variability in yields that could not be attributed to fertility, it is unlikely that (at least for many growers) that fertilizer rates are the most important factor affecting commercial flax yields in western Canada.

Although flax maturity was frequently delayed with increasing N rate, the effect was relatively minor and not likely to be of much concern under normal conditions. Aside from substantial site-to-site variability, the only factor to have any impact on flax test weight was N fertilizer rate; however, a response occurred less than half the time and, when it did, it was too small to be of any practical importance.

11. **Is there a need to conduct follow up research?** Detail any further research, development and/or communication needs arising from this project.

The results from this project will continue to be communicated when opportunities arise and may come in the form of oral presentations, short written materials directed towards producers/industry personnel, and peer-reviewed publication. Without going into specifics, future research might take into consideration different fertilizer formulations or placement/timing options and assess whether responses to nutrient applications and nutrient uptake are affected by other management factors.

12. **Patents/ IP generated/ commercialized products:** List any products developed from this research.

As expected, no patents, intellectual property, or commercialized products arose from this research.

13. **List technology transfer activities:** Include presentations to conferences, producer groups or articles published in science journals or other magazines.

a. 15-02-2016 to 15-02-2017:

At Indian Head, this trial was toured to 15-20 Australian producers in cooperation with Seed Hawk Inc. (June 16, 2016) and 33 Richardson Pioneer agronomists (July 27, 2016) in addition to several informal site visits.

At Redvers, the trial was showcased at the Southeast Research Farm Summer Field Day on July 20th where approximately 70 guests were in attendance.

At Scott, the trial was highlighted as part of a flax agronomy presentation by Rachel Evans during the Western Applied Research Corporation (WARC) Field Day on July 13, 2016 to approximately 200 guests.

At Swift Current, the trial was visited during 5 separate small tours where the number of guests on any given date ranged from 4-18.

At Yorkton, the trial was highlighted during the ECRF Summer Field Day which was held on July 21, 2016 and attended by approximately 60 guests.

At Vegreville, the trial was featured at four tours during the 2016 season. These included the Organic Alberta Tour (July 27, 40 guests), Field Day of Alberta Innovates – Technology Futures (July 28, 100 guests), Agricultural Financial Services Corporation Tour (August 17, 20 people) and the Heilongjiang Academy of Science (China) Tour (August 26, 8 people).

During the winter months, the project was introduced as part of a flax agronomy presentation at the Saskatchewan Oilseed Producer Meetings at Weyburn (40 guests), Humbolt (60 guests), Prince Albert (30 guests), Rosetown (70 guests), and Swift Current (100 guests) on November 14-18, 2016. The presenters at these meetings were Chris Holzapfel, Jessica Pratchler and Stewart Brandt and, cumulatively, several hundred people were in attendance. Jan Slaski introduced the study in Alberta during his talk entitled 'Flax Facts' at the Farming Smarter Conference at Medicine Hat (December 6, 260 guests). The trial was also introduced during a flax agronomy session at Crop Sphere at Saskatoon (January 10, approximately 50 guests) by Rachel Evans (Flax Council of Canada).

b. 15-02-2017 to 15-02-2018:

At Indian Head in 2017, the project was shown to approximately 200 guests at the Indian Head Crop Management Field Day (July 18) with discussions on flax fertility led by Chris Holzapfel (IHARF) and Rachel Evans (Flax Council of Canada) and the project was also visited during several smaller industry tours at this location with approximately 100 guests in total.

At the Melfort Research Farm Field Day (July 26, 2017), Chris Holzapfel (IHARF) presented preliminary results on the project and toured the plots with approximately 80 guests.

At Swift Current, the trial was highlighted on the June 27, 2017 "Walk the Plots" segment on Golden West radio with Bryan Nybo (WCA) and on numerous smaller tours for WCA directors and local crop consultants.

At Redvers, the plots were shown to approximately 70 guests at the SERF Field Day (July 19, 2017). Discussions on flax fertility and agronomy were led by Matthew Bernard (SK Ministry of Agriculture) and Rachel Evans (Flax Council of Canada).

