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, 2016 – March 31, 2017
Approved Project Date: March, 2015
Report prepared by: Chris Holzapfel, Indian Head Agricultural Research Foundation (Email: cholzapfel@iharf.ca)
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.*

In the spring of 2016, soybean field trials were established for a second (of three) growing season at three Saskatchewan locations: 1) Indian Head (Black soil zone), 2) Melfort (Moist Black soil zone) and 3) Outlook (Dark Brown soil zone). With the exception of Outlook in 2016, no other field trial sites had any previous history of soybeans in rotation. 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 targeted for early pod fill (R2). The 16 treatments were arranged in a Randomized Complete Block Design with four replicates.

Seeding equipment, plot size and basic crop management practices 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, again, soybeans in all treatments received seed-applied liquid inoculant (Optimize Liquid Soybean). Weeds were controlled with registered herbicide applications tailored to each site and the plots were straight-combined when the plants were mature and dry. Pertinent site information and agronomic details are provided for each location in Tables 1(2015) and 2 (2016).

The data collected included background residual soil nutrient testing, emergence measurements at approximately 4 weeks after planting, above-ground biomass measurements during pod fill (target R5-R6; specific crop stage varied from site to site), pod clearance (not completed at all sites), plant tissue N concentrations/N uptake, seed yield, seed N concentrations/total N exports. All soil and plant tissue analyses are being processed through AgVise laboratories (Northwood, ND).

All response data available to date has been 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 replicate effects were considered random. Treatment means were separated using Tukey's studentized range test and orthogonal contrasts were used to test whether inoculant rate responses were non-significant, linear or curvilinear. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

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
Soybean History	no previous soybeans	no previous soybeans	no previous soybeans
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

Table 2. Pertinent site and agronomic information for soybean nitrogen fertility study in 2016.

Agronomic Factor / Data Collection	Indian Head	Outlook	Melfort
Soybean History	no previous soybeans	2013 & 2010	no previous soybeans
Previous crop	Spring Wheat	Spring Wheat	Spring Wheat
Tillage System	no-till	cultivator/harrow	no-till
Row spacing	30 cm	25 cm	30 cm
Seeding date	May 22	May-19	May-18
Seeding rate	63 seeds m^{-2}	53 seeds m^{-2}	55 seeds m^{-2}
Emergence counts	Jun-14	June 24	June 15
In-crop herbicide 1	890 g glyphosate ha^{-1} + 50 g imazethapyr ha^{-1} Jun-17	890 g glyphosate ha^{-1} June 22	1334 g glyphosate ha^{-1} Jun-15
In-crop herbicide 2	890 g glyphosate ha^{-1} Jul-5	n/a	1334 g glyphosate ha^{-1} Jul-5
UAN Treatments	July 22	July 21	July 19
Biomass harvest	Aug-19	Aug 27	Aug-16
Seed harvest	Oct-1	Nov-4	Nov-8

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 or 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 in Saskatchewan.	Two of three years of field trials have been completed and all available response data has been summarized and analyzed. Any conclusions regarding the specific objectives of this project are still considered 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 currently available response data has been analysed and is presented in the following section. Only limited discussion and interpretation of results are offered as the study will continue in 2017 and final data will be combined and re-analysed as appropriate. Soil test results are presented in Table 3. In general, the sites at Indian Head have been low in residual NO_3-N while those at Outlook and Melfort, residual N levels have been considered moderate to high.

Table 3. Soil test results for 2015 and 2016 soybean P fertility trials at Indian Head, Outlook, Melfort and Scott. Samples were collected in the early spring and submitted to AgVise laboratories for various analyses.

Soil Test	Indian Head		Outlook		Melfort	
Parameter	2015	2016	2015	2016	2015	2016
NO_3-N (0-60 cm) [z]	15 kg/ha	21 kg/ha	53 kg/ha	35 kg/ha	62 kg ha^{-1}	102 kg/ha
Olsen-P (0-15 cm)	5 ppm	4 ppm	7 ppm	12 ppm	15 ppm	13 ppm
K (0-15 cm)	676 ppm	545 ppm	290 ppm	231 ppm	515 ppm	594 ppm
S (0-60 cm)	18 kg/ha	70 kg/ha	179 kg/ha	47 kg/ha	47 kg ha^{-1}	29 kg/ha
OM % (0-15 cm)	5.6	4.8	—	2.4	12.4%	10.3
pH (0-15)	7.7	8.0	8.0	7.6	5.8	6.4

[z] Soil only sampled to 30 cm at Melfort (N and S)

Mean monthly temperatures for each location are presented in Table 4 and total precipitation amounts are in Table 5. Temperatures have been average to slightly above-average for the respective locations over the past two seasons, with particularly warm weather in June in all cases. Early frost was not considered a yield limiting factor in

any cases. Cumulative growing season precipitation amounts were also above average except for Indian Head in 2015 where May-September rainfall amounts were about average; however, even there late season precipitation was abundant and moisture was not considered limiting to yield at any time during the season. Hail occurred in both years at Indian Head with the damage occurring in late June (V1-V2) while in 2016 it occurred late July (R2). In both cases the damage was uniform and not believed to have affected data quality although yields were reduced substantially in 2016 as a result of the damage.

Table 4. Mean monthly temperatures along with long-term (1981-2010) averages for the 2015-16 growing seasons at Indian Head, Outlook, Melfort and Scott, SK.

Year	May	June	July	August	September	Avg. / Total
	---------- Mean Temperature (°C) ----------					
Indian Head-16	14.0	17.5	18.5	17.2	12.8	16.0
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-16	13.5	17.5	18.6	16.9	12.1	15.7
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-16	13.6	17.1	18.1	16.3	12.0	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

Table 5. Total precipitation amounts along with long-term (1981-2010) averages for the 2015-16 growing seasons at Indian Head, Outlook, Melfort and Scott, SK.

Year	May	June	July	August	September	Avg. / Total
	---------- Precipitation (mm) ----------					
Indian Head-16	73	63	113	30	41	320
Indian Head-15	16	38	95	59	68	275
Indian Head-LT	52	77	64	51	35	280
Outlook-16	56	46	195	70	24	319
Outlook-15	9	39	135	58	48	289
Outlook-LT	39	64	56	43	33	235
Melfort-16	17	53	129	81	41	321
Melfort-15	7	55	150	57	70	339
Melfort-LT	40	54	77	52	34	258

Plant density measurements were targeted for approximately 4 weeks after seeding when emergence was complete. Main effect means for this variable are presented in Table 6. Averaged across treatments, final plant populations ranged from 33-58 plants/m^2. Target plant densities for soybeans are about 44-57 plants/m^2; however, this crop does have the ability to compensate for lower plant populations through increased branching. Emergence was not affected by N treatment any site-years (P = 0.52-0.99) except for Melfort in 2016 (P < 0.001) where plant populations were reduced with side-banded urea and, to a lesser extent, ESN. This suggests that soybeans can be sensitive to N fertilizer (particularly urea) if adequate seed/fertilizer separation is not achieved. Inoculant did not affect emergence at any locations (P = 0.17-0.89) except Melfort in 2015 where the overall F-test for inoculant effects on emergence was significant (P = 0.03). In this case, emergence tended to be higher at the two highest

inoculant rates and the overall quadratic response was significant ($P < 0.01$). This unusual response at Melfort in 2015 may have been due to the application methods whereby inoculant and seed could not be metered independently and therefore were mixed together prior to seeding. It is possible that the inoculant either affected the flow of the seed at the higher 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 = 0.17-0.89), therefore individual treatment means are reserved for the Appendices (Table A-1).

