2016 Interim Report

for the

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

a. **Title:** Flax (*Linum usitatissimum)* response to a wide range of nitrogen and phosphorus fertilizer rates in western Canada

b. **ADF File Number:** 20150105

c. **Reporting Period:** February 15, 2016 to February 15, 2017

2. Special Project Activities Undertaken During this Reporting Period

a. **Methodology:** Following consultations with the Saskatchewan Flax Development Commission (SFDC), an extensive field study to revaluate flax (*Linum usitatissimum*) fertility requirements was conceived and designed. The project aimed to investigate flax response to nitrogen (N) and phosphorus (P) fertilizer applications in a broad range of western Canadian environments and using modern varieties and seeding equipment. The three-year project was initiated in 2016 with eight locations including 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) across locations, all plots were direct-seeded into cereal stubble and all fertilizer was side-banded during seeding. The fertilizer products utilized in the treatments were commercial grade urea (46-0-0) and monoammonium phosphate (11-52-0).

Pertinent agronomic information for each location is provided in Table 1 of the Appendices. Specific management practices and decisions were largely left to individual site managers and tailored to regional practices, available equipment and pests encountered; however, all controllable factors other than fertility were intended to be non-limiting. Seeding dates ranged from May 5 to June 2, weeds were kept at acceptably low using registered pre-emergent and in-crop herbicides. Foliar fungicide applications were utilized to keep minimize disease (pasmo) and insecticides were utilized only if considered necessary. Pre-harvest herbicides or desiccants were applied at or after the latest maturing plots reached physiological maturity if considered necessary or desirable. All plots were combined when fit to do so and, wherever possible, outside rows were excluded to minimize edge effects. Due to heavy and widespread snowfall in early October and extremely wet conditions through that entire month, harvest was delayed late into the fall at some locations, specifically 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 the affected sites. Data from some locations, Melfort in particular, will likely have to be discarded prior to the final, combined analyses.

A composite soil sample (targeted depth intervals of 0-15 cm and 15-60 cm) was collected from each trial location in the early spring and submitted to AgVise laboratories for various analyses. There was some variation in the specific sampling depths and analyses requested amongst sites (Table 2). 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 average plants/m^2 for each plot. These counts were targeted for approximately 3-4 weeks after planting but the specific dates varied amongst individual sites (Table 1). 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. 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 and, with the exception of Vegreville, were determined from the cleaned samples using standard methods (Canadian Grain Commission 2016). At Vegreville, test weights were determined using the HarvestMaster weighing system (uncleaned samples) and therefore this data will not likely be utilized in any final combined analyses. Mean monthly temperatures and precipitation amounts were estimated for each location from the nearest Environment Canada or private weather station.

For the purposes of interim reporting and initial data evaluation, all available response data were statistically analysed on an individual site basis using the Mixed procedure of SAS. The effects of N and P fertilizer rates and the N × P interaction were fixed while replicate effects were considered random. Orthogonal contrasts were used to determine whether the observed responses to N and P were insignificant, linear or quadratic in shape. At this stage, the orthogonal contrasts were completed for both the main effects and for each N × P combination individually, regardless of whether the interactions were significant. All treatment effects and differences between means are considered significant at $P \leq 0.05$.

b. Research Accomplishments:

In 2016, growing season temperatures and especially precipitation amounts were above-average at all 8 sites, therefore the flax was never limited by lack of moisture in any cases. Mean monthly temperatures and precipitation amounts are presented in Tables 3 and 4 of the Appendices, respectively. Excess moisture resulted in high variability and yield loss in one replicate at Vegreville therefore it was discarded prior to statistical analyses. While severe summer storms were noted at both Indian Head and Brandon, no significant crop damaged was observed at either location. At Melfort, Swift Current and Vegreville the plots were not yet harvested when wet, snowy weather hit in early October and, consequently, the flax at these locations was exposed to prolonged severe weather resulting in lodging, reduced yields, lower test weights and increased variability. Data from these locations is presented but, particularly in the case of Melfort, should be interpreted cautiously and, at least in some cases, will be excluded from any future combined analyses.

Soil test results for all locations are presented Table 4 of the Appendices. Overall, there was a wide range of soil properties with textures ranging from coarse loam to heavy clay (data not presented), pH values ranging from 4.9-7.9, soil organic matter levels ranging from 2.7-9.5%. Total NO_3-N ranged from 25-104 kg N/ha and extractable P (Olsen) ranged from 4-24 ppm. Generally, soil test P levels of less than 10-15 ppm are considered low in P.

Objectives: *To evaluate the response of flax to varying rates and combinations of nitrogen (N) and phosphorus (P) fertilizer, including higher N and P rates than are typically recommended or utilized.*

Focussing on plant density (Tables 5-8), treatment effects were detected at 4/7 viable locations and, in all cases where effects were detected, N fertilizer rate affected emergence but P rate did not and there were N × P interactions. The locations where N rate affected emergence were Scott, Swift Current, Yorkton and Brandon (Table 5) and in all cases plant densities declined with increasing N rate. At the affected locations, the observed decline in actual plant densities was 25-37% (with rate increased from 13-150 kg N/ha) with the strongest impacts at Swift Current, the site with the coarsest textured soil and (normally) driest conditions. At Swift Current, effects on emergence were already observed at 50 kg N/ha while at Brandon and Yorkton losses occurred at 100 kg N/ha and, at Scott, reductions only occurred at the 150 kg N/ha rate. Mean plant populations (across all treatments) ranged from 259-576 plants/m^2 at individual locations with the lowest populations at Swift Current and the highest at Yorkton. Except for Scott and Swift Current, plant populations always averaged well above the minimum recommended threshold of 300 plants/m^2; however, establishment was extremely variable at Melfort and considered limiting in several plots (Tables 6 and 7).

Maturity was measured at all locations except Melfort and Redvers and, in all cases, was affected by N but never P (Table 9). The N × P interaction for maturity was significant at Indian Head; however, the variation in P effects as a function of N rate was inconsistent. Averaged across treatments, flax reached physiological maturity in 101-111 days depending on the location. When the N rate was increased from 13-150 kg N/ha maturity was delayed by approximately 2-5 days depending on location (Table 10). While delays in maturity are not desirable, they tend to coincide with higher yield and the observed differences would not pose any agronomic challenges under most conditions.

Overall F-tests for N and P effects on seed yield are presented in Table 13 of the Appendices. Nitrogen rate affected seed yield at all locations except Melfort (P < 0.001-0.037). Again, the data from Melfort will be excluded from final analyses due to variable establishment and serious weather related difficulties during harvest. The P response was only significant at Indian Head (P < 0.001); however, the N × P interaction was significant at both Indian Head and Scott (P < 0.001-0.014). Excluding all sites where yields were affected by severe fall weather and harvest delays (Melfort, Swift Current and Vegreville), average yields ranged from 2100-3360 kg/ha (33-53 bu/ac). Yields at Swift Current and Vegreville were lower at 968-1637 kg/ha (15-26 bu/ac) but treatment effects were still evident, despite the relatively high variability (Table 14). Maximum yields were achieved at 100-150 kg N/ha and the magnitude of the response ranged from 13-115% over the lowest rate of 13 kg/ha. In absolute terms, the maximum increase observed at individual locations (excluding Melfort) was 218-1229 kg/ha (3.5-19.5 bu/ac). In most cases, the responses to N were quadratic indicating diminishing benefits at the higher rates. Focussing on yield response to P fertilizer, benefits were only detected at Indian Head and, to lesser extent, Scott. At Indian Head, the response was reasonably strong with significant yield increases observed right up to the highest rate; however, the magnitude of the increase was modest compared to N with an increase of only 131 kg/ha (2.1 bu/ac) compared to 1225 kg/ha (19.5 bu/ac) with N fertilizer. At Scott, while the overall F-test for P was not significant, a subtle linear yield increase with increasing P rates was detected (P = 0.038); however, the yield difference between the control and 60 kg P_2O_5/ha rate was only 104 kg/ha (1.7 bu/ac). The interaction at Indian Head (Table 15) was due the response to P only being significant when N fertilizer was applied indicating that N was the more limiting nutrient and P did not become a limiting factor until N fertilizer was applied. At Scott, the interaction was due to P responses occurring at 13 and 100 kg N/ha but not at 50 or 150 kg N/ha; however, the overall trends were generally similar at all N rates (Table 15).