At Yorkton, the trial was shown during the ECRF Field Day (July 13, 2017) with a presentation by Mike Hall (Parkland College / ECRF). Mr. Hall also posted on online video showing preliminary results from the trial on the ECRF website. Online [Available}: http://www.ecrf.ca/?page=flaxresponsetonandp2016

At Vegreville, the site was toured during one major field day (July 20, 2017) field day with a presentation on flax fertility and agronomy by Jan Slaski (Innotech Alberta). The plots were also visited by Flax Council of Canada staff on June 16, 2017.

During the winter months, preliminary results from this project were presented to approximately 70 attendees by Jan Slaski (Innotech Alberta) at CropSphere 2018 in a presentation entitled "Factors affecting the agronomic performance of flax on the Prairies." Jessica Pratchler (NARF) and Jessica Weber (WARC) provided updates on this work and other pertinent flax research and developments at the Top Notch Farming meetings at Humboldt (February 14, 2018) and Davidson (February 15, 2018).

In the article 'Moderate Flax Response to Nitrogen' (Bruce Barker), an update on the results of this project was provided as part of an overview of western Canadian flax N research in the mid-March 2017 edition of Top Crop Manager West (page 20).

Finally, the full technical report from the 2015-16 field seasons has been available for download on the IHARF website. Online [Available]: http://iharf.ca/wp-content/uploads/2017/04/Flax-Response-to-a-Wide-Range-of-Nitrogen-Phosphorus-Fertilizer-Rates-in-Western-Canada-interim-report.pdf

c. 15-02-2018 to 15-02-2019:

At Indian Head, the site was visited during a tour hosted for the Saskatchewan Ministry of Agriculture Ag Awareness Unit (36 attendees; July 10, 2018) and numerous informal tours for agronomists and industry (including SFDC) representatives.

At Vegreville, Jan Slaski showed the plots and discussed the project at the Innotech Alberta Field Day in July and during a tour for Agriculture Financial Services Corporation (AFSC) Alberta staff.

In the article 'Optimal N and P Management for Flax', Donna Fleury provided an overview of the project and key findings from the first two years of field trials. The article appeared on page 32 of the February 2019 edition of Top Crop Manager West.

Key findings from the first two years of the project were presented by Chris Holzapfel to approximately 50 producers, agronomists, and industry personnel at the Crop Command Flying into Spring Agronomy Meeting at Southey, Saskatchewan (March 15, 2017). The final report will be made available online (www.iharf.ca) in the coming months and, as time permits, results will be further incorporated into fact sheets and updated N and P fertility recommendations for flax.

14. List any industry contributions or support received.

Various crop protection products were provided in-kind with the specific donations varying from year to year and location to location. Several of the participants in the project (i.e. IHARF, WCA, WARC, and NARF) have close working relationships and memorandums of understanding with Agriculture and Agri-Food Canada which should also be acknowledged.

15. Acknowledgements. Include actions taken to acknowledge support by the Ministry of Agriculture and the Canada-Saskatchewan Growing Forward 2 bilateral agreement (for projects approved during 2013-2017) or Canadian Agriculture Partnership (For projects approved beyond 2017).

This project was jointly funded through the Canada-Saskatchewan ADF program (administered by the Saskatchewan Ministry of Agriculture), Saskatchewan Flax Development Commission, and Western Grains Research Foundation. Plot signs have acknowledged this support during field tours, appropriate logos and acknowledgements have been utilized during oral presentations, and the funding agencies/programs have been acknowledged in written materials wherever possible. In addition, the contributions of all three funding partners have been acknowledged in IHARF's annual partners lists which are both available online (https://iharf.ca/our-partners/) and included on all IHARF promotional materials (i.e. field day and AGM brochures). Collaborating organizations take similar measures to acknowledge their many partners and program sponsors.

16. Appendices: Include any additional materials supporting the previous sections, e.g. detailed data tables, maps, graphs, specifications, literature cited.

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Table A-1. Selected agronomic information for flax nitrogen and phosphorus trials at conducted at eight western Canadian locations over a three-year period (2016-2018).