Table 6. Main effect means, overall F-test and contrast results for soybean emergence. 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	Emergence (plants/m^2)					
Control (0N)	51.2 a	48.2 a	58.2 a	52.9 a	32.5 a	44.5 a
55 N – urea	51.0 a	47.2 a	58.3 a	52.8 a	34.7 a	33.2 b
55N – ESN	51.5 a	47.1 a	58.4 a	52.9 a	30.4 a	38.1 ab
55N – UAN	52.6 a	48.7 a	59.2 a	52.6 a	34.8 a	44.0 a
S.E.M.	1.19	1.30	1.85	3.05	2.86	1.94
Inoculant [Y]						
Liquid Only	52.1 a	48.8 a	57.7 a	53.0 a	37.5 a	40.2 a
1x granular	52.7 a	46.7 a	60.5 a	52.5 a	36.2 a	40.4 a
2x granular	49.6 a	47.0 a	57.0 a	53.2 a	29.5 a	41.5 a
4x granular	51.8 a	48.7 a	58.8 a	52.5 a	29.2 a	37.6 a
S.E.M.	1.19	1.30	1.85	3.05	2.86	1.94
	Pr > F (p-value)					
Nitrogen (N)	0.798	0.800	0.922	0.992	0.516	**< 0.001**
Inoculant (I)	0.276	0.534	0.171	0.893	**0.026**	0.544
N × I	0.172	0.189	0.383	0.177	0.375	0.893
Inoculant – lin	0.621	0.824	0.948	0.773	0.473	0.334
Inoculant – quad	0.263	0.166	0.985	0.859	**0.005**	0.317

[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 be influenced by both environment and management practices. In both years at Indian Head, pod clearance was relatively low (< 5 cm) and not affected by either N treatment or inoculant (Table 7; P = 0.11-0.65). In 2015 at Indian Head the soybeans were damaged by hail in late June which may have reduced pod height and masked potential treatment effects; however, the overall pod height and (lack of) treatment effects were similar in 2016. The plots at Indian Head were also damaged by hail in 2016; however this storm occurred later (late July), primarily damaged upper plants and was not believed to have affected pod height in any way. At Melfort in 2015, the effect of N treatment was significant (P = 0.02) with a slight tendency for higher pods when starter N (urea or ESN) was applied. 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 in either year. Individual treatment means for pod clearance are presented in the Appendices (Table A-2).

Table 7. Main effect means, overall F-test and contrast results for soybean pod clearance (cm 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, $P \leq 0.05$).

Main Effect	Indian Head		Outlook		Melfort	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	Pod Clearance (cm)					
Control (0N)	4.7 a	4.8 a	–	–	11.4 ab	–
55 N – urea	4.8 a	4.7 a	–	–	12.4 a	–
55N – ESN	5.3 a	4.7 a	–	–	12.1 ab	–
55N – UAN	4.2 a	4.1 a	–	–	10.9 b	–
S.E.M.	0.45	0.24	–	–	0.41	–
Inoculant [Y]						
Liquid Only	5.0 a	4.2 a	–	–	12.1 a	–
1x granular	4.8 a	4.9 a	–	–	11.7 a	–
2x granular	4.4 a	4.4 a	–	–	11.5 a	–
4x granular	4.7 a	4.9 a	–	–	11.6 a	–
S.E.M.	0.45	0.24	–	–	0.41	–
	Pr > *F* (p-value)					
Nitrogen (N)	0.184	0.156	–	–	0.021	–
Inoculant (I)	0.648	0.110	–	–	0.608	–
N × I	0.328	0.685	–	–	0.170	–
Inoculant – lin	0.465	0.147	–	–	0.341	–
Inoculant – quad	0.379	0.751	–	–	0.343	–

[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)

Above-ground biomass yield was measured during pod filling at all sites; however, the specific crop stage varied to some extent affecting the relative magnitude of the absolute values across sites (Table 8). Consequently, comparisons of above-ground biomass yields should not be made across site-years. Nitrogen treatment affected above-ground biomass yield at 4/6 site-years ($P < 0.01$-0.03) with the exceptions being Outlook and Melfort in 2016 ($P = 0.08$-0.91). In all cases where the effect was significant, the tendency was for increased biomass when N fertilizer was applied at seeding. At Indian Head in 2015, the late season application also, somewhat unexpectedly, led to higher biomass yields. The difference in response to UAN at Indian Head in 2015 relative to the other responsive sites may have been partly due to the relative timing of the in-crop N application and biomass measurements. Later sampling combined with slightly earlier N application provided more time for the crop to respond to post-emergent N. At Melfort in 2016, while the overall F-test was not significant at the desired probability ($P = 0.08$), there was also a tendency for increased vegetative growth with N fertilizer. Inoculant effects on above-ground biomass were only significant at 2/6 locations, Indian Head in 2016 and Outlook in 2015 ($P < 0.01$-0.03) and in both cases, as expected, biomass production increased with granular inoculant. While biomass yields generally peaked at greater than 1x the label recommended rate of granular inoculant, there were never any statistically significant differences detected amongst the dual inoculated treatments. At Indian Head (2016), the orthogonal contrasts indicated that the biomass response to granular inoculant rate was quadratic ($P = 0.01$), levelling off at the 2x rate while at Outlook (2015) the response was linear ($P < 0.01$). No interactions between N fertilizer treatment and granular inoculant rate were detected for biomass yield at any site-years, therefore, individual treatment means are deferred to the Appendices (Table A-3).

