SASKATCHEWAN pulse Growers

SPG Project Annual Progress Report

1. SPG project details

Project File number: AGR1508
Project title: Developing nitrogen management recommendations for soybean production in Saskatchewan
Reporting period: April 1, 2015 – March 31, 2016
Approved Project Date: March, 2015
Report prepared by: Chris Holzapfel, Indian Head Agricultural Research Foundation (Email:)
Date submitted to SPG: March 23

2. Specify project activities undertaken during this reporting period. *Please note that changes from the original work plan will require consultation with, and written approval from SPG.*

a.) Methodology: *Include strategy, experimental design, tests, materials, sites, etc.*

The first year of soybean field trials were established at three locations in Saskatchewan: 1) Indian Head (Black soil zone), 2) Melfort (Moist Black soil zone) and 3) Outlook (Dark Brown soil zone). The treatments evaluated were 4 N fertilizer treatments (0 N or 55 kg N ha^{-1} as side-banded urea, side-banded ESN® or post-emergent surface dribble-banded urea ammonium-nitrate) and four granular inoculant rates (0, 1x, 2x and 4x the label recommended rate). All treatments received seed-applied liquid inoculant and the surface-dribbled banded (SBD) urea ammonium-nitrate (UAN) was applied during the early reproductive stages (R1-R2). The 16 treatments were arranged in a Randomized Complete Block Design with four replicates.

Seeding equipment, plot size and basic crop management varied from site-to-site depending on equipment and the specific environmental conditions encountered; however, all factors other than those being evaluated were held constant within each site. All other crop inputs (i.e. seeding rate, P fertility and pest control products) were based on current recommendations and intended to be non-limiting. The variety was 2310 YR and the soybeans in all treatments received seed-applied liquid inoculant. Weeds were controlled with registered herbicide applications tailored to each site and the plots were mechanically combined when mature and dry.

The data collected included background soil testing, emergence counts at approximately 4 weeks after planting, above-ground biomass measurements during pod fill (specific crop stage varied from site to site), pod clearance, plant tissue N concentrations and total N uptake, seed yield, seed N concentrations and total N exports. Not all laboratory results are available at the time of writing; however, all samples have been submitted and are being processed through AgVise laboratories (Northwood, ND).

All available response data from the first year of field trials was analysed separately for each site using the mixed procedure of SAS. The effects of N treatment, inoculant treatment and their interactions were considered fixed while the effect of replicate was considered random. Treatment means were separated using Tukey's studentized range test and orthogonal contrasts were used to investigate whether inoculant rate responses were non-significant, linear or curvilinear for each individual N treatment and averaged across N treatments. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

Pertinent site information and agronomic details are provided for each site in Table 1.

Table 1. Pertinent site and agronomic information for soybean nitrogen fertility study in 2015.

Agronomic Factor / Data Collection	Indian Head 2015	Outlook 2015	Melfort 2015
Previous crop	Spring Wheat	Spring Wheat	Oat
Tillage System	no-till	cultivator/harrow	rototilled
Row spacing	30 cm	25 cm	19 cm
Seeding date	May 21	May-26	May-21
Seeding rate	55 seeds m^{-2}	53 seeds m^{-2}	55 seeds m^{-2}
Emergence counts	Jun-16	June 24	June 19
In-crop herbicide 1	890 g glyphosate ha^{-1} + 50 g imazethapyr ha^{-1} Jun-8	1334 g glyphosate ha^{-1} June-22	1334 g glyphosate ha^{-1} Jul-2
In-crop herbicide 2	890 g glyphosate ha^{-1} Jul-4	1334 g glyphosate ha^{-1} Jul-15	1334 g glyphosate ha^{-1} Jul-16
UAN Treatments	July 16	July 21	July 20
Biomass harvest	Aug-26	Aug-27	date not available
Seed harvest	Oct-13	Oct 13	Oct-16

b.) List and explain any deviations from the approved objectives:

All activities are proceeding on schedule with no major deviations from the original research plan and proposed milestones.

c.) Research results in the reporting period. *(Describe progress towards meeting objectives. Please use revised objectives if approved revisions have been made to original objectives.*

Objectives	**Progress**
To investigate soybean responses to and interactions between granular inoculant rates and contrasting N fertilization practices.	The first year of field trials has been completed and all available response data has been summarized and analyzed. Any conclusions regarding the specific objectives of this project are very much preliminary and subject to change.

add additional lines as required

d.) Discussion: *Provide discussion and interpretation necessary to the full understanding (including on-farm use of information, if any) of progress made during this reporting period and the relevance of any findings. Detail any major concerns or project setbacks.*

All available response data to date has been analysed and is, for the most part, presented in its entirety in the following section. Only limited discussion and interpretation of results are offered as we are still waiting on some data and this is only the first year of a 3-year study.

Soil test results are presented in Table 2. Overall in 2015, the site at Indian Head was very low in residual NO_3-N while, at Outlook and Melfort, residual N levels were comparatively high.

Table 2. Soil test results for 2015 soybean N fertility / inoculant trials at Indian Head, Outlook and Melfort. Samples were collected in the early spring and submitted to AgVise laboratories for various analyses.