Location	Year	Previous Crop	Variety	Seeding Date	Row Spacing	Plant Counts	Harvest Date
Indian Head	2016	Wheat	Bethune	May-5	30 cm	May-30	Sep-16
	2017	Wheat	Bethune	May-11	30 cm	Jun-5	Sep-5
	2018	Wheat	Glas	May-9	30 cm	May-30	Aug-21
Melfort	2016	Canola	Bethune	May-17	30 cm	May-30	Nov-8
	2017	Wheat	Sorrel	May-19	30 cm	Jun-16	Sep-18
	2018	Wheat	Glas	May-22	30 cm	Jun-20	Oct-18
Scott	2016	Wheat	Glas	May-6	25 cm	Jun-3	Sep-14
	2017	Wheat	Glas	May-16	25 cm	Jun-13	Sep-18
	2018	Wheat	Glas	May-22	25 cm	Jun-13	Oct-8
Swift Current	2016	Wheat	Sorrel	Jun-2	23 cm	Jun-28	Oct-31
	2017	Wheat	Sorrel	May-17	23 cm	Jun-6	Aug-8
	2018	Wheat	Sorrel	May-7	23 cm	Jun-4	Aug-9
Redvers	2016	Barley	Bethune	May-9	25 cm	Jun-16	Oct-9
	2017	Barley	Bethune	May-10	25 cm	Jun-5	Sep-11
	2018	Field Pea	Glas	May-11	30 cm	Jun-6	Sep-28
Yorkton	2016	Wheat	Bravo	May-9	25 cm	Jun-16	Sep-13
	2017	Wheat	Prairie Thunder	May-10	25 cm	May-31	Sep-1
	2018	Wheat	Prairie Thunder	May-14	30 cm	May-28	Sep-26
Brandon	2016	Wheat	Bethune	May-9	20 cm	Jun-7	Aug-29
	2017	Wheat	Bethune	May-11	20 cm	Jun-28	Sep-13
	2018	Wheat	Bethune	May-22	20 cm	Jun-19	Sep-7
Vegreville	2016	Barley	Bethune	May-26	20 cm	Jun-23	Nov-10
	2017	Barley	Bethune	Jun-7	20 cm	Jun-28	Oct-6
	2018	Canola	Glas	May-28	20 cm	Jun-20	Oct-5

Table A-2. Mean monthly temperatures for the 2016-18 growing seasons along with the long-term (LT; 1981-2010) averages at eight western Canadian Locations.

Location	Year	May	June	July	August	Average
		°C				
Indian Head	2016	14.0	17.5	18.5	17.2	16.8
	2017	11.6	15.5	18.4	16.7	15.6
	2018	13.9	16.5	17.5	17.6	16.4
	LT	10.8	15.8	18.2	17.4	15.6
Melfort	2016	13.6	17.1	18.1	16.3	16.3
	2017	10.8	15.2	18.7	17.2	15.5
	2018	13.9	16.8	17.5	15.9	16.0
	LT	10.7	15.9	17.5	16.8	15.2
Scott	2016	12.4	15.8	17.8	16.1	15.5
	2017	11.5	15.1	18.3	16.6	15.4
	2018	13.6	16.1	17.4	16.2	15.8
	LT	10.8	15.3	17.1	16.5	14.9
Swift Current	2016	12.4	16.6	17.8	16.7	15.9
	2017	12.1	15.2	20.4	18.2	16.5
	2018	14.4	16.9	18.9	18.5	17.2
	LT	10.9	15.4	18.5	18.2	15.8
Redvers	2016	13.5	17.8	19.6	19.2	17.5
	2017	12.2	15.5	19.6	17.4	16.1
	2018	15.1	19.1	19.4	18.9	18.1
	LT	11.1	16.2	18.7	18.0	16.0
Yorkton	2016	13.5	17.2	18.5	17.0	16.6
	2017	11.1	15.5	19	17.4	15.8
	2018	13.9	17.6	18.3	18.1	17.0
	LT	10.4	15.5	17.9	17.1	15.2
Brandon	2016	13.1	17.2	18.9	17.5	16.7
	2017	11.4	16.3	19.3	17.5	16.1
	2018	14.1	18.6	18.9	17.8	17.4
	LT	11.4	16.6	19.2	18.2	16.4
Vegreville	2016	12.0	16.8	18.1	16.8	15.9
	2017	12.9	16.0	17.9	16.6	15.9
	2018	14.6	16.1	17.0	15.4	15.8
	LT	10.3	14.4	16.6	15.6	14.2

Table A-3. Monthly precipitation amounts for the 2016-18 growing seasons along with the long-term (LT; 1981-2010) averages at eight western Canadian Locations.