Table 8. Main effect means, overall F-test and contrast results for soybean above-ground biomass yields (target R4-R5). 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	Biomass (kg/ha)					
Control (0N)	7419 b	5135 b	5404 b	2522 a	4248 a	5990 a
55 N – urea	8446 ab	6650 a	6165 ab	2532 a	5565 a	7240 a
55N – ESN	8891 a	6280 a	6873 a	2640 a	5362 a	6804 a
55N – UAN	8622 a	5112 b	5717 b	2516 a	3963 a	6215 a
S.E.M.	303.5	241.8	328.0	196.6	432.4	367.4
Inoculant [Y]						
Liquid Only	8210 a	5037 b	5554 b	2815 a	4440 a	6345 a
1x granular	8177 a	5891 ab	5974 ab	2576 a	4606 a	6695 a
2x granular	8471 a	6221 a	5941 ab	2385 a	5259 a	7204 a
4x granular	8520 a	6030 a	6690 a	2434 a	4832 a	6005 a
S.E.M.	312.4	241.8	328.0	196.6	432.4	367.4
	Pr > *F* (p-value)					
Nitrogen (N)	**0.007**	**< 0.001**	**0.002**	0.905	**0.026**	0.082
Inoculant (I)	0.792	**0.006**	**0.027**	0.127	0.576	0.136
N × I	0.415	0.690	0.930	0.136	0.812	0.788
Inoculant – lin	0.378	**0.011**	**0.004**	0.058	0.456	0.458
Inoculant – quad	0.914	**0.011**	0.779	0.148	0.333	**0.034**

[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)

Whole plant N concentrations are presented in Table 9. Both N treatment and granular inoculant rate affected tissue N concentrations in all cases. Nitrogen effects on tissue N varied somewhat across site-years; however, the late season application of UAN consistently resulted in the highest concentrations. Starter N (side-banded urea and ESN) effects were somewhat inconsistent. At half of the site-years, including Indian Head (2015), Outlook (2015), and Melfort (2016), starter N reduced tissue N concentrations, perhaps an indication that the added mineral N was inhibiting nodulation to some extent. At Melfort in 2015, ESN resulted in higher N concentrations than urea or the control and at Outlook in 2016 neither of the starter N treatments differed from the control. At Indian Head in 2016, tissue N concentrations were similar between the control and starter N treatments but higher with the late season application of UAN. The addition of granular inoculant increased tissue N concentrations at all locations; however the response at Outlook in 2016 was relatively weak and not all individual granular inoculant treatments differed from the control where only seed-applied liquid inoculant was applied. With the exception of Melfort 2016 where tissue N increased right up the 4x inoculant rate, tissue N generally peaked at 1-2x the label recommended rate. The N treatment x inoculant rate interaction was also significant and due to the N fertilizer effects being largely limited to or strongest when only liquid inoculant was applied (Table A-4, Appendices).

Table 9. Main effect means, overall F-test and contrast results for soybean whole plant tissue nitrogen concentration. 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	Tissue N (%)					
Control (0N)	2.85 a	2.70 b	2.93 b	3.25 ab	2.74 b	2.54 b
55 N – urea	2.51 b	2.57 b	2.60 c	3.31 ab	2.73 b	2.28 c
55N – ESN	2.53 b	2.63 b	2.72 bc	3.23 b	2.94 a	2.26 c
55N – UAN	2.79 a	2.91 a	3.26 a	3.41 a	3.07 a	2.71 a
S.E.M.	0.052	0.059	0.074	0.063	0.072	0.046
Inoculant [Y]						
Liquid Only	1.89 c	1.90 b	1.91 c	3.18 b	2.38 b	1.95 d
1x granular	2.81 b	2.91 a	2.99 b	3.43 a	2.96 a	2.41 c
2x granular	3.01 a	3.00 a	3.24 a	3.32 ab	3.03 a	2.62 b
4x granular	2.98 a	3.01 a	3.36 a	3.28 ab	3.12 a	2.81 a
S.E.M.	0.052	0.059	0.074	0.063	0.071	0.046
	Pr > *F* (p-value)					
Nitrogen (N)	**< 0.001**	**< 0.001**	**< 0.001**	**0.033**	**< 0.001**	**< 0.001**
Inoculant (I)	**< 0.001**	**< 0.001**	**< 0.001**	**0.006**	**< 0.001**	**< 0.001**
N × I	0.246	**< 0.001**	0.328	0.586	0.963	**< 0.001**
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.654	**< 0.001**	**< 0.001**
Inoculant – quad	**< 0.001**	**< 0.001**	**< 0.001**	**0.008**	**< 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)

Whole plant N uptake was calculated from the above-ground biomass yields and tissue N concentrations (Table 10). Similar to the above-ground biomass yields and because of variation in crop stage at sampling combined with the rapid biomass application that occurred during the reproductive stages of soybeans, N uptake values should not be compared across site-years. Whole plant N uptake was only affected by N treatment at 1/6 site-years but by inoculant treatment at 5/6 site-years, the exception being Outlook in 2016 ($P = 0.25$). At the site where the N treatment effect was significant (Indian Head 2016; $P = 0.04$), there was a tendency for higher N uptake in the treatments that received starter N; however, the effects were small enough that no individual treatment differences were significant when averaged across inoculant rates. At the 5/6 sites where granular inoculant effects were significant, its addition consistently increased total N uptake. At 4/5 responsive sites, total N uptake peaked at approximately 1x the label recommended rate while at Outlook in 2015 the response was stronger with significant increases in N uptake detected up the 2x rate. No interactions between N treatment and granular inoculant rate were detected for this variable.

Table 10. Main effect means, overall F-test and contrast results for soybean whole plant nitrogen uptake. 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	N Uptake (kg N/ha)					
Control (0N)	214.4 a	143.5 a	160.7 a	81.7 a	84.3 a	154.0 a
55 N – urea	211.8 a	172.6 a	163.7 a	83.6 a	85.3 a	162.8 a
55N – ESN	224.9 a	166.9 a	187.3 a	84.9 a	88.7 a	153.8 a
55N – UAN	239.8 a	151.3 a	188.9 a	85.3 a	92.4 a	167.4 a
S.E.M.	9.09	8.71	11.54	6.60	2.68	9.32
Inoculant [Y]						
Liquid Only	154.4 b	96.0 b	105.7 c	89.8 a	63.4 b	123.3 b
1x granular	228.3 a	171.3 a	178.8 b	87.6 a	92.1 a	160.9 a
2x granular	254.7 a	186.8 a	192.3 ab	78.6 a	97.6 a	185.8 a
4x granular	253.5 a	180.2 a	223.8 a	79.5 a	97.7 a	168.1 a
S.E.M.	9.09	8.71	11.54	6.60	2.68	9.32
	Pr > *F* (p-value)					
Nitrogen (N)	0.055	**0.042**	0.078	0.949	0.146	0.666
Inoculant (I)	**< 0.001**	**< 0.001**	**< 0.001**	0.251	**< 0.001**	**< 0.001**
N × I	0.323	0.551	0.893	0.257	0.704	0.270
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.091	**< 0.001**	**0.003**
Inoculant – quad	**< 0.001**	**< 0.001**	**0.002**	0.433	**< 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 11. Averaged across treatments, yields ranged from 2334-4518 kg/ha (35-67 bu/ac) and were generally highest at Outlook, followed by Melfort and then Indian Head. Yields were affected by N treatment at 3/6 site-years, by granular inoculant rate at 5/6 sites and there was a significant N × inoculant interaction at 2/6 sites, in both cases at Indian Head. Focussing on overall N effects, the observed responses varied to some extent at the sites where they were significant. At Indian Head in 2015, there was no overall benefit to starter N (side-banded urea or ESN) but a modest yield increase with a late season application of UAN. In 2016 at Indian Head, starter N resulted in a slight yield increase over the control while the late season UAN again resulted in the highest overall yields. In both cases at Indian Head the N × inoculant interaction was significant, however, and showed that the benefits to N (regardless of form or timing) were only observed when no granular inoculant was applied (Table 12). At Melfort in 2016 where initial residual N levels were high, soybean yields were highest with no supplemental N fertilizer and significantly lower with side-banded urea. The inoculant effects were generally consistent across locations with significant benefits to dual inoculation at 5/6 site-years but no significant yield increases with rates of granular inoculant exceeding the label recommendation. The magnitude of the yield increases with dual inoculation ranged from 5% at Outlook in 2016 (ns) to 53% at Indian Head in 2016 and averaged 25% across all six sites.