Soil Test Parameter	Indian Head 2015	Outlook 2015[Z]	Melfort 2015
NO_3-Nitrogen (0-60 cm)	15 kg ha^{-1}	53 kg ha^{-1}	62 kg ha^{-1}
Olsen Phosphorus (0-15 cm)	5 ppm	7 ppm	15 ppm
Potassium (0-15 cm)	676 ppm	290 ppm	515 ppm
Sulphur (0-60 cm)	18 kg ha^{-1}	179 kg ha^{-1}	47 kg ha^{-1}
Organic Matter (0-15 cm)	5.6%	—	12.4%
pH (0-15)	7.7	8.0	5.8

Mean monthly temperatures and precipitation amounts for each location during the 2015 growing season are presented in Table 3. Overall, it was a relatively warm and dry start to the season; however conditions improved in late June / early July and precipitation amounts were generally above average in August and September.

Table 3. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2015 growing season at Indian Head, SK.

Year	May	June	July	August	September	Avg. / Total
	---------- Mean Temperature (°C) ----------					
Indian Head-15	10.3	16.2	18.1	17.0	22.2	16.8
Indian Head-LT	10.8	15.8	18.2	17.4	11.5	14.7
Outlook-15	10.4	17.3	19.2	17.4	12.6	15.4
Outlook-LT	11.5	16.1	18.9	18.0	12.3	15.4
Melfort-15	9.9	16.4	17.9	17.0	11.9	14.6
Melfort-LT	10.7	15.9	17.5	16.8	10.8	14.3
	---------- Precipitation (mm) ----------					
Indian Head-15	15.6	38.3	94.6	58.8	67.8	275.1
Indian Head-LT	51.8	77.4	63.8	51.2	35.3	279.5
Outlook-15	9.3	38.6	135.4	57.5	47.9	288.7
Outlook-LT	39.0	63.9	56.1	42.8	32.8	234.6
Melfort-15	7.1	54.8	149.8	57.4	70.0	339.1
Melfort-LT	39.8	54.3	76.7	52.4	34.3	257.5

Measurements of plant density were targeted for 4-5 weeks after seeding when emergence was complete. Main effect means for this variable are presented in Table 4. Averaged across treatments, final plant populations were similar at Indian Head and Outlook (50-60 plants m^{-2}) but somewhat lower at Melfort (33 plants m^{-2}). Emergence was not affected by N treatment any of the three locations (P = 0.52-0.92). Inoculant did not affect emergence at Indian Head or Outlook (P = 0.17-0.28) but the overall F-test at Melfort was significant for this variable (P = 0.026). While the multiple comparisons test did not detect individual treatment differences, emergence tended to be higher at the two highest inoculant rates and, consequently, the quadratic response was significant (P = 0.005). The unusual response at Melfort may have been due to the application methods used at this site. Inoculant and seed could not be metered independently and therefore were mixed together prior to seeding. It is possible that the inoculant affected the flow of the seed at the high inoculant rates and/or the two products did not stay uniformly mixed due to size/density differences. There were no interactions between N treatment and inoculant at any locations for plant density (P = 0.17-0.38); however, all individual treatment means are documented in the Appendices (Table A-1).

Table 4. Nitrogen and inoculant means, overall F-test and contrast results for soybean emergence at ~4 weeks after planting). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Main Effect	Indian Head	Outlook	Melfort
	---------- Emergence (plants m^{-2}) ----------		
N Fertilizer [Z]			
Control (0N)	51.2 a	58.2 a	32.5 a
55 N – urea	51.0 a	58.3 a	34.7 a
55N – ESN	51.5 a	58.4 a	30.4 a
55N – UAN	52.6 a	59.2 a	34.8 a
S.E.M.	1.19	1.85	2.86
Inoculant [Y]			
Control (0 granular)	52.1 a	57.7 a	37.5 a
1x granular	52.7 a	60.5 a	36.2 a
2x granular	49.6 a	57.0 a	29.5 a
4x granular	51.8 a	58.8 a	29.2 a
S.E.M.	1.19	1.85	2.86
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	0.798	0.922	0.516
Inoculant (I)	0.276	0.171	0.026
N × I	0.172	0.383	0.375
Inoculant – lin	0.621	0.948	0.473
Inoculant – quad	0.263	0.985	0.005

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage
[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Pod clearance, or the distance from the bottom of the lowest soybean pod to the soil surface, affects harvestability and can also be influenced by management practices. At Indian Head, pod clearance was relatively low (< 5 cm) and not affected by either N treatment or inoculant (P = 0.18-0.65); however, the plants at this site were damaged by hail in late June which may have affected results (Table 5). While the soybeans recovered well, many plants were broken off below the first trifoliate. New growth and subsequent pod formation occurred at lower point on the plant than if the plants had not been damaged and potential treatment effects on this variable may have been lost as a result. At Melfort, the effect of N treatment was significant (P = 0.02) with a slight tendency for more clearance with the side-banded N treatments (urea and ESN). Granular inoculant rate had no effect on pod clearance at Melfort (P = 0.61). Averaged across all treatments, pod clearance was more than two times higher at Melfort than at Indian Head, likely due in part to the hail damage at Indian Head. These measurements were not completed at Outlook in 2015.

Table 5. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean pod clearance (distance from bottom of lowest pod to soil surface). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, *P* ≤ 0.05).