Overall F-test results for N and P effects on test weight are provided in Table 17 and showed that test weight was affected by N rates at 5/7 sites including Indian Head, Scott, Swift Current, Redvers and Vegreville (P < 0.017). Phosphorus rate only affected test weight at Indian Head. Again, the results from Vegreville were determined from uncleaned samples and will be removed from any subsequent combined analyses. Test weights from Redvers and Melfort were also both unusually low and variable, presumably due to the severe weather conditions and/or difficulties cleaning the samples (Table 18). Averaged across all treatments, test weights ranged from 260-348 g/0.5 l (35-54 lb/W bu). In the cases where N rate impacted test weight the effects were variable from site-to-site. At Indian Head, Scott and Redvers, test weight increased by 0.6-5.8% with N fertilization while at Swift Current and Vegreville the effect was negative (reduced by 1-10% with N). At Indian Head, where the yield response to P was also significant, test weight increased linearly (P = 0.007) from 329 g/0.5 l at in the control to 332 g/0.5 l). At Scott, while the F-test for N rate was not significant (P = 0.162) a slight but significant linear decline in test weight with P rate was detected (P = 0.028). Upon closer inspection of the (non-significant) interactions the effect was inconsistent across N rates and due a linear decline in test weight with P at 50 kg N/ha (P = 0.020; Table 20); however, with no significant N × P interaction in the F-test (P = 0.158), this was likely little more than experimental error.

c. Discussion: Overall, preliminary results showed reasonably consistent and strong responses to N fertilizer but P responses were smaller and much less frequent. At 4/7 sites, side-banded N fertilizer reduced plant populations by 25-37% with the greatest reductions at Swift Current, the site with the coarsest textured soil and lowest organic matter. This reaffirms that, in certain soils or when seed/fertilizer separation is inadequate, flax is quite susceptible to injury from high rates of N; however, higher rates of P appear to be less of a concern. Care should be taken to ensure adequate seed/fertilizer separation and/or seeding rates should be sufficient to allow for higher mortality. Maturity was affected by N rate but not P rate at 5/6 locations where it was measured. At the affected sites, maturity was delayed by 2-5 days (depending on location) with N fertilizer. The overall average number of days from planting to maturity ranged from 101-111 days. While maturity in flax can be an important consideration since flax requires a relatively long growing season, the observed delays coincided with higher yields and were, in themselves, unlikely to result in agronomic challenges. Focussing on yield, the N response was significant at all seven of the locations where data can be considered reliable. Despite the wide range in actual yields, the response to N was generally strong and clearly quadratic at 5/7 sites with maximum yields occurring at 106-128 kg N/ha (Figure 1). At Yorkton, the response was more linear than quadratic but when plotted using a polynomial equation maximum yields were estimated at a rate 192 kg N/ha. At Vegreville, the response was linear but weak with an increase of only 1.5 kg seed yield per 1 kg N/ha fertilizer, or 42 kg N/ha per 63 kg/ha (1 bu/ac) seed yield. As for phosphorus, responses were much less frequent and the overall F-test was only significant at Indian Head. At Scott, while the F-test was not significant, a small but significant linear increase was detected. Despite being linear, the yield increase with P rate was modest at 1.8 kg yield/kg P_2O_5 at Scott and 2.2 kg yield/kg P_2O_5 at Indian Head. A significant N × P interaction at Indian Head was due to the lack of response to P fertilizer at 13 kg N/ha rate but yield increases at all other N levels. While the N × P interaction was also significant at Scott, it was less consistent and appeared to be due to the P response being significant at 13 kg N/ha and 100 kg N/ha but not at 50 kg N/ha or 150 kg N/ha. It is difficult to explain this interaction biologically. While the yield responses to P were infrequent and relatively weak, this is not uncommon in many soils. Flax is a considered to be a good scavenger of soil nutrients and is also dependant on relationships with arbuscular mycorrhizal (AM) fungi for maximum nutrient uptake. The site where the strongest P response occurred (Indian Head) was both high yielding and low in residual P, thus conditions were optimal for a potential P deficiency. Nitrogen rate effects on flax test weight were significant at 4/6 (usable) sites but somewhat inconsistent with higher test weight with N at three locations and a reduction at one. At Swift Current, the location where the negative response occurred, results may have been affected by the facts that the crop was seeded relatively late and harvest was delayed by wet snowy weather.

All factors considered, our results were consistent with previous western Canadian research, albeit with responses to slightly higher rates of N than many previous studies have reported. That said, many studies (i.e. Nuttall and Malhi 1991, Lafond 1992, Grant et al. 1999 and Vera et al. 2014) did not utilize rates exceeding 100 kg N/ha. Of several that did (i.e. Malhi et al. 2007, Lafond et al. 2008 and May et al. 2010), only May et al. (2010) showed a response to N rates higher than 100 kg N/ha. In this case, maximum yields were observed at 169 kg N/ha; however, the maximum economic rate only exceeded 110 kg N/ha when grain prices were high and N fertilizer prices were low. The negative impacts of side-banded urea on emergence have also been previously documented with flax. For example, Grant et al. (2016) saw lower plant densities with N fertilizer 50% of time with the greatest effects with side-banded urea; however, the authors noted that reductions were unlikely to be of economic importance unless base populations were already marginal.

Regarding phosphorus, our results are, again, consistent with previous research. In early trials with low P soils, Bailey and Grant (1989) showed strong yield responses to P provided that the fertilizer was banded either below and to the side or directly below the seed-row. With in-furrow placement, they observed significant crop injury which offset any potential yield benefits. Under high residual P conditions in Manitoba, Grant et al. (1999) only saw a yield response to applied P at 1/9 site-years, presumably due to dry conditions early on in the season at that location. Lafond et al. (2003) only detected a P yield response at 3/12 site-years and observed that soil test P levels were not good predictors of whether a yield response to fertilizer was likely (residual P ranged from 24-51 kg/ha at responsive sites). Grant et al. (2009) detected a small but significant flax response to applied phosphorus at 1/6 site-years and also looked at residual P effects (from previous year applications of 0, 25 or 50 kg P_2O_5/ha) but did not detect any benefits to higher rates of P from the previous year. That said, Bailey et al. (1977) showed that flax does in fact benefit from high residual P over longer periods of time so strategies that ensure long-term soil fertility are important. For this reason, with flax and any other crop, annual P fertilizer applications are generally recommended regardless of the expected yield response.

d. Interim Conclusions:

Overall, our results to date have shown consistent, and in some cases strong yield responses to relatively high rates of N fertilizer (i.e. > 100 kg N/ha) while responses to P fertilizer were much less frequent and, when they did occur, smaller. All factors considered, the results are largely consistent with previous research and bear in mind that the optimum economic N rate will often be slightly lower than that where maximum yield is achieved. The lack of a P yield response at many sites does not suggest that P fertilizer should not be applied to flax, but rather that current P fertilization practices are not likely major limiting factors to flax yield in western Canada. The lack of response to P fertilization at many sites may be explained by contributions of residual inorganic P and organic P mineralization, in addition to the strong AM fungi relationships that flax can develop to assist with P uptake. The significant reductions in plant density frequently detected with high rates of side-banded N suggest that care must be taken to ensure adequate seed/fertilizer separation during planting and/or that seeding rates must be sufficient to account for some loss. The extent of seedling loss at the affected sites ranged from 25-37%; however, high rates of P fertilizer did not affect emergence in any cases. Nitrogen fertilizer delayed maturity by 2-5 days but this delay coincided with higher yields and, in itself, was unlikely to result in any agronomic challenges. Phosphorus rate did not affect maturity. Where they occurred, N fertilizer effects on test weight were inconsistent and relatively small with environmental conditions having a much greater impact on test weight than fertility. These conclusions should all be considered preliminary and interpreted cautiously as 2016 was only the first of a three-year study.