Table 11. 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	Seed Yield (kg/ha)					
Control (0N)	2627 b	2200 c	3779 a	4551 a	3046 a	2725 a
55 N – urea	2528 b	2327 b	3733 a	4621 a	3115 a	2327 b
55N – ESN	2578 b	2339 b	3834 a	4387 a	3015 a	2599 a
55N – UAN	2772 a	2470 a	3733 a	4512 a	3004 a	2545 ab
S.E.M.	45.9	68.8	72.3	116.4	91.6	81.5
Inoculant [Y]						
Liquid Only	2232 b	1672 b	2971 b	4352 a	2670 b	2344 b
1x granular	2745 a	2538 a	3989 a	4586 a	3118 a	2547 ab
2x granular	2746 a	2567 a	3963 a	4540 a	3237 a	2732 a
4x granular	2781 a	2560 a	4156 a	4594 a	3155 a	2571 ab
S.E.M.	45.9	68.8	72.3	116.4	91.6	81.5
	Pr > *F* (p-value)					
Nitrogen (N)	**< 0.001**	**< 0.001**	0.723	0.166	0.670	**0.003**
Inoculant (I)	**< 0.001**	**< 0.001**	**< 0.001**	0.085	**< 0.001**	**0.004**
N × I	**0.039**	**< 0.001**	0.709	0.632	0.762	0.438
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.063	**< 0.001**	**0.034**
Inoculant – quad	**< 0.001**	**< 0.001**	**< 0.001**	0.186	**< 0.001**	**0.003**

[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 contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean seed yield (kg/ha). 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	
	2015	2016	2015	2016	2015	2016
	---------- Control (ON) [Z] ----------					
Control	2170 cd	1240 d	2858	4292 a	2574 b	2412 abc
1x	2792 ab	2496 a	4134	4612 a	3131 a	2725 abc
2x	2850 ab	2538 a	3948	4715 a	3202 a	3060 a
4x	2696 ab	2527 a	4176	4586 a	3277 a	2703 abc
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.233	**0.002**	0.169
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.088	**0.035**	**0.007**
	---------- 55N – urea ----------					
Control	2185 cd	1764 c	2788	4524 a	2711 ab	2161 c
1x	2613 ab	2492 a	3891	4782 a	3160 ab	2377 abc
2x	2667 ab	2500 a	4015	4510 a	3255 ab	2274 bc
4x	2648 ab	2553 a	4237	4669 a	3333 a	2496 abc
Inoculant – lin	**< 0.001**	**< 0.001**	**<.0001**	0.769	**0.005**	0.145
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.913	0.083	0.957
	---------- 55N – ESN ----------					
Control	2048 d	1665 c	3183	4377 a	2761 ab	2342 abc
1x	2745 ab	2549 a	4004	4275 a	3151 ab	2549 abc
2x	2709ab	2578 a	3997	4440 a	3224 ab	2956 ab
4x	2810 ab	2562 a	4153	4455 a	2923 ab	2548 abc
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.543	0.648	0.273
Inoculant - quad	**< 0.001**	**< 0.001**	**0.008**	0.874	**0.013**	**0.010**
	---------- 55N – UAN ----------					
Control	2527 bc	2017 b	3055	4215 a	2635 ab	2462 abc
1x	2832 ab	2615 a	3926	4674 a	3029 ab	2538 abc
2x	2757 ab	2650 a	3893	4494 a	3265 ab	2640 abc
4x	2970 a	2600 a	4059	4665 a	3086 ab	2538 abc
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.097	0.038	0.707
Inoculant - quad	0.345	**< 0.001**	**0.006**	0.327	**0.014**	0.444
S.E.M.	77.1	74.8	144.6	172.9	150.7	146.7

[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)

Overall tests of fixed effects and main effects means for seed N concentrations are presented along with their interactions in Tables 13 and A-6 (Appendices), respectively. The effect of N fertilizer treatment on seed N concentrations was significant at 4/6 site-years while the inoculant effect was always significant ($P < 0.001$-0.006). At the sites where the N fertilizer effect was significant, N concentrations were generally highest with the late season UAN application, to lesser extent, the control where no supplemental N was provided. Side-banded N frequently reduced seed N concentrations (i.e. Indian Head 2015, Melfort 2016). Dual inoculation consistently increased seed N concentrations; however, the granular inoculant rate where values were maximized ranged from

1-4x the label recommended rates. The N × I interaction was significant at Indian Head in both years and appeared to be due to the N effects being most prominent in the treatment where only liquid inoculant was applied.

Table 13. Main effect means, overall F-test and contrast results for soybean seed nitrogen 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	Seed N (%)					
Control (0N)	5.94 a	5.64 b	5.84 a	3.25 ab	6.29 a	6.40 a
55 N – urea	5.67 c	5.58 bc	5.80 a	3.31 ab	6.23 a	6.20 b
55N – ESN	5.68 c	5.56 c	5.82 a	3.23 b	6.28 a	6.20 b
55N – UAN	5.82 b	5.79 a	5.84 a	3.41 a	6.28 a	6.34 a
S.E.M.	0.020	0.039	0.023	0.063	0.071	0.031
Inoculant [Y]						
Liquid Only	5.05 c	4.69 c	5.45 b	3.18 b	5.98 b	5.8 d
1x granular	5.93 b	5.90 b	5.92 a	3.43 a	6.34 a	6.3 c
2x granular	6.06 a	5.96 ab	5.95 a	3.32 ab	6.39 a	6.4 b
4x granular	6.07 a	6.01 a	5.98 a	3.28 ab	6.38 a	6.6 a
S.E.M.	0.020	0.039	0.023	0.063	0.071	0.031
	Pr > *F* (p-value)					
Nitrogen (N)	**< 0.001**	**< 0.001**	0.419	**0.033**	0.854	**< 0.001**
Inoculant (I)	**< 0.001**	**< 0.001**	**< 0.001**	**0.006**	**< 0.001**	**< 0.001**
N × I	**0.002**	**< 0.001**	0.066	0.586	0.656	0.091
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.654	**< 0.001**	**< 0.001**
Inoculant – quad	**< 0.001**	**< 0.001**	**< 0.001**	**0.008**	**< 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)