Location	Year	May	June	July	August	Average
		----------	----------	mm	----------	----------
Indian Head	2016	72.6	63.0	112.8	29.8	278
	2017	10.4	65.6	15.4	25.2	117
	2018	23.7	90.0	30.4	3.9	148
	LT [Z]	51.8	77.4	63.8	51.2	244
Melfort	2016	16.8	53.2	128.7	80.8	280
	2017	46.4	44.1	33.3	3.1	127
	2018	38.5	46.6	69.5	43.2	198
	LT	42.9	54.3	76.7	52.4	226
Scott	2016	64.8	20.8	88.1	98.2	272
	2017	69.0	34.3	22.4	53.0	179
	2018	29.6	58.0	48.2	85.8	194
	LT	36.3	61.8	72.1	45.7	216
Swift Current	2016	129.7	80.4	119.0	45.9	375
	2017	16.4	31.1	7.5	24.8	80
	2018	14.9	20.2	32.0	28.0	95
	LT	48.5	72.8	52.6	41.5	215
Redvers	2016	96.1	72.4	77.9	32.1	279
	2017	41.1	61.5	17.5	33.3	153
	2018	11.4	100.8	54.1	23.5	190
	LT	60.0	95.2	65.5	46.6	267
Yorkton	2016	74.9	62.8	141.7	59.1	339
	2017	12.5	53.9	59.1	32.5	158
	2018	0.8	120.1	53.8	21.1	196
	LT	51.3	80.1	78.2	62.2	272
Brandon	2016	67.1	67.4	60.6	43.1	238
	2017	15.9	61.1	31.3	30.1	138
	2018	36.7	36.5	43.3	26.9	143
	LT	56.5	79.6	68.2	65.5	270
Vegreville	2016	109.2	65.4	94.7	50.8	320
	2017	61.5	90.5	46.3	26.6	225
	2018	17.9	35.1	70.9	37.1	161
	LT	37.1	60.6	76.3	51.8	226

Table A-4. Nitrogen fertilizer rate effects on flax emergence for individual site-years. P-values greater than 0.05 indicate that the N rate effect was not significant for the corresponding site-year. Data were analysed using the Mixed procedure of SAS with site effects considered fixed.

	Plant Density	
Site-Year [Z]	**S × NR**	**Overall Mean**
	---------------- p-values ----------------	---------------- plants/m² ----------------
01_BR-2016	<0.001	487 c
02_BR-2017	<0.001	289 h
03_BR-2018	0.004	387 f
04_IH-2016	0.104	617 a
05_IH-2017	0.022	370 fg
06_IH-2018	0.461	434 e
07_ME-2016	–	–
08_ME-2017	0.012	303 h
09_ME-2018	–	–
10_RV-2016	0.648	346 g
11_RV-2017	0.015	506 c
12_RV-2018	0.224	369 fg
13_SC-2016	0.023	258 i
14_SC-2017	0.124	223 j
15_SC-2018	<0.001	369 fg
16_SW-2016	<0.001	234 j
17_SW-2017	<0.001	146 k
18_SW-2018	<0.001	262 i
19_VG-2016	–	–
19_VG-2017	–	–
19_VG-2018	–	–
22_YK-2016	<0.001	576 b
23_YK-2017	<0.001	461 d
24_YK-2018	<0.001	506 c
S.E.M.	–	9.1
Frequency of Response (%)	73.7%	

[Z] BR – Brandon, MB; IH – Indian Head, SK; ME – Melfort, SK; RV – Redvers, SK; SC – Scott, SK; SW – Swift Current, SK; VG – Vegreville, AB; YK – Yorkton, SK

Table A-5. Nitrogen fertilizer rate effects on flax maturity for individual site-years (n=17). P-values greater than 0.05 indicate that the N rate effect was not significant for the corresponding site-year. Data were analysed using the Mixed procedure of SAS with site effects considered fixed.