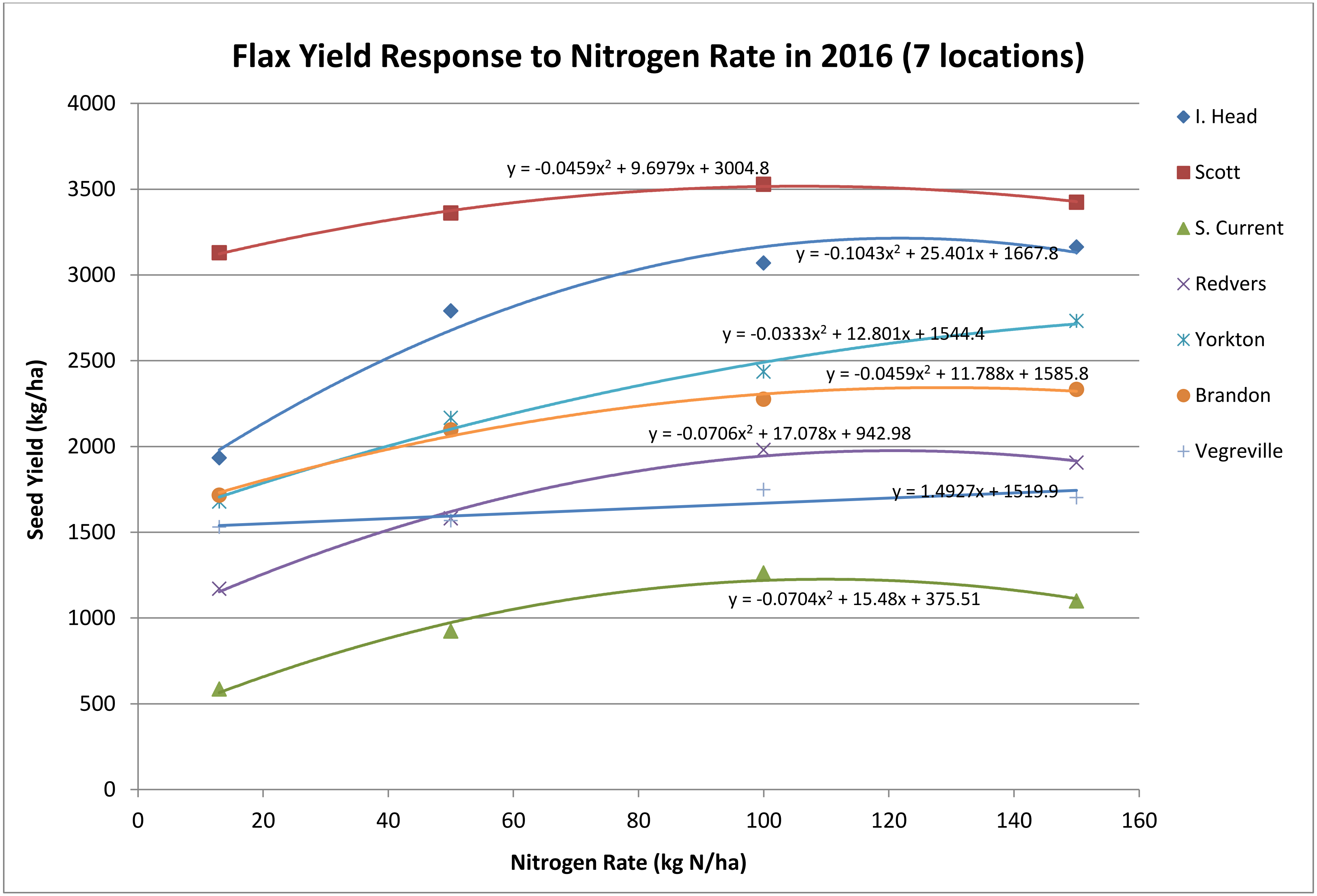

Figure 1. Flax seed yield response to nitrogen (N) fertilizer rate at seven locations in western Canada (2016).

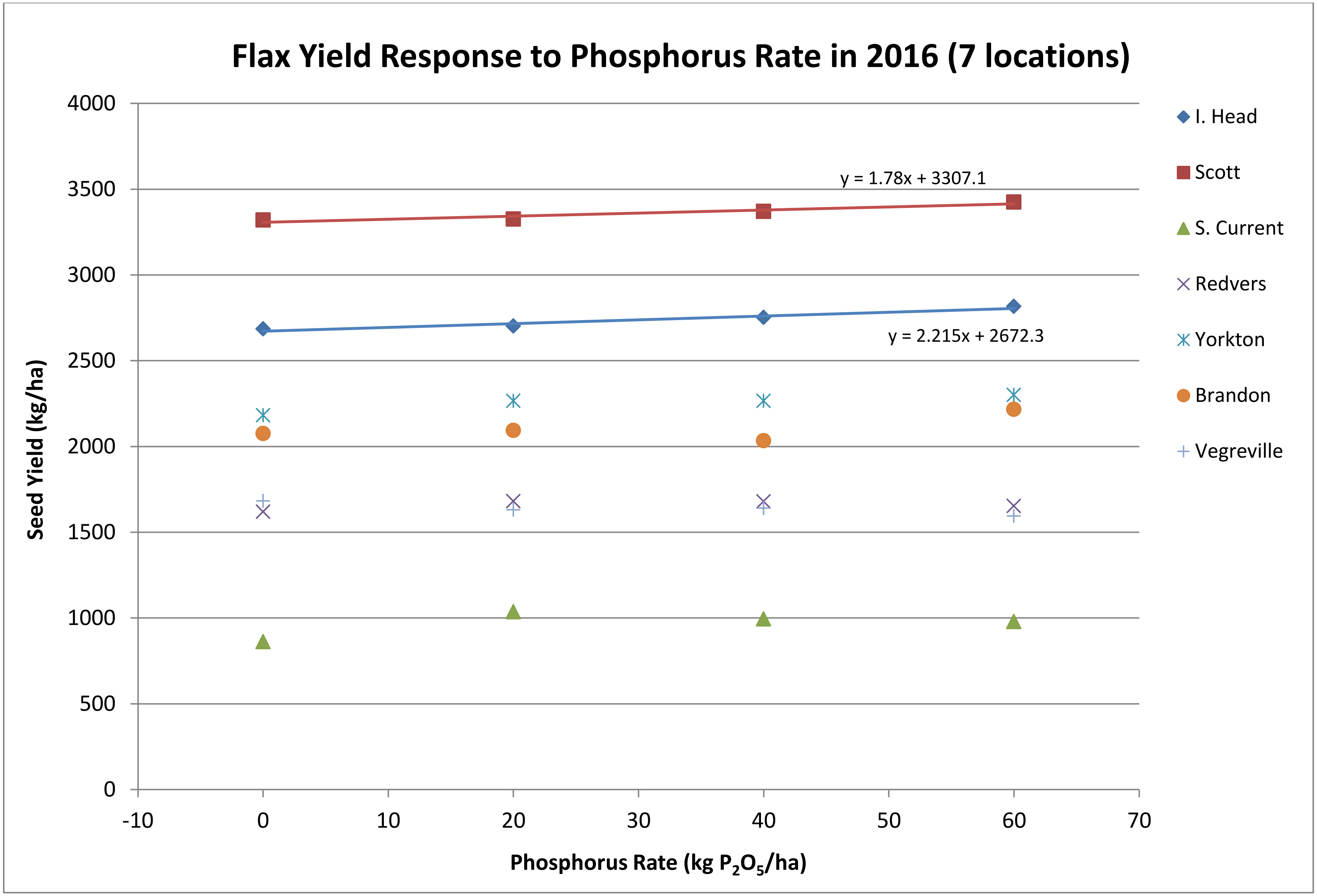

Figure 2. Flax seed yield response to phosphorus (P_2O_5) fertilizer rate at seven locations in western Canada (2016).