Results for total N exports (calculated from seed yields and seed N concentrations) are presented in Tables 14 and A-7 (Appendices). Nitrogen fertilizer treatment affected total N exports at 3/6 site-years; however the specific nature of the effects varied. At Indian Head in 2015 total N exports were lower with banded N and higher in both the control and with post-emergent UAN while at Melfort in 2016 total N exports also tended to be highest in the control. At Indian Head in 2016, where the strongest yield response to N was observed, N exports were lowest in the control, higher with side-banded N and highest with post-emergent UAN. Total N exports were affected by granular inoculant rates at 5/6 locations, including all site-years except Outlook 2016 where there was no yield benefit to dual inoculation. In all cases, total N exports were maximized with approximately 1x the label recommended rate of granular inoculant. Again, the N × I interaction was only significant at Indian Head (both years) and, similar to the other variables, largely due to N fertilizer effects being most prominent when no granular inoculant was applied.

Table 14. Main effect means, overall F-test and contrast results for soybean nitrogen exports in the harvested seed. 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	
	2015	2016	2015	2016	2015	2016
N Fertilizer [Z]	N Exports (kg N/ha)					
Control (0N)	157.0 a	127.4 c	222.3 a	272.2 a	193.2 a	174.7 a
55 N – urea	144.4 b	131.8 bc	217.9 a	276.1 a	194.2 a	144.6 b
55N – ESN	147.8 b	132.6 b	224.5 a	262.0 a	189.2 a	161.6 ab
55N – UAN	161.9 a	143.8 a	218.3 a	268.8 a	188.7 a	161.4 ab
S.E.M.	2.75	4.79	4.45	6.99	5.64	5.04
Inoculant [Y]						
Liquid Only	113.0 b	78.7 b	162.0 b	260.1 a	159.6 b	136.8 b
1x granular	163.0 a	149.9 a	236.4 a	273.3 a	198.5 a	160.3 a
2x granular	166.3 a	153.0 a	235.7 a	271.2 a	206.2 a	176.1 a
4x granular	168.8 a	154.0 a	248.8 a	274.6 a	201.0 a	169.1 a
S.E.M.	2.75	4.79	4.52	6.99	5.64	5.04
	Pr > *F* (p-value)					
Nitrogen (N)	**< 0.001**	**< 0.001**	0.652	0.153	0.823	**< 0.001**
Inoculant (I)	**< 0.001**	**< 0.001**	**< 0.001**	0.094	**< 0.001**	**< 0.001**
N × I	**0.034**	**< 0.001**	0.611	0.557	0.959	0.395
Inoculant – lin	**< 0.001**	**<.0001**	**< 0.001**	0.056	**< 0.001**	**< 0.001**
Inoculant – quad	**< 0.001**	**<.0001**	**< 0.001**	0.214	**< 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)

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

Overall, the first two years of this project have been considered successful with relatively high soybean yields at all site-years and all work progressing on schedule. Nitrogen fertilization occasionally increased above-ground biomass but rarely affected seed yields. The exceptions were specifically at Indian Head and only in the absence of granular inoculant and, consequently, poor nodulation. The greatest benefits to N were observed with the late season surface dribble-band applications of UAN; however at Indian Head in 2016 starter N was also beneficial, albeit to a lesser extent than the later application. When no granular inoculant was applied, surface dribble banded UAN applied at early pod fill resulted in 16% and 62% yield increases at Indian Head in 2015 and 2016. This response to N did not occur at the other site-years despite relatively strong responses to dual inoculation. Starter N only affected seed N concentrations at Indian Head but the results were inconsistent with a slight reduction in 2015 but a positive effect in 2016, particularly when no granular inoculant was applied. Granular inoculant, on the other hand, resulted in significant seed yield increases at 5/6 sites and overall average increase of 25% over where only a liquid inoculant was applied. Granular inoculant also consistently increased both seed N concentrations and total N exports in the harvested seed. Under the environmental conditions encountered to date, the label recommended rate was sufficient to maximize seed yield. While the observed increases in seed N (i.e. protein) is less important to producers who are not generally paid for protein, this can be important from an industry standpoint as high protein meal is desirable to those utilizing it for food and feed purposes. Even in the case where dual inoculation did not come with a yield benefit (Outlook 2016), there was a positive effect on seed N concentrations.

Overall, the results to date suggest that proper inoculation is extremely important; however, supplemental N is not required for soybeans under normal conditions. That said, there can be benefits to supplemental N when residual N levels are extremely low or, especially, when nodulation is poor (due to either poor inoculation or unfavourable

environmental conditions) and unlikely to meet the crop's N demands. The largest and most consistent responses to N fertilizer occurred when applied late in the season, closer to peak uptake and after root nodules have had sufficient time to become fully established. In conclusion, growers should always aim to ensure adequate nodulation by properly inoculating their crop. On sites such as ours with limited or no history of soybeans, dual inoculation (liquid plus granular) is likely to be economical. If poor nodulation is suspected, regardless of the reason, late season (i.e. R2-R3) surface application of 55 kg N/ha (as surface applied UAN or other plant available forms such as granular urea) can prevent a significant amount of yield loss; however, yields will not likely be recovered to what could have been achieved with strong initial nodulation.

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 and 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 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 commercially applied liquid inoculant. The addition of supplemental granular inoculant increased yields at all locations except Outlook in 2016 where the site had a strong history of soybeans in rotation. At the responsive sites, yield increases with dual inoculation ranged from 12-53% and averaged 29%. Dual inoculation also consistently increased tissue and seed N, or protein, and in some cases responses to granular inoculant rates exceeding those required to maximize yield were observed. As a matter of interest, soybeans are tremendous users of N whereby, in the current trial, observed N exports (in the harvested seed) for the dual inoculated soybeans ranged from 152-273 kg N/ha and averaged 200 kg N/ha. While N fertilization sometimes resulted in increased above-ground biomass (particularly when residual N was low), this response rarely translated into a positive effect on seed yield and, when N was applied at seeding, appeared to negatively impact N fixation in some cases (i.e. Indian Head, 2015). The most compelling benefits to N fertilizer applications were observed at Indian Head but only occurred in the absence of granular inoculant and were strongest for late season (R2-R3 stage) surface applications of UAN. 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 to N fertilizer in any cases where both liquid inoculant plus a 1x 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 recovered with late season surface applications of N during the early reproductive stages, prior to peak biomass application and N uptake. While the specific N formulation evaluated in the current trial was liquid UAN, similar results may be expected with other readily available (to plants) formulations such as granular urea or ammonium nitrate. This work is continuing at all three locations IN 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.*