	Maturity	
Site-Year [Z]	**S × NR**	**Overall Mean**
	---------------- p-values ----------------	---------- days from seeding ----------
01_BR-2016	<0.001	100.8 e
02_BR-2017	<0.001	107.5 b
03_BR-2018	<0.001	88.2 k
04_IH-2016	<0.001	103.7 d
05_IH-2017	0.002	97.8 h
06_IH-2018	0.528	91.7 i
07_ME-2016	–	–
08_ME-2017	1.000	104.0 d
09_ME-2018	–	–
10_RV-2016	–	–
11_RV-2017	0.017	90.7 j
12_RV-2018	0.890	91.8 i
13_SC-2016	<0.001	107.6 b
14_SC-2017	0.363	99.3 f
15_SC-2018	<0.001	106.0 c
16_SW-2016	<0.001	111.1 a
17_SW-2017	–	–
18_SW-2018	<0.001	85.8 l
19_VG-2016	–	–
19_VG-2017	–	–
19_VG-2018	–	–
22_YK-2016	<0.001	105.6 c
23_YK-2017	<0.001	98.5 g
24_YK-2018	<0.001	99.2 f
S.E.M. (L.S.D.)	–	0.19 (0.50)
Frequency of Response (%)	70.6%	

Table A-6. Nitrogen fertilizer rate effects on flax seed yield for individual site-years (n=18). P-values greater than 0.05 indicate that the N rate effect was not significant for the corresponding site-year. Data were analysed using the Mixed procedure of SAS with site effects considered fixed.

	Seed Yield	
Site-Year [Z]	**S × NR**	**Overall Mean**
	---------------- p-values ----------------	------------------ kg/ha ------------------
01_BR-2016	<0.001	2104 g
02_BR-2017	<0.001	1652 hi
03_BR-2018	0.523	1229 j
04_IH-2016	<0.001	2739 c
05_IH-2017	<0.001	1612 i
06_IH-2018	<0.001	1720 h
07_ME-2016	–	–
08_ME-2017	0.149	2555 d
09_ME-2018	–	–
10_RV-2016	<0.001	1658 hi
11_RV-2017	<0.001	2380 e
12_RV-2018	<0.001	2442 e
13_SC-2016	<0.001	3360 a
14_SC-2017	<0.001	3081 b
15_SC-2018	<0.001	1574 i
16_SW-2016	<0.001	968 l
17_SW-2017	–	–
18_SW-2018	0.376	1102 k
19_VG-2016	–	–
19_VG-2017	–	–
19_VG-2018	–	–
22_YK-2016	<0.001	2253 f
23_YK-2017	<0.001	2171 fg
24_YK-2018	<0.001	2637 d
S.E.M. (L.S.D.)	–	41.8 (88.2)
Frequency of Response (%)	83.3%	

Table A-7. Nitrogen fertilizer rate effects on flax test weight for individual site-years (n=17). P-values greater than 0.05 indicate that the N rate effect was not significant for the corresponding site-year. Data were analysed using the Mixed procedure of SAS with site effects considered fixed.

	Test Weight	
Site-Year Z	**S × NR**	**Overall Mean**
	---------------- p-values ----------------	------------------ kg/ha ------------------
01_BR-2016	0.755	341.7 e
02_BR-2017	0.038	324.4 h
03_BR-2018	0.141	319.0 i
04_IH-2016	0.027	329.4 g
05_IH-2017	<0.001	311.2 j
06_IH-2018	<0.001	309.1 k
07_ME-2016	–	–
08_ME-2017	0.867	351.5 l b
09_ME-2018	–	–
10_RV-2016	<0.001	271.4 l
11_RV-2017	0.092	353.3 a
12_RV-2018	0.458	–
13_SC-2016	0.565	348.3 c
14_SC-2017	0.438	347.8 c
15_SC-2018	0.195	338.3 f
16_SW-2016	<0.001	329.6 g
17_SW-2017	–	–
18_SW-2018	0.887	340.9 e
19_VG-2016	–	–
19_VG-2017	–	–
19_VG-2018	–	–
22_YK-2016	0.975	343.9 d
23_YK-2017	0.013	340.3 e
24_YK-2018	0.492	353.2 a
S.E.M. (L.S.D.)	–	0.58 (1.57)
Frequency of Response (%)	41.2%	

Table A-8. Main effect means for flax seed yields for individual years at Brandon, Manitoba. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ ($P < 0.05$).