3. Technology Transfer Activities in Relation to the Project

a. 15-02-2015 to 15-02-2018:

At Indian Head, this trial was not featured at the Indian Head Crop Management Field Day for logistic reasons; however, it was shown during two other tours to 15-20 Australian producers (Seed Hawk Inc. June 16, 2016) and 33 agronomists (Richardson Pioneer 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, while this trial was not shown during the Crop Diagnostic School or WCA Annual Field Day, it was shown during 5 separate smaller 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 the total number of people who attended these meetings is not known. 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).

4. Changes Expected to Industry Contributions, In-Kind Support, Collaborations, Etc.

a. 15-02-2015 to 15-02-2018:

No changes to industry contributions or in-kind support occurred and none are expected going into the second year of the study. With regard to collaboration, the original site proposed at Roblin (Parkland Crop Diversification Foundation) was dropped due to staffing issues and replaced with a site at Brandon under the supervision of Ramona Mohr (Agriculture and Agri-Food Canada). This revision is not expected to have any impacts on budget or the deliverables of the project.

5. Appendices

a. Acknowledgements

Financial support for this project was provided Saskatchewan Ministry of Agriculture and the Canada-Saskatchewan Growing Forward 2 bi-lateral agreement, the Saskatchewan Flax Development Commission, and the Western Grains Research Foundation. Initial project input was provided by the SaskFlax Board of Directors and scientific guidance and oversight is being provided in-kind by Dr. Jeff Schoneau of the University of Saskatchewan's Department of Soil Science. The field trials were carried out by the staff and using the facilities, land and equipment of the Indian Head Agricultural Research Foundation, Northeast Agricultural Research Foundation, Western Applied Research Corporation, Southeast Applied Research Farm, East Central Research Foundation, Wheatland Conservation Area Inc., InnoTech Alberta, and Agriculture and Agri-Food Canada. The many contributions of the technical and professional staff at each location is greatly appreciated.

b. Resources / Literature Cited

Bailey, L. D. and C. A. Grant. 1989. Fertilizer phosphorus placement studies on calcareous and non-calcareous soils: growth, P-uptake and yield of flax. Commun. in Soil Sci. Plant Anal. **20:** 635-654.

Bailey, L. D., Spratt, E. D., Read, D. W. L., Warder, F. G., and W. S. Ferguson. 1977. Residual effects of phosphorus fertilizer. II. For wheat and flax grown on chernozemic soils in Manitoba. Can. J. Soil Sci. **57:** 263-270.

Canadian Grain Commission. 2016. Determining test weight. Chapter 1 – Official Grain Grading Guide. Online [Available]: https://www.grainscanada.gc.ca/oggg-gocg/01/oggg-gocg-1-eng.htm (10-02-2017).

Grant, C. A., Dribnenki, J. C. P., and L. D. Bailey. 1999. A comparison of the yield response of solin (cv. Linola 947) and flax (cvs. McGregor and Vimy) to application of nitrogen, phosphorus, and Provide (*Penicillium bilaji*). Can. J. Plant Sci. **79:** 527-533.

Grant, C. A., Monreal, M. A., Irvine, R. B., Mohr, R. M., McLaren, D. L., and M. Khakbazan. 2009. Crop response to current and previous seasons of phosphorus as affected by crop sequence and tillage. Can. J. Plant Sci. **89:** 49-66.

Grant et al. 2016. Nitrogen source and placement effects on stand density, pasmo severity, seed yield, and quality of no-till flax. Can. J. Plant Sci. **96:** 34-47.

Lafond, G. P. 1992. The effects of nitrogen, row spacing and seeding rate on the yield of flax under a zero-till production system. Can. J. Plant Sci. **73:** 375-382.

Lafond, G. P, Grant, C. A., Johnston, A. M., McAndrew, D., and W. E. May. 2003. Management of nitrogen and phosphorus fertilizer in no-till flax. Can. J. Plant Sci. **83:** 681-688.

Lafond, G. P., Irvine, B. I., Johnston, A. M., May, W. E., McAndrew, D. W., Shirtliffe, S. J., and F. C. Stevenson. 2008. Impact of agronomic factors on seed yield formation and quality in flax. Can. J. Plant Sci. **88:** 485-500.

Malhi, S. S., Lemke, R., Mooleki, S. P., Schoenau, J. J., Brandt, S., Lafond, G., Wang, H., Hultgreen, G. E., and W. E. May. 2007. Fertilizer N management and P placement effects on yield, seed protein content and N uptake of flax under varied conditions in Saskatchewan. Can. J. Plant Sci. **88:** 11-33.

May, W. E., Brandt, S. A., Gan, Y., Kutcher, H. R., Holzapfel, C. B., and G. P. Lafond. 2010. Adaptation of oilseed crops across Saskatchewan. Can. J. Plant Sci. **90:** 667-677.

Nuttall, W. F. and S. S. Malhi. 1991. The effect of time and rate of N application on the yield and N uptake of wheat, barley, flax and four cultivars of rapeseed. Can. J. Plant Sci. **71:** 227-238.

Vera, C. L., Irvine, R. B., Duguid, S. D., Rashid, K. Y., Clarke, F. R., and J. J. Slaski. 2014. Pasmo disease and lodging in flax as affected by pyraclostrobin fungicide, N fertility and year. Can. J. Plant Sci. **94:** 119-126.

Table 1. Selected agronomic information for the flax N and P rate study at 8 locations in western Canada (2016).

	Location (2016)							
Factor / Field Operation	Indian Head	Melfort	Scott	Swift Current	Redvers	Yorkton	Brandon	Vegreville
Previous Crop	Wheat	Canola	Wheat	Durum	Barley	Wheat	Wheat	Barley
Variety	CDC Bethune	CDC Bethune	CDC Glas	CDC Sorrel	CDC Bethune	AAC Bravo	CDC Bethune	CDC Bethune
Pre-emergent Herbicide	May-7 to May-15	May-19	May-1	May-30	May-10	May-4	May-7	May-2
Seeding Date	May-5	May-17	May-6	Jun-2	May-9	May-15	May-9	May-26
Seeding Rate	53 kg/ha	182 kg/ha [Z]	32 kg/ha	63 kg/ha	45 kg/ha	67 kg/ha	55 kg/ha	40 kg/ha
Row spacing	30 cm	30 cm	25 cm	23 cm	25 cm	25 cm	20 cm	20 cm
Emergence Counts	May-30	Jun-23	Jun-3	Jun-28	Jun-20	Jun-16	June 7	Jun-23
In-crop Herbicide	Jun-7 to Jun-18	Jun-21 to Jun-28	Jun-14	Jun-24	Jun-13	Jun-16	Jun-14	Jun-10 to Jun-24
Fungicide	Jul-3	Jul-12	Jul-5	n/a	Jul-21	Jul-16	Jul-5	Aug-4
Insecticide	n/a	n/a	Jun-23[Y]	n/a	n/a	n/a	n/a	n/a
Pre-harvest herbicide	Aug-25	n/a	Sep-1	Sep-26	n/a	Aug-30	n/a	n/a
Harvest date	Sep-16	Nov-8	Sep-14	Oct-31	Oct-9	Sep-13	Aug-29	Nov-10

[Z] Error during seeding (wrong calibration curve) [Y] Oversprayed for logistic reasons, no insect pests observed on the flax

Table 2. Soil test results for flax N and P rate study at 8 locations in western Canada (2016-2018).

		Soil Test Parameter						
Location	Year	pH (0-15 cm)	SOM	CEC	NO_3-N (0-60 cm)	Olsen-P (0-15 cm)	K (0-15 cm)	S (0-60 cm)
			%	Meq	kg/ha	ppm	ppm	kg/ha
Indian Head	2016	7.6	4.0	43.7	25	10	566	7
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Melfort	2016	7.1	9.5	–	55[Z]	22	483	99[Z]
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Scott	2016	4.9	4.1	9.5	37	24	263	25
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Swift Current	2016	7.4	2.7	–	46	7	350	> 227
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Redvers	2016	7.7	–	–	104[Y]	4	162	–
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Yorkton	2016	7.8	5.7	35.3	36	6	280	419
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Brandon	2016	7.9	5.1	26	37	6	202	16
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–
Vegreville	2016	7.5	8.2	35.7	26	11	202	> 227
	2017	–	–	–	–	–	–	–
	2018	–	–	–	–	–	–	–

[Z] 0-30 cm sample depth [Y] 0-46 cm sample depth

Table 3. Mean monthly temperatures for the 2016 growing season relative to the long-term averages (1981-2010) at 8 locations in western Canada.