In 2015, the research was introduced and field trials shown at two major field days at Indian Head, to approximately 70 retail agronomists on July 10 (Federated Coop Limited Tour) and 200 producers and agronomists on July 21 (Indian Head Crop Management Field Day). The first tour was hosted by Chris Holzapfel while, at the latter, both John Heard (MAFRI) and Chris Holzapfel (IHARF) discussed soybean inoculation, starter N and options for rescuing crops in cases where nodulation is inadequate. The trial was also highlighted at a Faba bean and Soybean tour at Melfort on July 29, 2015 which was attended by 75 people. In 2016, the trial was again shown and discussed by Chris Holzapfel (IHARF) and Corey Loessin (SPG) at the Indian Head Crop Management Field Day (July 19, 212 people) and again on tours coordinated with Arysta Lifesciences (July 26, 45 guests) Richardson Pioneer (July 27, 33 guests). At Outlook in 2016, the trial was shown to approximately 300 guests at the ICDC Field Day and again to approximately 50 guests on a smaller tour on August 16. Preliminary results were presented by Chris

Holzapfel at both the Corn and Soybean Summit in Estevan (December 9, 2016, approximately 40 guests) and at the IHARF Winter Seminar and AGM in Weyburn (February 1, approximately 100 guests). Jessica Pratchler presented preliminary results at the SIA Ag Update in Melfort (February 2, approximately 150 guests).

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 help establish best management practices for ensuring adequate N supply and maximum economic yields for soybean production in Saskatchewan to help producers grow this crop in the most economically, agronomically and environmentally sound 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 1.6 million acres in 2016. In Saskatchewan, 2016 soybean acres were estimated at approximately 240,000 acres compared to 170,000 in 2013. 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 is subsequently 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 a relatively new addition to crop rotations, such as most Saskatchewan fields, 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 17 sites (Tone et al. 2014). 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 and after that economic response 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 soybean production 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 operation of a post-emergent application. In cases where responses to N have been reported, low rates (50 kg N/ha or less) have generally been 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 was desirable from a scientific perspective, we have chosen to exclude this treatment as it created 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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Acknowledgements

Direct collaborators in this project include Garry Hnatowich (Irrigation Crop Diversification Corporation) and Stewart Brandt (Northeast Agriculture Research Foundation) who are responsible for the sites at Outlook and

Melfort, respectively and for assisting with interpretation of results, reporting and extension. Financial support for the project is provided by the Saskatchewan Pulse Crop Development Board while seed and inoculant have been provided in-kind by Dekalb and Monsanto BioAg. The many contributions of the professional and technical staff at all locations are greatly appreciated.

Additional Results Tables

Table A-1. Treatment means and contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean emergence (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	
	2015	2016	2015	2016	2015	2016
	---------- Control (ON) [Z] ----------					
Control	49.8 a	49.5 a	54.7 a	54.7 a	28.1 a	46.8 a
1x	50.9 a	49.2 a	62.3 a	54.6 a	36.5 a	43.1 a
2x	51.9 a	45.3 a	56.3 a	50.8 a	28.8 a	45.9 a
4x	52.3 a	48.8 a	59.5 a	51.6 a	36.5 a	42.3 a
Inoculant – lin	0.456	0.765	0.407	0.107	0.366	0.512
Inoculant - quad	0.787	0.344	0.492	0.426	0.961	0.982
	---------- 55N – urea ----------					
Control	54.0 a	43.7 a	56.8 a	51.0 a	26.7 a	34.9 a
1x	52.3 a	47.6 a	57.0 a	52.9 a	42.1 a	31.2 a
2x	44.9 a	47.4 a	59.9 a	55.2 a	42.2 a	34.9 a
4x	52.9 a	50.2 a	59.5 a	51.9 a	27.8 a	32.0 a
Inoculant – lin	0.635	0.103	0.329	0.737	0.708	0.747
Inoculant - quad	0.016	0.700	0.670	0.070	0.004	0.995
	---------- 55N – ESN ----------					
Control	49.9 a	49.4 a	59.1 a	52.7 a	28.5 a	39.0 a
1x	56.6 a	42.9 a	62.1 a	52.6 a	34.4 a	39.0 a
2x	50.3 a	45.5 a	55.6 a	52.4 a	32.3 a	41.0 a
4x	49.2 a	50.7 a	56.8 a	54.1 a	26.3 a	33.2 a
Inoculant – lin	0.370	0.383	0.224	0.494	0.559	0.283
Inoculant - quad	0.265	0.054	0.883	0.595	0.275	0.351
	---------- 55N – UAN ----------					
Control	55.0 a	52.7 a	60.3 a	53.7 a	34.8 a	40.2 a
1x	51.1 a	47.2 a	60.6 a	49.9 a	36.9 a	48.4 a
2x	51.3 a	49.6 a	56.4 a	54.5 a	41.4 a	44.3 a
4x	52.9 a	45.1 a	59.5 a	52.5 a	26.0 a	43.1 a
Inoculant – lin	0.717	0.080	0.647	0.969	0.170	0.905
Inoculant - quad	0.247	0.790	0.355	0.874	0.080	0.293
S.E.M.	2.38	2.59	2.71	3.34	5.01	3.86

[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 contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean pod clearance (cm). 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	
	2015	2016	2015	2016	2015	2016
	Control (ON) [Z]					
Control	4.4 a	4.8 a	—	—	10.9 b	—
1x	5.0 a	5.1 a	—	—	12.0 ab	—
2x	4.0 a	4.5 a	—	—	11.4 ab	—
4x	5.3 a	4.9 a	—	—	11.5 ab	—
Inoculant – lin	0.499	0.995	—	—	0.737	—
Inoculant - quad	0.536	0.655	—	—	0.546	—
	55N – urea					
Control	5.6 a	4.5 a	—	—	14.5 a	—
1x	4.2 a	5.1 a	—	—	11.6 ab	—
2x	4.8 a	4.5 a	—	—	12.0 ab	—
4x	4.5 a	4.8 a	—	—	11.4 ab	—
Inoculant – lin	0.449	0.892	—	—	0.011	—
Inoculant - quad	0.519	0.897	—	—	0.063	—
	55N – ESN					
Control	5.5 a	4.5 a	—	—	12.2 ab	—
1x	4.7 a	5.1 a	—	—	12.3 ab	—
2x	5.2 a	4.1 a	—	—	11.5 ab	—
4x	5.9 a	5.2 a	—	—	12.3 ab	—
Inoculant – lin	0.556	0.445	—	—	0.956	—
Inoculant - quad	0.392	0.485	—	—	0.482	—
	55N – UAN					
Control	4.5	3.0 a	—	—	10.7 b	—
1x	5.6	4.4 a	—	—	10.8 b	—
2x	3.5	4.5 a	—	—	11.0 ab	—
4x	3.1	4.6 a	—	—	11.1 ab	—
Inoculant – lin	0.053	**0.046**	—	—	0.647	—
Inoculant - quad	0.720	0.104	—	—	0.928	—
S.E.M.	0.77	0.48	—	—	0.72	—