Main Effect	Indian Head	Outlook [Z]	Melfort
	---------- Pod Clearance (cm) ----------		
N Fertilizer [Y]			
Control (0N)	4.7 a	—	11.4 ab
55 N – urea	4.8 a	—	12.4 a
55N – ESN	5.3 a	—	12.1 ab
55N – UAN	4.2 a	—	10.9 b
S.E.M.	0.5	—	0.41
Inoculant [X]			
Control (0 granular)	5.0 a	—	12.1 a
1x granular	4.8 a	—	11.7 a
2x granular	4.4 a	—	11.5 a
4x granular	4.7 a	—	11.6 a
S.E.M.	0.45	—	0.41
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	0.184	—	0.021
Inoculant (I)	0.648	—	0.608
N × I	0.328	—	0.170
Inoculant – lin	0.465	—	0.341
Inoculant – quad	0.379	—	0.343

[Z] Data not collected
[Y] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage
[X] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Above-ground biomass yield was measured during pod filling; however, the specific crop stage varied across sites and affected the relative magnitude of the values from site-to-site (Table 6). At Indian Head, above-ground biomass varied with N treatment (*P* = 0.007) but not inoculant treatment (*P* = 0.79) and there was no interaction between the two factors (*P* = 0.42). Regardless of N form, timing or placement, N fertilizer application resulted in increased vegetative growth at Indian Head with an overall increase of approximately 17%. At Outlook, biomass yields were affected by both N treatment (*P* = 0.002) and granular inoculant rate (*P* = 0.03) but with no interaction between them (*P* = 0.93). At Outlook, there was also a tendency for higher biomass yields with side-banded N (particularly ESN) but not post-emergent UAN. Biomass also increased linearly (from 5554 kg ha^{-1} to 6690 kg ha^{-1}) with increasing granular inoculant rate at Outlook. At Melfort, the overall F-test for N treatment was significant (*P* = 0.03) and, while no individual treatment differences were detected with Tukey's multiple comparisons test, the overall trends were similar to those observed at Outlook. Inoculant rate did not affect above-ground biomass at Melfort. The difference in response to UAN at Indian Head relative to Outlook and Melfort may have been partly due to timing of the measurements with later sampling at Indian Head providing more time for the crop to respond to post-emergent N.

Table 6. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean above-ground biomass yield (R3-R4 stage). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Main Effect	Indian Head	Outlook	Melfort
	---------- Biomass (kg ha^{-1}) ----------		
N Fertilizer [Z]			
Control (0N)	7419 b	5404 b	4248 a
55 N – urea	8446 ab	6165 ab	5565 a
55N – ESN	8891 a	6873 a	5362 a
55N – UAN	8622 a	5717 b	3963 a
S.E.M.	303.5	328.0	432.4
Inoculant [Y]			
Control (0 granular)	8210 a	5554 b	4440 a
1x granular	8177 a	5974 ab	4606 a
2x granular	8471 a	5941 ab	5259 a
4x granular	8520 a	6690 a	4832 a
S.E.M.	312.4	328.0	432.4
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	0.007	0.002	0.026
Inoculant (I)	0.792	0.027	0.576
N × I	0.415	0.930	0.812
Inoculant – lin	0.378	0.004	0.456
Inoculant – quad	0.914	0.779	0.333

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage
[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Nitrogen concentrations of the above-ground biomass yields are presented for all sites where data was available at the time of writing in Table 7. At Melfort, both N treatment and granular inoculant rate affected tissue N concentrations ($P < 0.001$). Tissue N at Melfort was most concentrated with UAN and ESN and also increased quadratically with granular inoculant rate where there was a sharp rise from the control to the 1x rate but diminishing effects with further inoculant rate increases. There was no interaction between N treatment and granular inoculant rate at Melfort in 2015 ($P = 0.963$) Tissue N concentration data are not yet available for Indian Head and Outlook.

Table 7. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean tissue N concentrations (R3-R4 stage). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Main Effect	Indian Head	Outlook	Melfort
	---------- Tissue N (%) ----------		
N Fertilizer [Z]			
Control (0N)	2.85 a	—	2.74 b
55 N – urea	2.51 b	—	2.73 b
55N – ESN	2.53 b	—	2.94 a
55N – UAN	2.79 a	—	3.07 a
S.E.M.	0.052	—	0.072
Inoculant [Y]			
Control (0 granular)	1.89 c	—	2.38 b
1x granular	2.81 b	—	2.96 a
2x granular	3.01 a	—	3.03 a
4x granular	2.98 a	—	3.12 a
S.E.M.	—	—	0.071
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	< 0.001	—	< 0.001
Inoculant (I)	< 0.001	—	< 0.001
N × I	0.246	—	0.963
Inoculant – lin	< 0.001	—	< 0.001
Inoculant – quad	< 0.001	—	< 0.001

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage
[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Nitrogen uptake during pod-filling was calculated from the above-ground biomass yields and tissue N concentrations and results from all sites where data is available are presented in Table 8. At Melfort, total N uptake was not affected by N treatment ($P = 0.15$) but was affected by inoculant with a quadratic increase in total N uptake with increasing inoculant rate. Again, data for Indian Head and Outlook are not available at this time.

Table 8. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean N uptake (R3-R4 stage). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, *P* ≤ 0.05).