Location	Year	Mean Monthly Temperature				
		May	**June**	**July**	**August**	**Average**
		ºC				
Indian Head	2016	14.0	17.5	18.5	17.2	16.8
	LT	10.8	15.8	18.2	17.4	15.6
Melfort	2016	13.6	17.1	18.1	16.3	16.3
	LT	10.7	15.9	17.5	16.8	15.2
Scott	2016	12.4	15.8	17.8	16.1	15.5
	LT	10.8	15.3	17.1	16.5	14.9
Swift Current	2016	12.4	16.6	17.8	16.7	15.9
	LT	10.9	15.4	18.5	18.2	15.8
Redvers	2016	13.5	17.8	19.6	19.2	17.5
	LT	11.1	16.2	18.7	18.0	16.0
Yorkton	2016	13.5	17.2	18.5	17.0	16.6
	LT	10.4	15.5	17.9	17.1	15.2
Brandon	2016	13.1	17.2	18.9	17.5	16.7
	LT	11.4	16.6	19.2	18.2	16.4
Vegreville	2016	12.0	16.8	18.1	16.8	15.9
	LT	10.3	14.4	16.6	15.6	14.2

[z] LT- Long-Term average (1981-2010)

Table 4. Monthly precipitation amounts for the 2016 growing season relative to the long-term averages (1981-2010) at 8 locations in western Canada.

Location	Year	Total Monthly Precipitation				
		May	**June**	**July**	**August**	**Average**
		ºC				
Indian Head	2016	72.6	63	112.8	29.8	278
	LT [Z]	51.8	77.4	63.8	51.2	244
Melfort	2016	16.8	53.2	128.7	80.8	280
	LT	42.9	54.3	76.7	52.4	226
Scott	2016	64.8	20.8	88.1	98.2	272
	LT	36.3	61.8	72.1	45.7	216
Swift Current	2016	129.7	80.4	119.0	45.9	375
	LT	48.5	72.8	52.6	41.5	215
Redvers	2016	83.0	133.0	69.0	6.0	291
	LT	60.0	95.2	65.5	46.6	267
Yorkton	2016	74.9	62.8	141.7	59.1	338.5
	LT	51.3	80.1	78.2	62.2	272
Brandon	2016	67.1	67.4	60.6	43.1	238
	LT	56.5	79.6	68.2	65.5	270
Vegreville	2016	109.2	65.4	94.7	50.8	320
	LT	37.1	60.6	76.3	51.8	226

[Z] LT- Long-Term average (1981-2010)

Years analyzed individually

Table 5. Side-banded nitrogen and phosphorus fertilizer effects on flax plant density at multiple locations in 2016.

	Plant density							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville** [X]
Effect	---------- p-values [Z] ----------							
N Rate (N)	0.192	0.970	< **0.001**	< **0.001**	0.649	< **0.001**	< **0.001**	0.292
P_2O_5 Rate (P)	0.429	0.509	0.798	0.456	0.744	0.895	0.044	0.915
N × P	0.247	0.993	0.179	0.583	0.101	0.494	0.273	0.270
AICC [Y]	577.8	723.5	514.8	524.1	569.9	627.9	564.2	353.5

[Z] p-values ≤ 0.05 indicate that a treatment effect was significant and not due to random variability

[Y] Measure of overall model fit, smaller is better

[X] Only three replicates, rep 1 discarded due to excess moisture, poor establishment and low, variable yields

Table 6. Least squares means for main effects of N and P fertilizer rates on flax plant density at multiple locations in 2016.

Main effect	Plant Density							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
N Rate	---------- plants m^{-2} ----------							
13 kg/ha	638 a	528 a	289 a	299 a	365 a	671 a	547 a	473 a
50 kg/ha	599 a	494 a	269 a	246 b	338 a	628 ab	534 a	493 a
100 kg/ha	639 a	548 a	260 a	203 c	346 a	548 b	476 c	457 a
150 kg/ha	592 a	501 a	216 b	189 c	337 a	458 c	391 c	477 a
S.E.M.	19.3	88.1	10.0	11.0	17.9	32.0	16.8	21.0
L.S.D.	55.0	251.0	28.5	31.5	49.1	90.5	47.8	37.9
P_2O_5 Rate								
0 kg/ha	613 a	415 a	265 a	233 a	352 a	593 a	470 b	478 a
20 kg/ha	632 a	510 a	252 a	246 a	330 a	558 a	482 ab	470 a
40 kg/ha	631 a	546 a	260 a	221 a	352 a	575 a	467 b	470 a
60 kg/ha	592 a	600 a	256 a	236 a	353 a	578 a	529 a	481 a
S.E.M.	19.3	88.1	10.0	11.0	17.9	32.0	16.8	21.0
L.S.D.	55.0	251.0	28.5	31.5	49.1	90.5	47.8	37.9
Contrast	---------- p-values [Y] ----------							
N – linear	0.279	0.950	< **0.001**	< **0.001**	0.359	< **0.001**	< **0.001**	0.631
N – quadratic	0.741	0.907	0.302	**0.030**	0.608	0.669	0.095	0.816
P – linear	0.465	0.140	0.686	0.731	0.764	0.832	**0.036**	0.896
P – quadratic	0.142	0.817	0.651	0.945	0.504	0.558	0.147	0.487

Table 7. Least squares means for N by P fertilizer rate interactions on flax plant density at multiple locations in 2016.

Main effect	Plant Density							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
N × P Rate	plants m^{-2}							
13N – 0P	657 ab	331 a	305 a	321 a	412 a	719 a	521 b-e	494 a
13N – 20P	661 ab	509 a	258 abc	303 a	352 a	712 a	565 abc	514 a
13N – 40P	612 b	618 a	302 a	282 abc	339 a	573 a-e	532 bcd	413 a
13N – 60P	623 b	656 a	289 a	291 ab	357 a	679 ab	570 ab	471 a
50N – 0P	638 ab	308 a	268 ab	231 b-e	267 a	633 ab	474 c-g	505 a
50N – 20P	597 b	532 a	271 ab	233 b-e	338 a	637 a-d	525 b-e	463 a
50N – 40P	609 b	526 a	272 ab	259 a-d	397 a	575 a-d	508 b-f	497 a
50N – 60P	553 b	609 a	264 ab	261 a-d	351 a	666 abc	629 a	508 a
100N – 0P	593 b	502 a	283 a	201 de	358 a	551 a-f	465 d-g	443 a
100N – 20P	629 ab	544 a	274 a	224 cde	299 a	495 c-f	459 d-g	445 a
100N – 40P	734 a	587 a	217 bc	173 e	386 a	624 a-d	500 b-f	470 a
100N – 60P	598 b	557 a	267 ab	213 de	339 a	524 b-f	482 b-f	468 a
150N – 0P	565 b	518 a	204 c	180 e	370 a	524 def	420 fgh	471 a
150N – 20P	641 ab	454 a	203 c	226 cde	331 a	470 f	379 gh	459 a
150N – 40P	568 b	452 a	251 abc	171 e	285 a	528 b-f	330 h	500 a
150N – 60P	595 b	579 a	204 c	178 e	363 a	442 ef	434 efg	477 a
S.E.M.	38.6	176.3	20.0	22.1	34.8	63.7	33.5	31.0
L.S.D.	110.0	502.1	57.1	62.9	98.15	181.0	95.5	75.9

Table 8. Orthogonal contrast results for N by P fertilizer rate interactions on flax plant density at multiple locations in 2016.