[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-3. Treatment means and contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean above-ground biomass yield (kg/ha). 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	
	2015	2016	2015	2016	2015	2016
	---------- Control (ON) [Z] ----------					
Control	6529 a	3689 b	4850 b	2875 a	4494 a	5229 a
1x	7251 a	5678 ab	5525 ab	2615 a	3563 a	6262 a
2x	8489 a	5323 ab	5438 ab	2635 a	4587 a	6255 a
4x	7407 a	5851 ab	5805 ab	1962 a	4350 a	6214 a
Inoculant – lin	0.282	0.011	0.248	0.022	0.877	0.439
Inoculant - quad	0.062	0.096	0.685	0.638	0.834	0.421
	---------- 55N – urea ----------					
Control	8547 a	6384 a	5745 ab	2324 a	4461 a	7055 a
1x	8465 a	6492 a	6378 ab	2635 a	5146 a	7130 a
2x	8104 a	7038 a	6158 ab	2408 a	6565 a	8785 a
4x	8670 a	6687 a	6380 ab	2759 a	6085 a	5988 a
Inoculant – lin	0.898	0.595	0.493	0.347	0.159	0.357
Inoculant - quad	0.548	0.493	0.681	0.939	0.292	0.038
	---------- 55N – ESN ----------					
Control	8908 a	5477 ab	6605 ab	3411 a	5180 a	6978 a
1x	8916 a	6401 a	6358 ab	2606 a	5960 a	6750 a
2x	9211 a	6795 a	6680 ab	2148 a	5907 a	7357 a
4x	8530 a	6448 a	7850 a	2397 a	4401 a	6132 a
Inoculant – lin	0.661	0.209	0.056	0.017	0.404	0.455
Inoculant - quad	0.560	0.125	0.308	0.019	0.238	0.489
	---------- 55N – UAN ----------					
Control	8858 a	4597 ab	5018 b	2650 a	3626 a	6119 a
1x	8079 a	4992 ab	5638 ab	2450 a	3756 a	6640 a
2x	8079 a	5728 ab	5488 ab	2348 a	3979 a	6418 a
4x	9473 a	5131 ab	6725 ab	2618 a	4492 a	5684 a
Inoculant – lin	0.321	0.411	0.027	0.998	0.452	0.555
Inoculant - quad	0.100	0.192	0.722	0.373	0.927	0.470
S.E.M.	604.0	483.6	555.2	307.4	864.7	734.8

[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-4. Treatment means and contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean whole plant tissue nitrogen concentrations (%). 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	
	2015	2016	2015	2016	2015	2016
	---------- Control (ON) [Z] ----------					
Control	1.97 de	1.60 d	1.95 f	3.13 b	2.23 d	1.75 f
1x	3.06 ab	3.00 ab	3.08 cd	3.38 ab	2.78 abc	2.50 bcd
2x	3.23 a	3.08 ab	3.25 abc	3.20 ab	2.90 ab	2.73 bc
4x	3.16 ab	3.13 ab	3.45 abc	3.30 ab	3.08 a	3.18 a
Inoculant – lin	< 0.001	< 0.001	< 0.001	0.420	< 0.001	< 0.001
Inoculant - quad	< 0.001	< 0.001	< 0.001	0.535	0.014	0.001
	---------- 55N – urea ----------					
Control	1.72 e	1.88 d	1.70 f	3.23 ab	2.28 cd	1.93 f
1x	2.63 c	2.75 b	2.60 de	3.40 ab	2.83 ab	2.18 def
2x	2.88 abc	2.80 ab	3.10 bcd	3.30 ab	2.88 ab	2.45 cd
4x	2.84 bc	2.85 ab	3.00 cd	3.33 ab	2.95 ab	2.55 bcd
Inoculant – lin	< 0.001	< 0.001	< 0.001	0.686	< 0.001	< 0.001
Inoculant - quad	< 0.001	< 0.001	< 0.001	0.494	0.008	0.053
	---------- 55N – ESN ----------					
Control	1.73 e	1.80 d	1.75 f	3.13 b	2.53 bcd	1.95 ef
1x	2.61 c	2.85 ab	3.05 cd	3.25 ab	3.03 ab	2.15 def
2x	2.86 abc	2.98 ab	2.93 cd	3.35 ab	3.08 a	2.38 cde
4x	2.95 abc	2.90 ab	3.15 bcd	3.18 b	3.15 a	2.58 bcd
Inoculant – lin	< 0.001	< 0.001	< 0.001	0.788	< 0.001	< 0.001
Inoculant - quad	< 0.001	< 0.001	< 0.001	0.084	0.016	0.309
	---------- 55N – UAN ----------					
Control	2.16 d	2.33 c	2.25 ef	3.25 ab	2.50 bcd	2.18 def
1x	2.94 abc	3.03 ab	3.25 abc	3.68 a	3.23 a	2.80 abc
2x	3.09 ab	3.15 a	3.70 ab	3.43 ab	3.25 a	2.93 ab
4x	2.99 abc	3.15 a	3.83 a	3.30 ab	3.30 a	2.93 ab
Inoculant – lin	< 0.001	< 0.001	< 0.001	0.560	< 0.001	< 0.001
Inoculant - quad	< 0.001	< 0.001	< 0.001	0.018	< 0.001	< 0.001
S.E.M.	0.084	0.087	0.127	0.102	0.116	0.086