Main Effect	Indian Head	Outlook	Melfort
	---------- N Uptake (kg N ha^{-1}) ----------		
N Fertilizer [Z]			
Control (0N)	214.4 a	—	84.3 a
55 N – urea	211.8 a	—	85.3 a
55N – ESN	224.9 a	—	88.7 a
55N – UAN	239.8 a	—	92.4 a
S.E.M.	9.09	—	2.68
Inoculant [Y]			
Control (0 granular)	154.4 b	—	63.4 b
1x granular	228.3 a	—	92.1 a
2x granular	254.7 a	—	97.6 a
4x granular	253.5 a	—	97.7 a
S.E.M.	9.09	—	2.68
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	0.055	—	0.146
Inoculant (I)	< 0.001	—	< 0.001
N × I	0.323	—	0.704
Inoculant – lin	< 0.001	—	< 0.001
Inoculant – quad	< 0.001	—	< 0.001

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage
[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Overall F-tests and main effect means for soybean seed yield are presented in Table 9. Overall, yields were highest at Outlook (3770 kg ha^{-1}), followed by Melfort (3045 kg ha^{-1}) and then Indian Head (2626 kg ha^{-1}). At Indian Head, yield was affected by both N treatment (*P* < 0.001) and granular inoculant rate (*P* < 0.001); however, there was also a significant interaction between the two factors (*P* = 0.04). Focussing on the main effects first, soybean yields were slightly higher with post-emergent UAN than for any of the other N treatments and there was a significant yield increase with up to the 1x label rate of granular inoculant but no benefit to increasing rates past this point. However, inspection of individual treatment means for Indian Head revealed that post-emergent UAN was only beneficial when no granular inoculant was applied. While the yields achieved with post-emergent UAN but no granular inoculant did not generally significantly differ from most of the dual inoculated treatments (liquid plus 1x granular inoculant or higher); the tendency was for the highest yields where extra inoculant was applied, regardless of the N treatment. In all cases where the plots were dual inoculated there was no benefit to N fertilization regardless of form or placement / timing (Table 10). Nitrogen fertilizer did not affect soybean yield at Outlook (*P* = 0.72) or Melfort (*P* = 0.67); however, the effect of inoculant was highly significant at both sites (*P* < 0.001). There was no interaction between N fertilizer treatment and inoculant rate for seed yield at Outlook or Melfort (*P* = 0.71-0.76) and, similar to Indian Head, soybean yields at these sites leveled off at approximately 1x the

label recommend rate of granular inoculant with no measurable benefits to further increases.

Table 9. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean seed yield. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Main Effect	Indian Head	Outlook	Melfort
	---------- Seed Yield (kg ha^{-1}) ----------		
N Fertilizer [Z]			
Control (0N)	2627 b	3779 a	3046 a
55 N – urea	2528 b	3733 a	3115 a
55N – ESN	2578 b	3834 a	3015 a
55N – UAN	2772 a	3733 a	3004 a
S.E.M.	45.9	72.3	91.6
Inoculant [Y]			
Control (0 granular)	2232 b	2971 b	2670 b
1x granular	2745 a	3989 a	3118 a
2x granular	2746 a	3963 a	3237 a
4x granular	2781 a	4156 a	3155 a
S.E.M.	45.9	72.3	91.6
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	< 0.001	0.723	0.670
Inoculant (I)	< 0.001	< 0.001	< 0.001
N × I	0.039	0.709	0.762
Inoculant – lin	< 0.001	< 0.001	< 0.001
Inoculant – quad	< 0.001	< 0.001	< 0.001

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Table 10. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean seed yield (kg ha^{-1}). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook	Melfort
	---------- Control (ON) [Z] ----------		
Control	2170 cd	2858	2574 b
1x	2792 ab	4134	3131 a
2x	2850 ab	3948	3202 a
4x	2696 ab	4176	3277 a
Inoculant – lin	< 0.001	< 0.001	0.002
Inoculant - quad	< 0.001	< 0.001	0.035
	---------- 55N – urea ----------		
Control	2185 cd	2788	2711 ab
1x	2613 ab	3891	3160 ab
2x	2667 ab	4015	3255 ab
4x	2648 ab	4237	3333 a
Inoculant – lin	< 0.001	<.0001	0.005
Inoculant - quad	< 0.001	< 0.001	0.083
	---------- 55N – ESN ----------		
Control	2048 d	3183	2761 ab
1x	2745 ab	4004	3151 ab
2x	2709ab	3997	3224 ab
4x	2810 ab	4153	2923 ab
Inoculant – lin	< 0.001	< 0.001	0.648
Inoculant - quad	< 0.001	0.008	0.013
	---------- 55N – UAN ----------		
Control	2527 bc	3055	2635 ab
1x	2832 ab	3926	3029 ab
2x	2757 ab	3893	3265 ab
4x	2970 a	4059	3086 ab
Inoculant – lin	< 0.001	< 0.001	0.038
Inoculant - quad	0.345	0.006	0.014
S.E.M.	77.1	144.6	150.7

[Z] N – Nitrogen treatment; 55 kg N ha^{-1} applied in all treatments except control urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] I – Inoculant treatment; All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

For the locations where data is available, overall tests of fixed effects and main effects means for seed N concentrations are presented along with their interactions in Tables 11 and 12. At Indian Head, seed N concentrations were affected by both N treatment ($P < 0.001$) and inoculant rate ($P < 0.001$) with a significant interaction between factors ($P = 0.002$). Interestingly, seed N concentrations were highest in the treatments where no supplemental N was applied, thus suggesting that the additional mineral N was inhibiting nodule development and subsequent N fixation later in the season. Seed N concentrations were lowest with side-banded urea or ESN and intermediate with post-emergent UAN. Granular inoculant had a greater impact on seed N concentrations than yield, increasing up the 2x rate whereas yields leveled off at approximately 1x. The interaction (Table 12) was subtle but appeared to be due to there being a stronger response to granular inoculant for the treatments where N fertilizer was side-banded at seeding, presumably a result of inhibited nodulation due to added mineral N. At Melfort, neither the N treatments nor N × I interaction was significant for seed N ($P = 0.66$-0.85) but seed N increased with granular inoculant up to the 1x rate (Table 11). The difference in results at Indian Head relative to Melfort may have been due to the fact that residual N levels at Melfort were much higher than at Indian Head.