Treatment/ Main Effect	BR-2016	BR-2017	BR-2018
Nitrogen Rate		kg/ha	
13 kg N/ha	1712 c	1221 b	1153 a
50 kg N/ha	2097 b	1762 a	1222 a
100 kg N/ha	2275 a	1841 a	1272 a
150 kg N/ha	2332 a	1783 a	1269 a
Phosphorus Rate		kg/ha	
0 kg P_2O_5/ha	2076 ab	1544 b	978 b
20 kg P_2O_5/ha	2090 ab	1654 ab	1317 a
40 kg P_2O_5/ha	2034 b	1642 ab	1254 a
60 kg P_2O_5/ha	2216 a	1768 a	1366 a

Table A-9. Main effect means for flax seed yields for individual years at Indian Head, Saskatchewan. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ ($P < 0.05$).

Treatment/ Main Effect	IH-2016	IH-2017	IH-2018
Nitrogen Rate		kg/ha	
13 kg N/ha	1933 c	1279 b	1288 c
50 kg N/ha	2790 b	1685 a	1731 b
100 kg N/ha	3069 a	1734 a	1907 a
150 kg N/ha	3162 a	1748 a	1955 a
Phosphorus Rate		kg/ha	
0 kg P_2O_5/ha	2685 a	1617 a	1651 a
20 kg P_2O_5/ha	2702 a	1616 a	1680 a
40 kg P_2O_5/ha	2752 a	1615 a	1744 a
60 kg P_2O_5/ha	2816 a	1599 a	1805 a

Table A-10. Main effect means for flax seed yields for individual years at Melfort, Saskatoon. Data from 2016 and 2018 were excluded from the analyses. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).

Treatment/ Main Effect	ME-2016	ME-2017	ME-2018
Nitrogen Rate		kg/ha	
13 kg N/ha	–	2420 b	–
50 kg N/ha	–	2587 a	–
100 kg N/ha	–	2604 a	–
150 kg N/ha	–	2611 a	–
Phosphorus Rate		kg/ha	
0 kg P_2O_5/ha	–	2453 a	–
20 kg P_2O_5/ha	–	2622 a	–
40 kg P_2O_5/ha	–	2555 a	–
60 kg P_2O_5/ha	–	2592 a	–

Table A-11. Main effect means for flax seed yields for individual years at Redvers, Saskatchewan. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).

Treatment/ Main Effect	RV-2016	RV-2017	RV-2018
Nitrogen Rate		kg/ha	
13 kg N/ha	1170 c	1796 c	2002 c
50 kg N/ha	1580 b	2346 b	2455 b
100 kg N/ha	1979 a	2658 a	2526 b
150 kg N/ha	1905 a	2718 a	2786 a
Phosphorus Rate		kg/ha	
0 kg P_2O_5/ha	1620 a	2153 c	2468 a
20 kg P_2O_5/ha	1681 a	2311 b	2374 a
40 kg P_2O_5/ha	1680 a	2565 a	2464 a
60 kg P_2O_5/ha	1653 a	2490 a	2462 a

Table A-12. Main effect means for flax seed yields for individual years at Scott, Saskatchewan. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ ($P < 0.05$).

Treatment/ Main Effect	SC-2016	SC-2017	SC-2018
Nitrogen Rate		kg/ha	
13 kg N/ha	3129 b	2346 c	1292 b
50 kg N/ha	3361 a	3036 b	1577 a
100 kg N/ha	3528 a	3479 a	1695 a
150 kg N/ha	3424 a	3466 a	1733 a
Phosphorus Rate		kg/ha	
0 kg P_2O_5/ha	3321 a	2931 b	1521 b
20 kg P_2O_5/ha	3326 a	3092 ab	1587 ab
40 kg P_2O_5/ha	3370 a	3146 a	1583 ab
60 kg P_2O_5/ha	3425 a	3158 a	1607 a

Table A-13. Main effect means for flax seed yields for individual years at Swift Current, Saskatchewan. Data from 2017 were excluded from the analyses. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ ($P < 0.05$).