Main effect	**Plant Density**							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
Contrast	----------	----------	----------	p-values [Y]	----------	----------	----------	----------
N (0P) – lin	0.069	0.334	**0.002**	< **0.001**	0.980	**0.006**	**0.045**	0.266
N (0P) – quad	0.993	0.997	0.309	0.085	**0.046**	0.840	0.923	0.601
N (20P) – lin	0.942	0.835	0.065	**0.026**	0.539	< **0.001**	< **0.001**	0.153
N (20P) – quad	0.367	0.752	**0.046**	0.097	0.446	0.970	0.746	0.194
N (40P) – lin	0.911	0.587	**0.030**	< **0.001**	0.212	0.736	< **0.001**	0.070
N (40P) – quad	**0.023**	0.890	0.067	0.396	**0.029**	0.417	**0.048**	0.339
N (60P) – lin	0.886	0.731	**0.007**	< **0.001**	0.954	**0.004**	< **0.001**	0.803
N (60P) – quad	0.445	0.822	0.380	0.864	0.647	0.778	0.255	0.680
P (13N) – lin	0.391	0.176	0.973	0.272	0.254	0.369	0.457	0.159
P (13N) – quad	0.937	0.692	0.394	0.531	0.255	0.382	0.920	0.487
P (50N) – lin	0.170	0.262	0.899	0.238	**0.050**	0.903	**0.004**	0.725
P (50N) – quad	0.841	0.690	0.795	0.999	0.097	0.497	0.298	0.318
P (100N) – lin	0.497	0.792	0.244	0.869	0.848	0.870	0.541	0.397
P (100N) – quad	0.031	0.839	0.146	0.712	0.854	0.732	0.870	0.938
P (150N) – lin	0.919	0.818	0.601	0.545	0.659	0.848	0.974	0.624
P (150N) – quad	0.524	0.592	0.250	0.391	0.095	0.966	**0.036**	0.816

Table 9. Side-banded nitrogen and phosphorus fertilizer effects on flax maturity at multiple locations in 2016.

	Days to Maturity							
	Indian Head	**Melfort** [X]	**Scott**	**S. Current**	**Redvers** [X]	**Yorkton**	**Brandon**	**Vegreville**
Effect	---------- p-values [Z] ----------							
N Rate (N)	**< 0.001**	–	0.113	**< 0.001**	–	**< 0.001**	**< 0.001**	**< 0.001**
P_2O_5 Rate (P)	0.212	–	0.681	0.283	–	0.862	0.695	0.296
N × P	**0.029**	–	0.895	0.806	–	0.302	0.961	0.924
AICC [Y]	111.7	–	265.0	212.5	–	149.8	149.0	100.2

[Z] p-values ≤ 0.05 indicate that a treatment effect was significant and not due to random variability
[Y] Measure of overall model fit, smaller is better
[X] Data not collected

Table 10. Least squares means for main effects of N and P fertilizer rates on flax maturity at multiple locations in 2016.

Main effect	**Days to Maturity**							
	Indian Head	**Melfort** [X]	**Scott**	**S. Current**	**Redvers** [X]	**Yorkton**	**Brandon**	**Vegreville**
N Rate	------------------------------- days -------------------------------							
13 kg/ha	102.0 d	–	106.8 b	108.6 b	–	105.1 bc	99.4 b	105.8 c
50 kg/ha	103.5 c	–	106.9 b	108.8 b	–	104.7 c	99.8 b	106.8 b
100 kg/ha	104.1 b	–	107.8 ab	113.0 a	–	105.5 b	101.9 a	107.4 ab
150 kg/ha	105.2 a	–	108.9 a	114.1 a	–	107.0 a	102.0 a	108.0 a
S.E.M.	0.16	–	1.23	0.47	–	0.22	0.24	0.26
L.S.D.	0.41	–	1.92	1.17	–	0.62	0.60	0.67
P_2O_5 Rate								
0 kg/ha	103.9 a	–	108.3 a	110.6 a	–	105.7 a	100.9 a	106.7 a
20 kg/ha	103.7 a	–	107.4 a	111.0 a	–	105.5 a	100.9 a	107.2 a
40 kg/ha	103.5 a	–	107.5 a	111.1 a	–	105.7 a	100.8 a	106.9 a
60 kg/ha	103.7 a	–	107.3 a	111.8 a	–	105.5 a	100.6 a	107.3 a
S.E.M.	0.16	–	1.23	0.47	–	0.22	0.24	0.26
L.S.D.	0.41	–	1.92	1.17	–	0.62	0.60	0.67
Contrast	------------------------------- p-values [Y] -------------------------------							
NR – linear	**< 0.001**	–	**0.019**	**< 0.001**	–	**< 0.001**	**< 0.001**	**< 0.001**
NR – quadratic	0.084	–	0.533	0.916	–	**< 0.001**	0.085	0.277
PR – linear	0.252	–	0.316	0.067	–	0.701	0.473	0.159
PR – quadratic	0.090	–	0.613	0.705	–	1.000	0.661	0.722

[X] Data not collected

Table 11. Least squares means for N by P fertilizer rate interactions on flax maturity at multiple locations in 2016.

Main effect	Days to Maturity							
	Indian Head	**Melfort [X]**	**Scott**	**S. Current**	**Redvers [X]**	**Yorkton**	**Brandon**	**Vegreville**
N × P Rate	---------- days ----------							
13N – 0P	102.0 f	–	107.8 ab	107.5 c	–	105.3 de	99.8 b	105.3 e
13N – 20P	101.9 f	–	107.8 ab	108.5 bc	–	104.5 ef	99.8 b	106.3 b-e
13N – 40P	102.1 f	–	106.5 ab	109.0 bc	–	105.5 cde	99.0 b	105.7 de
13N – 60P	102.1 f	–	105.3 b	109.3 bc	–	105.0 def	99.0 b	106.0 cde
50N – 0P	103.4 de	–	107.3 ab	108.8 bc	–	105.0 def	99.8 b	106.3 b-e
50N – 20P	103.3 de	–	107.3 ab	109.0 bc	–	104.0 f	99.8 b	107.0 a-d
50N – 40P	103.0 e	–	107.0 ab	107.5 c	–	105.1 def	99.8 b	106.3 b-e
50N – 60P	104.3 bc	–	106.3 b	110.0 b	–	104.8 def	100.0 b	107.3 abc
100N – 0P	104.5 bc	–	108.0 ab	112.8 a	–	105.1 def	102.0 a	107.0 a-d
100N – 20P	104.0 cd	–	106.5 ab	112.5 a	–	105.9 bcd	102.0 a	107.3 abc
100N – 40P	103.8 cde	–	107.8 ab	113.3 a	–	105.5 cde	101.5 a	107.7 ab
100N – 60P	104.0 cd	–	108.8 ab	113.5 a	–	105.4 cde	102.0 a	107.7 ab
150N – 0P	105.8 a	–	110.3 a	113.5 a	–	107.3 a	102.0 a	108.0 a
150N – 20P	105.5 a	–	108.0 ab	114.0 a	–	107.5 a	102.0 a	108.0 a
150N – 40P	105.0 ab	–	108.8 ab	114.5 a	–	106.5 abc	102.0 a	108.0 a
150N – 60P	104.5 bc	–	108.8 ab	114.3 a	–	106.8 ab	102.0 a	108.0 a
S.E.M.	0.30	–	1.70	0.85	–	0.44	0.44	0.48
L.S.D.	0.82	–	3.84	2.33	–	1.24	1.21	1.34

[X] Data not collected

Table 12. Orthogonal contrast results for N by P fertilizer rate interactions on flax maturity at multiple locations in 2016.