Table 11. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean seed N concentrations. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Main Effect	Indian Head	Outlook	Melfort
	---------- Seed N Concentration (%) ----------		
N Fertilizer [Z]			
Control (0N)	5.94 a	—	6.29 a
55 N – urea	5.67 c	—	6.23 a
55N – ESN	5.68 c	—	6.28 a
55N – UAN	5.82 b	—	6.28 a
S.E.M.	0.020	—	0.071
Inoculant [Y]			
Control (0 granular)	5.05 c	—	5.98 b
1x granular	5.93 b	—	6.34 a
2x granular	6.06 a	—	6.39 a
4x granular	6.07 a	—	6.38 a
S.E.M.	0.020	—	0.071
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	< 0.001	—	0.854
Inoculant (I)	< 0.001	—	< 0.001
N × I	0.002	—	0.656
Inoculant – lin	< 0.001	—	< 0.001
Inoculant – quad	< 0.001	—	< 0.001

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage
[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Table 12. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean seed N concentrations (% N). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook	Melfort
	---------- Control (ON) [Z] ----------		
Control	5.23 d	—	6.03 ab
1x	6.16 ab	—	6.42 ab
2x	6.17 ab	—	6.48 a
4x	6.20 a	—	6.25 ab
Inoculant – lin	< 0.001	—	0.377
Inoculant - quad	< 0.001	—	0.010
	---------- 55N – urea ----------		
Control	4.90 e	—	5.95 ab
1x	5.78 c	—	6.33 ab
2x	5.98 b	—	6.35 ab
4x	6.03 ab	—	6.28 ab
Inoculant – lin	< 0.001	—	0.127
Inoculant - quad	< 0.001	—	0.044
	---------- 55N – ESN ----------		
Control	4.90 e	—	5.85 b
1x	5.79 c	—	6.38 ab
2x	6.00 b	—	6.38 ab
4x	6.03 ab	—	6.53 a
Inoculant – lin	< 0.001	—	0.001
Inoculant - quad	< 0.001	—	0.055
	---------- 55N – UAN ----------		
Control	5.19 d	—	6.08 ab
1x	6.01 ab	—	6.25 ab
2x	6.07 ab	—	6.35 ab
4x	6.04 ab	—	6.45 ab
Inoculant – lin	< 0.001	—	0.033
Inoculant - quad	< 0.001	—	0.493
S.E.M.	0.038	—	0.125

[Z] N – Nitrogen treatment; 55 kg N ha^{-1} applied in all treatments except control urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] I – Inoculant treatment; All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Results for total N exports (calculated from seed yields and seed N concentrations) are presented in Tables 13 and 14. At Indian Head, N effects were such that total N exports were lowest when urea or ESN was side-banded at planting while granular inoculant increased N exports up to but not past the 1x rate. While the interaction between N treatment and inoculant rate was significant, the specific nature of this interaction was subtle as the effects of inoculant rate were relatively consistent across all N treatments (Table 14). At Melfort, similar to the results for seed N concentrations, N treatment had no effect on total N exports (P = 0.823) and there was no interaction between N treatment and inoculant rate (P = 0.959) but the effect of inoculant on its own was significant (P < 0.001). Nitrogen exports increased with granular inoculant up to the 1x rate but further increases had no effect.

Table 13. Nitrogen and inoculant main effect means, overall F-test and contrast results for soybean seed N exports. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Main Effect	Indian Head	Outlook	Melfort
	---------- Nitrogen Export (kg N ha^{-1}) ----------		
N Fertilizer [Z]			
Control (0N)	157.0 a	—	193.2 a
55 N – urea	144.4 b	—	194.2 a
55N – ESN	147.8 b	—	189.2 a
55N – UAN	161.9 a	—	188.7 a
S.E.M.	2.75	—	5.64
Inoculant [Y]			
Control (0 granular)	113.0 b	—	159.6 b
1x granular	163.0 a	—	198.5 a
2x granular	166.3 a	—	206.2 a
4x granular	168.8 a	—	201.0 a
S.E.M.	2.75	—	5.64
	---------- Pr > F (p-value) ----------		
Nitrogen (N)	< 0.001	—	0.823
Inoculant (I)	< 0.001	—	< 0.001
N × I	0.034	—	0.959
Inoculant – lin	< 0.001	—	< 0.001
Inoculant – quad	< 0.001	—	< 0.001