[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-5. Treatment means and contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean nitrogen uptake (kg N/ha). 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	
	2015	2016	2015	2016	2015	2016
	---------- Control (ON) [Z] ----------					
Control	128.2 e	58.5 e	94.8 d	90.4 a	56.7 e	91.5 b
1x	221.4 a-d	169.5 a-d	172.5 a-d	87.6 a	87.0 a-d	157.1 ab
2x	274.1 a	163.3 a-d	176.1 a-d	84.4 a	93.2 ab	169.0 ab
4x	234.1 ab	182.7 abc	199.5 ab	64.3 a	100.4 a	198.3 a
Inoculant – lin	< 0.001	< 0.001	0.001	0.045	< 0.001	< 0.001
Inoculant - quad	< 0.001	0.001	0.074	0.550	0.005	0.139
	---------- 55N – urea ----------					
Control	145.9 de	119.6 b-e	99.6 cd	75.2 a	61.7 de	133.5 ab
1x	222.8 a-d	181.5 abc	166.2 a-d	89.5 a	88.5 a-d	154.9 ab
2x	232.8 ab	199.4 ab	196.1 abc	78.3 a	93.1 ab	211.5 a
4x	245.7 ab	189.9 ab	193.0 a-d	91.6 a	97.8 a	151.5 ab
Inoculant – lin	< 0.001	0.007	0.002	0.346	< 0.001	0.428
Inoculant - quad	0.011	0.009	0.021	0.995	0.010	0.010
	---------- 55N – ESN ----------					
Control	153.7 cde	97.2 d	115.5 bcd	108.1 a	70.1 b-e	135.4 ab
1x	231.6 abc	180.3 abc	193.2 a-d	84.3 a	95.3 ab	146.0 ab
2x	263.4 ab	203.4 a	193.9 abc	71.7 a	98.7 a	176.3 ab
4x	251.1 ab	186.8 abc	246.5 a	75.5 a	91.0 abc	157.4 ab
Inoculant – lin	< 0.001	0.001	<.0001	0.027	0.031	0.353
Inoculant - quad	< 0.001	0.001	0.243	0.066	0.002	0.269
	---------- 55N – UAN ----------					
Control	189.8 b-e	108.7 cde	112.9 bcd	85.7 a	65.1 cde	133.0 ab
1x	237.7 ab	154.1 a-d	183.2 a-d	89.2 a	97.6 a	185.6 ab
2x	248.5 ab	181.0 abc	203.4 ab	79.9 a	105.5 a	186.3 ab
4x	283.1 a	161.3 a-d	256.3 a	86.6 a	101.5 a	165.0 ab
Inoculant – lin	< 0.001	0.033	<.0001	0.946	< 0.001	0.410
Inoculant - quad	0.314	0.014	0.235	0.759	< 0.001	0.045
S.E.M.	16.14	16.14	20.29	10.58	5.36	18.64

[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-6. Treatment means and contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean seed nitrogen concentrations (%). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, *P* ≤ 0.05).

Inoculant Treatment [Y]	Indian Head		Outlook		Melfort	
	2015	2016	2015	2016	2015	2016
	Control (ON) [Z]					
Control	5.23 d	4.58 ef	5.53 b	3.13 b	6.03 ab	5.94 de
1x	6.16 ab	5.93 abc	5.95 a	3.38 ab	6.42 ab	6.40 b
2x	6.17 ab	6.03 ab	5.93 a	3.20 ab	6.48 a	6.50 ab
4x	6.20 a	6.03 ab	5.98 a	3.30 ab	6.25 ab	6.75 a
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.420	0.377	**< 0.001**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.535	**0.010**	**0.006**
	55N – urea					
Control	4.90 e	4.68 e	5.33 b	3.23 ab	5.95 ab	5.64 e
1x	5.78 c	5.80 c	5.90 a	3.40 ab	6.33 ab	6.24 bcd
2x	5.98 b	5.85 bc	5.98 a	3.30 ab	6.35 ab	6.41 b
4x	6.03 ab	5.98 abc	6.00 a	3.33 ab	6.28 ab	6.53 ab
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.686	0.127	**< 0.001**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.494	**0.044**	**< 0.001**
	55N – ESN					
Control	4.90 e	4.45 f	5.43 b	3.13 b	5.85 b	5.69 e
1x	5.79 c	5.90 bc	5.93 a	3.25 ab	6.38 ab	6.21 bcd
2x	6.00 b	5.93 abc	5.93 a	3.35 ab	6.38 ab	6.37 b
4x	6.03 ab	5.95 abc	6.00 a	3.18 b	6.53 a	6.53 ab
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.788	**0.001**	**< 0.001**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.084	0.055	**< 0.001**
	55N – UAN					
Control	5.19 d	5.05 d	5.53 b	3.25 ab	6.08 ab	6.03 cd
1x	6.01 ab	5.98 abc	5.90 a	3.68 a	6.25 ab	6.31 bc
2x	6.07 ab	6.03 ab	5.98 a	3.43 ab	6.35 ab	6.50 ab
4x	6.04 ab	6.10 a	5.95 a	3.30 ab	6.45 ab	6.52 ab
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.560	**0.033**	**< 0.001**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.018	0.493	**0.003**
S.E.M.	0.038	0.049	0.042	0.102	0.125	0.063

[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-7. Treatment means and contrast results for nitrogen (N) by inoculant (I) treatment effects on soybean nitrogen exports in harvested seed (kg N/ha). 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	
	2015	2016	2015	2016	2015	2016
	Control (ON) [Z]					
Control	113.4 de	56.5 f	157.8 b	255.1 a	155.1 b	143.3 bcd
1x	172.0 ab	147.6 abc	246.8 a	275.9 a	204.7 ab	174.3 abc
2x	175.8 a	153.0 abc	234.6 a	282.8 a	206.8 a	198.8 a
4x	167.0 ab	152.5 abc	249.9 a	274.9 a	206.3 ab	182.3 ab
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.176	**0.004**	**0.005**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.066	**0.007**	**0.002**
	55N – urea					
Control	107.3 e	82.7 e	148.3 b	271.7 a	161.4 ab	121.9 d
1x	151.1 bc	145.2 c	229.7 a	285.4 a	199.6 ab	148.4 bcd
2x	159.5 ab	146.5 bc	239.4 a	268.4 a	206.2 ab	145.5 bcd
4x	159.8 ab	152.7 abc	254.1 a	279.0 a	209.5 a	162.7 a-d
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.837	**0.004**	**0.006**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.942	**0.034**	0.419
	55N – ESN					
Control	100.4 e	74.4 e	173.1 b	261.9 a	160.8 ab	133.5 cd
1x	158.8 ab	150.6 abc	237.5 a	254.9 a	201.0 ab	158.5 a-d
2x	162.6 ab	152.9 abc	237.8 a	265.5 a	205.0 ab	188.3 ab
4x	169.4 ab	152.4 abc	249.6 a	265.9 a	190.1 ab	166.3 a-d
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.563	0.121	**0.013**
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.863	**0.005**	**0.002**
	55N – UAN					
Control	131.0 cd	101.3 d	168.7 b	251.7 a	161.0 ab	148.6 bcd
1x	170.1 ab	156.1 abc	231.7 a	276.9 a	188.7 ab	160.1 a-d
2x	167.4 ab	159.6 a	231.2 a	268.0 a	206.8 a	171.7 abc
4x	179.3 a	158.3 ab	241.7 a	278.7 a	198.4 ab	165.3 a-d
Inoculant – lin	**< 0.001**	**< 0.001**	**< 0.001**	0.085	**0.015**	0.200
Inoculant - quad	**< 0.001**	**< 0.001**	**< 0.001**	0.380	**0.024**	0.195
S.E.M.	4.59	5.23	8.72	10.34	10.39	9.29

[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)