Main effect	**Days to Maturity**							
	Indian Head	**Melfort** [X]	**Scott**	**S. Current**	**Redvers** [X]	**Yorkton**	**Brandon**	**Vegreville**
Contrast	p-values [Y]							
N (0P) – lin	**< 0.001**	–	0.161	**< 0.001**	–	**0.002**	**< 0.001**	**< 0.001**
N (0P) – quad	0.455	–	0.355	0.407	–	**0.012**	0.593	0.832
N (20P) – lin	**< 0.001**	–	0.972	**< 0.001**	–	**<.0001**	**< 0.001**	**0.016**
N (20P) – quad	0.838	–	0.439	0.895	–	0.058	0.593	0.907
N (40P) – lin	**< 0.001**	–	0.217	**< 0.001**	–	0.073	**< 0.001**	**< 0.001**
N (40P) – quad	0.793	–	0.913	0.344	–	0.151	0.453	0.500
N (60P) – lin	**< 0.001**	–	0.038	**< 0.001**	–	**0.003**	**< 0.001**	**0.006**
N (60P) – quad	**0.007**	–	0.573	0.646	–	0.102	0.099	0.240
P (13N) – lin	0.631	–	0.154	0.124	–	0.898	0.121	0.525
P (13N) – quad	0.830	–	0.646	0.649	–	0.775	1.000	0.478
P (50N) – lin	0.073	–	0.593	0.542	–	0.848	0.695	0.270
P (50N) – quad	**0.022**	–	0.782	0.177	–	0.476	0.770	0.722
P (100N) – lin	0.183	–	0.565	0.417	–	0.848	0.794	0.270
P (100N) – quad	0.201	–	0.359	0.762	–	0.319	0.559	0.722
P (150N) – lin	**0.002**	–	0.538	0.457	–	0.205	1.000	1.000
P (150N) – quad	0.667	–	0.409	0.649	–	1.000	1.000	1.000

Table 13. Side-banded nitrogen and phosphorus fertilizer effects on flax seed yield at multiple locations in 2016.

	Seed Yield							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
Effect	p-values [Z]							
N Rate (N)	**< 0.001**	0.933	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**0.037**
P_2O_5 Rate (P)	**< 0.001**	0.542	0.185	0.325	0.915	0.645	0.224	0.768
N × P	**< 0.001**	0.915	**0.014**	0.609	0.811	0.681	0.183	0.253
AICC [Y]	600.7	718.4	651.1	704.8	703.6	705.4	685.8	450.3

[Z] p-values ≤ 0.05 indicate that a treatment effect was significant and not due to random variability
[Y] Measure of overall model fit, smaller is better

Table 14. Least squares means for main effects of N and P fertilizer rates on flax seed yield at multiple locations in 2016.

Main effect	**Seed Yield**							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
N Rate	---------- kg/ha ----------							
13 kg/ha	1933 d	923 a	3129 c	586 c	1170 c	1678 d	1716 a	1530 c
50 kg/ha	2790 c	926 a	3361 b	923 b	1580 b	2166 c	2097 ab	1568 bc
100 kg/ha	3069 b	986 a	3528 a	1262 a	1979 a	2436 b	2275 b	1748 a
150 kg/ha	3162 a	962 a	3424 ab	1099 ab	1905 a	2732 a	2332 c	1701 ab
S.E.M.	50.5	92.8	72..8	84.1	74.7	90.3	101.0	58.4
L.S.D.	63.2	226.2	106.7	195.0	196.0	194.6	180.8	168.6
P_2O_5 Rate								
0 kg/ha	2685 c	900 a	3321 a	862 a	1620 a	2181 a	2076 a	1682 a
20 kg/ha	2702 bc	889 a	3326 a	1036 a	1681 a	2265 a	2094 a	1631 a
40 kg/ha	2752 b	1033 a	3370 a	994 a	1680 a	2265 a	2034 a	1640 a
60 kg/ha	2816 a	976 a	3425 a	979 a	1653 a	2301 a	2216 a	1594 a
S.E.M.	50.5	92.8	72.8	84.1	74.7	90.3	101.0	58.4
L.S.D.	63.2	226.2	106.7	195.0	196.0	194.6	180.8	168.6
Contrast	---------- p-values [Y] ----------							
NR – linear	**< 0.001**	0.621	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**0.013**
NR – quadratic	**< 0.001**	0.818	**< 0.001**	**< 0.001**	**< 0.001**	0.054	**0.006**	0.309
PR – linear	**< 0.001**	0.302	**0.038**	0.321	0.756	0.348	0.212	0.338
PR – quadratic	0.298	0.774	0.511	0.173	0.528	0.385	0.206	0.974

Table 15. Least squares means for N by P fertilizer rate interactions on flax seed yield at multiple locations in 2016.

Main effect	Seed Yield							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
N × P Rate	kg/ha							
13N – 0P	2023 e	807 a	3004 de	482 d	1191 ef	1649 g	1829 d	1481 bcd
13N – 20P	1855 f	897 a	3070 bc	639 cd	1084 f	1852 fg	1789 de	1354 d
13N – 40P	1960 ef	885 a	3346 b	700 cd	1110 f	1643 g	1416 e	1753 ab
13N – 60P	1895 f	1105 a	3098 cd	525 d	1296 def	1566 g	1831 d	1532 a-d
50N – 0P	2659 d	855 a	3395 bc	694 cd	1529 cde	2114 ef	1924 cd	1704 abc
50N – 20P	2714 d	915 a	3452 b	1205 ab	1673 a-d	2071 ef	2180 bcd	1696 abc
50N – 40P	2697 d	1047 a	3224 cd	827 bcd	1586 bcd	2285 cde	2119 bcd	1478 bcd
50N – 60P	3090 bc	885 a	3374 bc	966 abc	1531 cde	2193 def	2163 bcd	1392 cd
100N – 0P	2974 c	940 a	3501 b	1246 a	1887 abc	2287 cde	2258 abc	1842 a
100N – 20P	3114 b	809 a	3409 bc	1150 ab	2029 a	2331 b-e	2273 abc	1712 abc
100N – 40P	3109 b	1154 a	3475 b	1319 a	1961 ab	2512 a-d	2316 ab	1662 a-d
100N – 60P	3080 bc	1039 a	3726 a	1333 a	2037 a	2614 abc	2252 bc	1776 ab
150N – 0P	3084 bc	998 a	3384 bc	1026 abc	1875 abc	2673 abc	2294 ab	1698 abc
150N – 20P	3126 ab	934 a	3372 bc	1152 ab	1935 ab	2804 a	2132 bcd	1763 ab
150N – 40P	3242 a	1043 a	3437 bc	1128 ab	2062 a	2763 a	2286 ab	1667 a-d
150N – 60P	3197 ab	874 a	3503 b	1091 ab	1746 abc	2687 ab	2618 a	1675 a-d
S.E.M.	63.2	165.9	97.5	145.4	140.7	148.8	150.1	116.8
L.S.D.	124.6	452.3	213.4	389.9	392.1	389.1	361.7	337.2

Table 16. Orthogonal contrast results for N by P fertilizer rate interactions on flax seed yield at multiple locations in 2016.

Main effect	**Seed Yield**							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
Contrast	p-values [Y]							
N (0P) – lin	< **0.001**	0.358	**0.001**	**0.001**	< **0.001**	< **0.001**	**0.004**	0.166
N (0P) – quad	< **0.001**	0.974	**0.001**	0.055	0.125	0.609	0.609	0.101
N (20P) – lin	< **0.001**	0.989	**0.023**	**0.029**	< **0.001**	< **0.001**	0.092	**0.030**
N (20P) – quad	< **0.001**	0.701	**0.008**	**0.044**	0.008	0.523	**0.042**	0.201
N (40P) – lin	< **0.001**	0.445	0.105	**0.006**	< **0.001**	< **0.001**	< **0.001**	0.978
N (40P) – quad	< **0.001**	0.358	0.807	0.137	0.097	0.098	**0.003**	0.295
N (60P) – lin	< **0.001**	0.477	< **0.001**	**0.002**	**0.005**	< **0.001**	< **0.001**	0.116
N (60P) – quad	< **0.001**	0.912	< **0.001**	**0.008**	**0.029**	**0.020**	0.979	0.894
P (13N) – lin	0.163	0.221	0.102	0.758	0.580	0.458	0.526	0.298
P (13N) – quad	0.245	0.686	**0.042**	0.232	0.293	0.310	0.092	0.694
P (50N) – lin	< **0.001**	0.755	0.389	0.479	0.895	0.464	0.254	**0.035**
P (50N) – quad	< **0.001**	0.488	0.539	0.180	0.470	0.856	0.406	0.739
P (100N) – lin	0.116	0.371	**0.032**	0.484	0.536	0.064	0.965	0.637
P (100N) – quad	0.060	0.964	**0.027**	0.691	0.810	0.835	0.759	0.304
P (150N) – lin	**0.025**	0.713	0.213	0.781	0.675	0.995	0.054	0.754
P (150N) – quad	0.326	0.742	0.606	0.556	0.179	0.454	0.058	0.809

Table 17. Side-banded nitrogen and phosphorus fertilizer effects on flax test weight at multiple locations in 2016.