[Z] N = kg N ha^{-1}; urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Table A-5. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean seed N exports (kg N ha^{-1}). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook	Melfort
	---------- Control (ON) [Z] ----------		
Control	113.4 de	—	155.1 b
1x	172.0 ab	—	204.7 ab
2x	175.8 a	—	206.8 a
4x	167.0 ab	—	206.3 ab
Inoculant – lin	< 0.001	—	0.004
Inoculant - quad	< 0.001	—	0.007
	---------- 55N – urea ----------		
Control	107.3 e	—	161.4 ab
1x	151.1 bc	—	199.6 ab
2x	159.5 ab	—	206.2 ab
4x	159.8 ab	—	209.5 a
Inoculant – lin	< 0.001	—	0.004
Inoculant - quad	< 0.001	—	0.034
	---------- 55N – ESN ----------		
Control	100.4 e	—	160.8 ab
1x	158.8 ab	—	201.0 ab
2x	162.6 ab	—	205.0 ab
4x	169.4 ab	—	190.1 ab
Inoculant – lin	< 0.001	—	0.121
Inoculant - quad	< 0.001	—	0.005
	---------- 55N – UAN ----------		
Control	131.0 cd	—	161.0 ab
1x	170.1 ab	—	188.7 ab
2x	167.4 ab	—	206.8 a
4x	179.3 a	—	198.4 ab
Inoculant – lin	< 0.001	—	0.015
Inoculant - quad	< 0.001	—	0.024
S.E.M.	4.59	—	10.39

[Z] N – Nitrogen treatment; 55 kg N ha^{-1} applied in all treatments except control urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] I – Inoculant treatment; All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

e.) List summary of findings, implications, and briefly discuss any conclusions.

Overall, the first year of this project was considered successful with relatively high soybean yields at all three locations and all work progressing on schedule. Nitrogen fertilization generally resulted in increased above-ground biomass yield but rarely affected seed yields. The exception was specifically with post-emergent UAN and in the absence of granular inoculant at Indian Head where 55 kg N ha^{-1} as UAN at the R1-R2 stage resulted in a 357 kg ha^{-1}, or 16%, yield increase. At Indian Head, where residual N levels were relatively low, there was evidence that N applied during seeding was having a negative impact on N fixation; however, this was not observed to the same extent where initial N levels were high (i.e. Melfort). The results to date suggest that, with adequate inoculation and under reasonably high yielding conditions (for Saskatchewan), N fertilization is not beneficial to soybeans; however, post-emergent applications during the early reproductive stages can provide significant yield benefits when nodulation is poor. We are still awaiting tissue N results for Indian Head and Outlook and seed N concentrations for Outlook.

3. Non-confidential abstract/summary: *This must include overall project objectives, a brief mention of methodology and research design, and a summary of findings for use in publications and on the SPG website. Maximum 500 words in lay language. Please note that this summary will be used as such and no additional permission will be sought from the project applicant to publish the summary.*

A project was initiated in 2015 to investigate soybean response to N fertilization strategies and granular inoculant rates under field conditions in Saskatchewan. Field trials were located at Indian Head, Outlook and Melfort where the treatments were four N fertilization strategies (0 N or 55 kg N ha^{-1} as side-banded urea, side-banded ESN or post-emergent surface dribble-banded UAN) and 4 granular inoculant rates (0, 1x, 2x and 4x the label recommended rate). Seed in all treatments received a full rate of liquid inoculant. While N fertilization frequently resulted in increased above-ground biomass yields, this response rarely translated into a positive effect on seed yield and, when N was applied at seeding, appeared to negatively impact N fixation at Indian Head. An exception to the lack of benefits to N fertilization occurred at Indian Head but only in the absence of granular inoculant and specifically for post-emergent application of UAN which resulted in a 16% yield gain. There were no yield benefits to N fertilization at Outlook or Melfort, regardless of the granular inoculant rate and, when the results from Indian Head were also taken into consideration, no benefits in any cases where both liquid inoculant plus a 1x label rate (or higher) of granular inoculant were applied. In general, these results are in agreement with most previous research suggesting that supplemental N fertilization for soybeans is not required under normal environmental conditions and with adequate inoculation. If nodulation is poor, yields may be at least partly maintained with post-emergent surface applications of N during the early reproductive stages. While the specific N formulation evaluated in the current trial was liquid UAN, similar results may be expected with other formulations such as granular urea or ammonium nitrate. This work is continuing at all three locations over the next two growing seasons (2016 and 2017) with funding provided by the Saskatchewan Pulse Crop Development Board.

4. List any technology transfer activities undertaken in relation to this project: *Include conference presentations, posters, papers published, etc.*

The current results have not been presented at any producer meetings or shared through the agricultural press at the time of writing this report; however, the research was introduced and field trials shown at several field days. At Indian Head, the trial was shown to approximately 70 retail agronomists on July 10 and to approximately 200 producers and agronomists on July 21 where John Heard (MAFRI) was invited to discuss soybean inoculation, starter N and options for rescuing crops where nodulation is inadequate. The trial was also highlighted at a Faba bean and Soybean tour at Melfort on July 29 which was attended by 75 people.

5. List any changes expected to industry contributions, in-kind support, collaborations or other resources.

There are no confirmed or anticipated changes to industry contributions, in-kind support, collaborations or other resources specifically attributable to this project.

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

Project Rationale and Review of the Literature

The current research was initiated to determine the best management practices to ensure adequate N supply and maximum economic yields for soybean production in Saskatchewan and to help producers grow this crop in the most economically, agronomically and environmentally sustainable manner possible. While still a relatively minor crop provincially, southeast Saskatchewan saw rapid adoption of this crop and, since then, producers throughout the province have expressed interest in this crop and have been experimenting with it. In Manitoba farmers have adopted soybeans as a major component of their crop rotation, with more than 1 million acres planted in 2013 up to a reported 1.3 million acres in 2015. In Saskatchewan, 2015 soybean acres were estimated at approximately 300,000 acres, up over 11% from the previous year. A study completed in Manitoba showed that a 3056 kg/ha (45.5 bus/ac) soybean crop can take up 223 kg N/ha in the above-ground plant material, 88% (197 kg N/ha) of which was removed in the harvested grain (Heard 2006). As legumes, soybeans are capable of acquiring N through biological N_2 fixation by Rhizobium bacteria; however, because the percentage of this nutrient removed in the grain so high, the N benefit of soybeans to subsequent crops is often low or even negative (Salvagiotti et al. 2008).