Treatment/ Main Effect	SW-2016	SW-2017	SW-2018
Nitrogen Rate		kg/ha	
13 kg N/ha	586 c	–	1015 a
50 kg N/ha	923 b	–	1105 a
100 kg N/ha	1262 a	–	1170 a
150 kg N/ha	1099 a	–	1119 a
Phosphorus Rate		kg/ha	
0 kg P_2O_5/ha	862 a	–	1070 a
20 kg P_2O_5/ha	1036 a	–	1075 a
40 kg P_2O_5/ha	994 a	–	1116 a
60 kg P_2O_5/ha	979 a	–	1147 a

Table A-14. Main effect means for flax seed yields for individual years at Yorkton, Saskatchewan. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).

Treatment/ Main Effect	YK-2016	YK-2017	YK-2018
Nitrogen Rate	---------- kg/ha	----------	----------
13 kg N/ha	1678 d	1834 b	2424 b
50 kg N/ha	2166 c	2233 a	2656 a
100 kg N/ha	2436 b	2376 a	2680 a
150 kg N/ha	2732 a	2243 a	2786 a
Phosphorus Rate	---------- kg/ha	----------	----------
0 kg P_2O_5/ha	2181 a	2044 b	2532 b
20 kg P_2O_5/ha	2265 a	2199 ab	2587 b
40 kg P_2O_5/ha	2301 a	2209 ab	2759 a
60 kg P_2O_5/ha	2265 a	2234 a	2669 ab

Table A-15. Overall tests of fixed effects for flax emergence, maturity, yield, and test weight at Vegreville, Alberta. Year effects were considered fixed and p-values greater than 0.05 indicate that an effect was not significant for the corresponding responding response variable.

Effect	Plant Density	Days to Maturity	Seed Yield	Test Weight
	----------	---------- p-values	----------	----------
Year (Y)	<0.001	<0.001	<0.001	<0.001
N Rate (NR)	0.731	<0.001	0.006	0.002
P Rate (PR)	0.955	0.011	0.231	0.952
NR × PR	0.945	0.998	0.301	0.005
Y × NR	0.525	<0.001	0.861	<0.001
Y × PR	0.821	0.082	0.239	0.998
Y × NR × PR	0.115	0.663	0.793	0.001

Table A-16. Main effect means for flax emergence at Vegreville, Alberta. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).

Treatment/ Main Effect	VG-2016	VG-2017	VG-2018	Average
Nitrogen Rate		plants/m^2		
13 kg N/ha	479 a	837 a	532 a	616 a
50 kg N/ha	499 a	803 a	516 a	606 a
100 kg N/ha	462 a	817 a	529 a	603 a
150 kg N/ha	482 a	812 a	554 a	616 a
S.E.M. (L.S.D)		19.4 (93.1)		13.0 (28.4)
Orthogonal Contrasts		p-values		
NR – linear	0.741	0.458	0.251	0.989
NR - quadratic	0.872	0.440	0.269	0.259
Phosphorus Rate		plants/m^2		
0 kg P_2O_5/ha	484 a	818 a	533 a	612 a
20 kg P_2O_5/ha	476 a	804 a	547 a	609 a
40 kg P_2O_5/ha	476 a	831 a	535 a	614 a
60 kg P_2O_5/ha	486 a	816 a	516 a	606 a
S.E.M. (L.S.D)		19.4 (93.1)		13.0 (28.4)
Orthogonal Contrasts		p-values		
PR – linear	0.928	0.777	0.394	0.798
PR – quadratic	0.632	0.974	0.329	0.802

Table A-17. Main effect means for flax maturity at Vegreville, Alberta. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).