	Test Weight							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville [X]**
Effect	p-values [Z]							
N Rate (N)	**< 0.001**	0.482	**0.006**	**0.017**	**< 0.001**	0.753	0.093	**0.010**
P_2O_5 Rate (P)	**0.028**	0.371	0.162	0.402	0.893	0.348	0.723	0.990
N × P	0.163	0.693	0.158	0.523	0.094	0.760	0.460	0.084
AICC [Y]	258.1	363.3	218.7	333.4	400.1	226.4	225.8	303.8

[Z] p-values ≤ 0.05 indicate that a treatment effect was significant and not due to random variability

[Y] Measure of overall model fit, smaller is better

[X] Test weight completed on uncleaned samples using combine weighing system – will not be utilized in combined analyses

Table 18. Least squares means for main effects of N and P fertilizer rates on flax test weight at multiple locations in 2016.

Main effect	**Test Weight**							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
N Rate	------------------------------ g 0.5/l ------------------------------							
13 kg/ha	327.4 c	233.1 a	347.5 b	332.4 a	263.2 b	343.7 a	341.3 a	278.2 a
50 kg/ha	328.3 c	232.2 a	347.5 b	331.6 ab	263.1 b	344.0 a	340.9 a	259.5 b
100 kg/ha	330.0 b	228.7 a	349.4 a	328.1 bc	278.4 a	344.2 a	342.2 a	251.2 b
150 kg/ha	331.9 a	232.1 a	348.6 ab	326.3 c	280.8 a	343.6 a	342.4 a	251.9 b
S.E.M.	2.01	2.08	0.58	1.56	3.87	0.54	0.53	5.91
L.S.D.	1.71	5.93	1.22	4.16	9.06	1.35	1.34	17.1
P_2O_5 Rate								
0 kg/ha	328.6 b	231.4 a	348.8 a	331.7 a	269.8 a	343.8 a	342.0 a	261.3 a
20 kg/ha	328.7 b	230.6 a	348.6 a	328.8 a	271.9 a	343.4 a	341.6 a	258.6 a
40 kg/ha	329.2 b	234.5 a	347.9 a	329.3 a	271.0 a	344.6 a	341.3 a	260.7 a
60 kg/ha	331.0 a	229.5 a	347.6 a	328.5 a	272.8 a	343.7 a	341.9 a	260.2 a
S.E.M.	2.01	2.08	0.58	1.56	3.87	0.54	0.54	5.91
L.S.D.	1.71	5.93	1.22	4.16	9.06	1.35	1.37	17.1
Contrast	------------------------------ p-values [Y] ------------------------------							
NR – linear	**< 0.001**	0.523	**0.008**	**0.002**	**< 0.001**	0.946	**0.028**	**0.003**
NR – quadratic	0.640	0.255	0.227	0.954	0.884	0.303	0.717	0.078
PR – linear	**0.007**	0.840	**0.028**	0.170	0.524	0.699	0.818	0.956
PR – quadratic	0.167	0.319	0.873	0.469	0.965	0.704	0.307	0.853

[Z] Test weight completed on uncleaned samples using combine weighing system – will not be utilized in combined analyses

Table 19. Least squares means for N by P fertilizer rate interactions on flax test weight at multiple locations in 2016.

Main effect	Test Weight							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
N × P Rate	g 0.5/l							
13N – 0P	327.9 d-h	233.8 a	348.0 a-e	332.1 abc	251.8 d	344.5 a	342.0 a	281.4 a
13N – 20P	326.8 gh	233.7 a	348.3 a-d	332.8 abc	262.8 cd	343.0 a	341.5 a	275.4 ab
13N – 40P	327.7 e-h	230.8 a	347.4 b-e	335.5 a	273.3 abc	344.3 a	339.6 a	273.5 ab
13N – 60P	327.2 fgh	233.9 a	346.4 cde	329.1 abcd	265.0 bcd	342.9 a	342.2 a	282.3 a
50N – 0P	325.9 h	234.7 a	349.1 ab	335.0 ab	269.3 abc	344.1 a	340.5 a	235.7 c
50N – 20P	327.5 e-h	228.2 a	349.0 ab	327.9 a-d	261.0 cd	343.2 a	341.0 a	271.6 ab
50N – 40P	328.6 c-h	233.5 a	345.9 de	330.0 a-d	252.3 d	345.5 a	340.1 a	250.1 abc
50N – 60P	331.2 a-d	232.4 a	345.8 e	333.4 ab	270.0 abc	343.2 a	342.2 a	280.5 a
100N – 0P	327.7 e-h	226.1 a	349.6 ab	329.2 a-d	275.0 abc	344.0 a	342.9 a	265.2 abc
100N – 20P	330.6 a-f	228.3 a	348.4 abc	327.1 bcd	283.8 a	344.1 a	341.9 a	233.5 c
100N – 40P	329.8 b-g	236.3 a	350.2 ab	329.4 a-d	274.8 abc	343.9 a	342.2 a	262.1 abc
100N – 60P	331.9 abc	224.3 a	349.4 ab	326.8 bcd	280.3 ab	345.0 a	341.7 a	243.9 bc
150N – 0P	333.0 ab	231.2 a	348.6 abc	330.7 abc	283.3 a	342.8 a	342.6 a	263.0 abc
150N – 20P	330.0 b-g	232.3 a	348.9 ab	327.5 a-d	280.0 ab	343.2 a	342.2 a	253.9 abc
150N – 40P	330.7 a-e	237.5 a	348.3 abcd	322.4 d	283.8 a	344.5 a	343.4 a	256.9 abc
150N – 60P	333.7 a	227.4	348.9 ab	324.9 cd	276.0 abc	343.9 a	341.6 a	233.8 c
S.E.M.	2.26	4.17	0.94	2.97	6.25	0.98	0.97	11.82
L.S.D.	3.42	11.9	2.44	8.31	16.11	2.70	2.69	34.6

Table 20. Orthogonal contrast results for N by P fertilizer rate interactions on flax test weight at multiple locations in 2016.

Main effect	**Test Weight**							
	Indian Head	**Melfort**	**Scott**	**S. Current**	**Redvers**	**Yorkton**	**Brandon**	**Vegreville**
Contrast	p-values [Y]							
N (0P) – lin	**0.002**	0.382	0.627	0.429	< 0.001	0.213	0.292	0.756
N (0P) – quad	**0.007**	0.493	0.208	0.951	0.329	0.707	0.736	0.112
N (20P) – lin	**0.023**	0.879	0.798	0.230	**0.005**	0.753	0.445	0.065
N (20P) – quad	0.452	0.263	0.904	0.346	0.572	0.501	0.787	0.195
N (40P) – lin	0.065	0.229	0.068	**0.004**	**0.023**	0.791	0.002	0.529
N (40P) – quad	0.910	0.798	0.502	0.858	**0.029**	0.890	0.914	0.489
N (60P) – lin	< **0.001**	0.148	**0.006**	0.120	0.101	0.287	0.604	**0.002**
N (60P) – quad	0.308	0.465	0.711	0.412	0.324	0.381	0.991	0.987
P (13N) – lin	0.793	0.889	0.140	0.643	0.053	0.417	0.791	0.988
P (13N) – quad	0.821	0.705	0.469	0.230	0.096	0.969	0.105	0.536
P (50N) – lin	**0.003**	0.938	**0.002**	0.843	0.798	0.897	0.348	**0.041**
P (50N) – quad	0.683	0.516	1.000	0.080	0.026	0.481	0.387	0.820
P (100N) – lin	**0.035**	0.889	0.775	0.701	0.791	0.524	0.445	0.511
P (100N) – quad	0.741	0.095	0.816	0.925	0.775	0.647	0.792	0.573
P (150N) – lin	0.603	0.744	0.948	0.089	0.480	0.284	0.711	0.120
P (150N) – quad	**0.016**	0.187	0.862	0.332	0.693	0.583	0.470	0.558