In regions where soybeans are relatively new to crop rotations, such as Saskatchewan, proper inoculation is critical. Applying both granular and seed applied inoculant has been common practice for new soybean growers in Saskatchewan and, in most cases, first time growers are being advised to use rates above those recommended by the product labels. Recent trials in eastern Manitoba, in fields where soybeans had been historically grown, only showed an economic response to granular inoculant (when also using a seed applied inoculant) in 3 of 10 sites (Tone et al. 2013). In the U.S. Midwest, many growers do not inoculate at all and De Bruin et al. (2010) found that there was no yield response to inoculant in 86% of 73 fields that were evaluated. The probability of a break-even economic response ranged from 4-59% for individual states while the probability of a 2:1 return on investment was only 0.2-11% (De Bruin et al. 2010). A general recommendation from Minnesota is that soybeans should be inoculated for at least the first five years of production in a field (i.e. 10 years total in a 2 year rotation) and after that responses may be unlikely (Randal 2012). That said, many soybeans grown in

Saskatchewan over the next several years will be grown fields that have not been historically seeded to soybeans and there are questions regarding whether the Bradyrhizobium will survive in our comparatively harsh environment. Consequently, inoculation will be an important component of our soybean production package in Saskatchewan for the foreseeable future and the question will not be so much whether to inoculate but how much to inoculate. Most of the soybeans in Saskatchewan and Manitoba are purchased pre-treated with both a seed treatment and liquid inoculant so growers need to know whether they should be applying granular inoculant on top of that and, if so, at what rate. While the consensus in Saskatchewan is that proper inoculation is currently critical for this crop, the probability of response to granular inoculant over and above a liquid applied product, sometimes at rates well above label recommendations, requires further validation over a range of environments.

Nitrogen fertilizer is generally not recommended for soybeans and can reduce nodulation and, subsequently, biological N_2 fixation; however, on average, biological fixation only supplies 50-60% of the total N requirements so additional N must come from either the soil or fertilizer (Salvagiotti et al. 2008). Despite the general recommendation not to apply N with soybeans, yield benefits to starter N are occasionally reported, particularly under cool/ dry conditions or in soils with very low organic matter or residual N (Osborne and Riedell 2006; Randal 2012). In a review of 637 data sets published between 1966-2006, soybean yields were increased with N fertilizer approximately half the time; however, Salvagiotti et al. (2008) noted that responses typically occurred either with high yielding (>4.5 Mg/ha) crops or under stressful conditions such as poor nodule establishment, extremely low soil N at planting, low soil temperature or with absence of native Bradyrhizobium. If N fertilizer is to be applied, the most logistically efficient method of N application is banding at seeding; however, there is evidence that soybeans respond better to N applied later in the growing season and that doing so can lessen the negative impacts of N fertilizer on biological fixation (Salvagiotti et al. 2008). Due to the negative impact on N fixation, banding a slow release form of N fertilizer, such as ESN® or SUPERU® may outperform untreated urea at seeding without the added cost of a post-emergent application. In cases where responses did occur, low rates (50 kg N/ha or less) were generally sufficient to maximize yield.

The proposed project will expand upon the current knowledge base by investigating soybean response to granular inoculant rates (when applied in addition to a liquid inoculant) and contrasting N fertilization strategies. The overall objective is to improve upon N management recommendations for the growing number of new soybean producers in the province of Saskatchewan. While we recognize that including a fully uninoculated control might be desirable from a scientific perspective, we have chosen to exclude this treatment as it adds cost and creates significant logistic challenges with seed sourcing, preparation and distribution amongst the sites and from year to year. We feel that the current treatments adequately address the most important questions on inoculation and N fertilization that producers will require answers to for the foreseeable future as soybean acres expand and this crop becomes more established in Saskatchewan.

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Additional Results Tables

Table A-1. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean plant density (plants m^{-2}). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook	Melfort
	---------- Control (ON) [Z] ----------		
Control (0 granular)	49.8 a	54.7 a	28.1 a
1x	50.9 a	62.3 a	36.5 a
2x	51.9 a	56.3 a	28.8 a
4x	52.3 a	59.5 a	36.5 a
Inoculant – lin	0.456	0.407	0.366
Inoculant - quad	0.787	0.492	0.961
	---------- 55N – urea ----------		
Control (0 granular)	54.0 a	56.8 a	26.7 a
1x	52.3 a	57.0 a	42.1 a
2x	44.9 a	59.9 a	42.2 a
4x	52.9 a	59.5 a	27.8 a
Inoculant – lin	0.635	0.329	0.708
Inoculant - quad	0.016	0.670	0.004
	---------- 55N – ESN ----------		
Control (0 granular)	49.9 a	59.1 a	28.5 a
1x	56.6 a	62.1 a	34.4 a
2x	50.3 a	55.6 a	32.3 a
4x	49.2 a	56.8 a	26.3 a
Inoculant – lin	0.370	0.224	0.559
Inoculant - quad	0.265	0.883	0.275
	---------- 55N – UAN ----------		
Control (0 granular)	55.0 a	60.3 a	34.8 a
1x	51.1 a	60.6 a	36.9 a
2x	51.3 a	56.4 a	41.4 a
4x	52.9 a	59.5 a	26.0 a
Inoculant – lin	0.717	0.647	0.170
Inoculant - quad	0.247	0.355	0.080
S.E.M.	2.38	2.71	5.01