Treatment/ Main Effect	VG-2016	VG-2017	VG-2018	Average
Nitrogen Rate	-- days from seeding --			
13 kg N/ha	105.9 d	103.5 b	96.3 b	101.9 d
50 kg N/ha	106.8 c	104.0 a	96.2 b	102.3 c
100 kg N/ha	107.5 b	104.1 a	96.6 b	102.7 b
150 kg N/ha	108.0 a	104.4 a	97.7 a	103.4 a
S.E.M. (L.S.D)		0.19 (0.49)		0.12 (0.30)
Orthogonal Contrasts	--- p-values ---			
NR – linear	<0.001	0.001	<0.001	<0.001
NR - quadratic	0.208	0.525	0.0003	0.616
Phosphorus Rate	-- plants/m^2 --			
0 kg P_2O_5/ha	106.7 b	103.9 a	96.4 b	102.3 b
20 kg P_2O_5/ha	107.2 ab	103.9 a	96.6 b	102.6 ab
40 kg P_2O_5/ha	107.0 ab	104.1 a	96.5 b	102.5 b
60 kg P_2O_5/ha	107.3 a	103.9 a	97.3 a	102.8 a
S.E.M. (L.S.D)		0.19 (0.49)		0.12 (0.30)
Orthogonal Contrasts	--- p-values ---			
PR – linear	0.101	0.812	<0.001	0.003
PR – quadratic	0.682	0.595	0.112	0.746

Table A-18. Main effect means for flax seed yield at Vegreville, Alberta. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).

Treatment/ Main Effect	VG-2016	VG-2017	VG-2018	Average
Nitrogen Rate		kg/ha		
13 kg N/ha	1560 b	1572 a	729 b	1287 b
50 kg N/ha	1598 ab	1553 a	763 ab	1305 b
100 kg N/ha	1779 a	1640 a	813 ab	1410 a
150 kg N/ha	1732 ab	1665 a	911 a	1436 a
S.E.M. (L.S.D)		82.0 (164.7)		64.4 (100.2)
Orthogonal Contrasts		p-values		
NR – linear	0.025	0.157	0.024	<0.001
NR - quadratic	0.376	0.828	0.671	0.834
Phosphorus Rate		kg/ha		
0 kg P_2O_5/ha	1712 a	1768 a	772 a	1417 a
20 kg P_2O_5/ha	1662 a	1531 b	834 a	1343 a
40 kg P_2O_5/ha	1671 a	1609 ab	809 a	1363 a
60 kg P_2O_5/ha	1624 a	1521 b	801 a	1315 a
S.E.M. (L.S.D)		82.0 (164.7)		64.4 (100.2)
Orthogonal Contrasts		p-values		
PR – linear	0.404	0.013	0.816	0.077
PR – quadratic	0.977	0.211	0.550	0.706

Table A-19. Main effect means for flax test weight at Vegreville, Alberta. Results presented are from the initial analyses with site effects considered fixed. Main effect means within columns followed by the same letter do not significantly differ (*P* < 0.05).				
Treatment/ Main Effect	**VG-2016**	**VG-2017**	**VG-2018**	**Average**
Nitrogen Rate		g/0.5 l		
13 kg N/ha	278.2 b	341.7 a	333.5 a	317.8 a
50 kg N/ha	259.5 a	342.0 a	333.6 a	311.7 b
100 kg N/ha	251.2 a	342.9 a	334.2 a	309.8 b
150 kg N/ha	251.9 a	343.3 a	334.3 a	309.4 b
S.E.M. (L.S.D)		7.54 (2.90)		1.68 (4.62)
Orthogonal Contrasts		p-values		
NR – linear	<0.001	0.647	0.814	0.001
NR - quadratic	<0.001	0.997	0.988	0.036
Phosphorus Rate		g/0.5 l		
0 kg P_2O_5/ha	261.3 a	342.9 a	334.6 a	312.9 a
20 kg P_2O_5/ha	258.6 a	341.7 a	334.7 a	311.7 a
40 kg P_2O_5/ha	260.7 a	342.8 a	333.4 a	312.3 a
60 kg P_2O_5/ha	260.2 a	342.4 a	333.0 a	311.8 a
S.E.M. (L.S.D)		7.54 (2.90)		1.68 (4.62)
Orthogonal Contrasts		p-values		
PR – linear	0.917	0.970	0.640	0.723
PR – quadratic	0.723	0.881	0.921	0.809