[Z] N – Nitrogen treatment; 55 kg N ha^{-1} applied in all treatments except control urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] I – Inoculant treatment; All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Table A-2. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean pod clearance (distance from lowest pod to the soil surface; cm). Treatments within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook [Z]	Melfort
	---------- Control (ON) [Z] ----------		
Control (0 granular)	4.4 a	—	10.9 b
1x	5.0 a	—	12.0 ab
2x	4.0 a	—	11.4 ab
4x	5.3 a	—	11.5 ab
Inoculant – lin	0.499	—	0.737
Inoculant - quad	0.536	—	0.546
	---------- 55N – urea ----------		
Control (0 granular)	5.6 a	—	14.5 a
1x	4.2 a	—	11.6 ab
2x	4.8 a	—	12.0 ab
4x	4.5 a	—	11.4 ab
Inoculant – lin	0.449	—	0.011
Inoculant - quad	0.519	—	0.063
	---------- 55N – ESN ----------		
Control (0 granular)	5.5 a	—	12.2 ab
1x	4.7 a	—	12.3 ab
2x	5.2 a	—	11.5 ab
4x	5.9 a	—	12.3 ab
Inoculant – lin	0.556	—	0.956
Inoculant - quad	0.392	—	0.482
	---------- 55N – UAN ----------		
Control (0 granular)	4.5	—	10.7 b
1x	5.6	—	10.8 b
2x	3.5	—	11.0 ab
4x	3.1	—	11.1 ab
Inoculant – lin	0.053	—	0.647
Inoculant - quad	0.720	—	0.928
S.E.M.	0.77	—	0.72

[Z] Data not available; [Y] N – Nitrogen treatment; 55 kg N ha^{-1} applied in all treatments except control urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[X] I – Inoculant treatment; All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)

Table A-3. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean tissue N concentrations (R3-R4 stage; kg N ha^{-1}). Treatments within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook	Melfort
	---------- Control (ON) [Z] ----------		
Control (0 granular)	1.97 de	—	2.23 d
1x	3.06 ab	—	2.78 abc
2x	3.23 a	—	2.90 ab
4x	3.16 ab	—	3.08 a
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	< 0.001	—	0.014
	---------- 55N – urea ----------		
Control (0 granular)	1.72 e	—	2.28 cd
1x	2.63 c	—	2.83 ab
2x	2.88 abc	—	2.88 ab
4x	2.84 bc	—	2.95 ab
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	< 0.001	—	0.008
	---------- 55N – ESN ----------		
Control (0 granular)	1.73 e	—	2.53 bcd
1x	2.61 c	—	3.03 ab
2x	2.86 abc	—	3.08 a
4x	2.95 abc	—	3.15 a
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	< 0.001	—	0.016
	---------- 55N – UAN ----------		
Control (0 granular)	2.16 d	—	2.50 bcd
1x	2.94 abc	—	3.23 a
2x	3.09 ab	—	3.25 a
4x	2.99 abc	—	3.30 a
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	< 0.001	—	< 0.001
S.E.M.	0.084	—	0.116

Table A-4. Treatment means and orthogonal contrast results nitrogen (N) by inoculant (I) treatment effects on soybean N uptake (R3-R4 stage; kg N ha^{-1}). Treatments within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).

Inoculant Treatment [Y]	Indian Head	Outlook	Melfort
	---------- Control (ON) [Z] ----------		
Control (0 granular)	128.2 e	—	56.7 e
1x	221.4 a-d	—	87.0 a-d
2x	274.1 a	—	93.2 ab
4x	234.1 ab	—	100.4 a
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	< 0.001	—	0.005
	---------- 55N – urea ----------		
Control (0 granular)	145.9 de	—	61.7 de
1x	222.8 a-d	—	88.5 a-d
2x	232.8 ab	—	93.1 ab
4x	245.7 ab	—	97.8 a
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	0.011	—	0.010
	---------- 55N – ESN ----------		
Control (0 granular)	153.7 cde	—	70.1 b-e
1x	231.6 abc	—	95.3 ab
2x	263.4 ab	—	98.7 a
4x	251.1 ab	—	91.0 abc
Inoculant – lin	< 0.001	—	0.031
Inoculant - quad	< 0.001	—	0.002
	---------- 55N – UAN ----------		
Control (0 granular)	189.8 b-e	—	65.1 cde
1x	237.7 ab	—	97.6 a
2x	248.5 ab	—	105.5 a
4x	283.1 a	—	101.5 a
Inoculant – lin	< 0.001	—	< 0.001
Inoculant - quad	0.314	—	< 0.001
S.E.M.	16.14	—	5.36

[Z] N – Nitrogen treatment; 55 kg N ha^{-1} applied in all treatments except control urea and ESN side-banded at seeding; UAN surface dribble banded at R1-R2 growth stage

[Y] I – Inoculant treatment; All seed treated with liquid inoculant; Cell-Tech® granular soybean inoculant applied in-furrow as per protocol with rates based on label recommendations (adjusted for row spacing)