2019 and 2020 Annual Report

Soybean and Pulse Agronomy Lab
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MacMillan, K. 2021. Soybean and Pulse Agronomy Program Lab 2019 and 2020 Annual Report.

About the Soybean and Pulse Agronomy Lab

The Soybean and Pulse Agronomy team led by Kristen P. MacMillan focuses on soybean, dry bean and pea agronomy and cropping systems. Our Mission is to study and develop best management practices for soybean and pulse cropping systems that optimize agronomy, profitability and sustainability for farmers in Manitoba and western Canada through applied agronomic research, extension and training. Established in 2017, this program is a unique collaboration between the Manitoba Pulse & Soybean Growers and the University of Manitoba that arose in response to the growth of soybean acres, steady dry bean production and re-emerging interest in peas. The Manitoba Pulse & Soybean Growers initiated and provided core funding for a 6-year research program focused specifically on soybean, dry bean and pea agronomy that would address production questions, extend knowledge and bring an applied professional to the classroom. This annual report is a summary of the Soybean and Pulse Agronomy lab's research trials in Manitoba in 2019 and 2020. It has been developed as a reference for farmers, crop advisors and industry members and is meant to provide a concise summary of each experiment.

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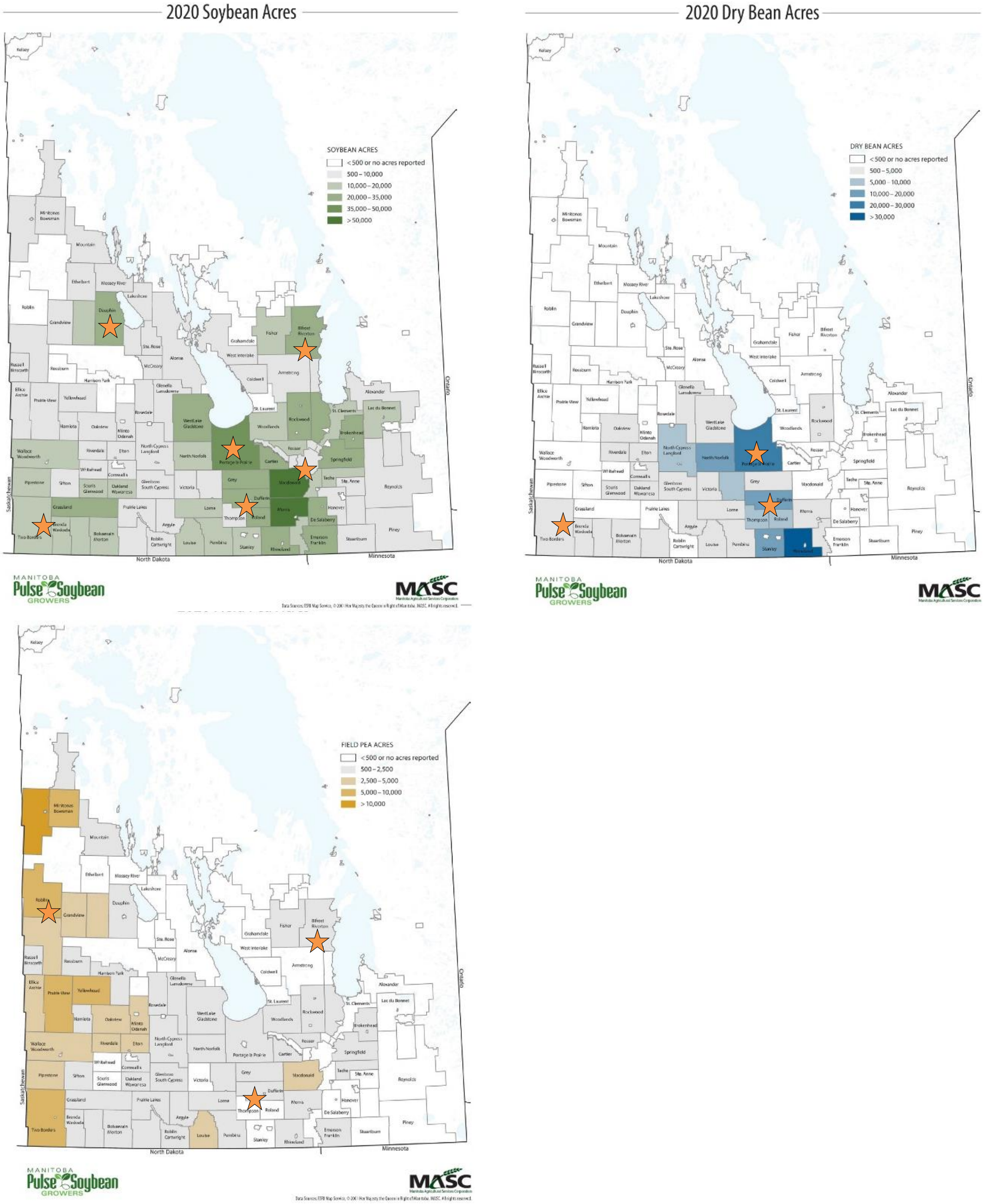

Figure A. Soybean, dry bean and field pea acre distribution by municipality in Manitoba and locations of research trials in the Soybean and Pulse Agronomy research lab (Maps developed by Manitoba Pulse & Soybean Growers with data from Manitoba Agricultural Services Corporation).

Collaborating Partners

The soybean and pulse agronomy research lab would like to thank the following organizations and teams for their contribution to our research in 2019 and 2020 and for making province-wide research possible:

- Alvin Iverson and team at the University of Manitoba Ian N. Morrison research farm in Carman, MB where we operate the majority of our research trials.
- Curtis Cavers, Zisheng Xing, Danny Bouchard and team at the Canada-Manitoba Crop Diversification Centre (CMCDC) in Portage la Prairie for hosting multiple soybean and dry bean trials.
- Scott Chalmers and team from the Western Agricultural Diversification Organization (WADO) at Melita for hosting a dry bean inoculant experiment.
- Nirmal Hari and team from the Prairies East Sustainable Agriculture Initiative (PESAI) in Arborg for hosting a soybean and pea intercropping experiment.
- James Frey and team at the Parkland Crop Diversification Foundation (PCDF) in Roblin for hosting a pea agronomy experiment.
- Ag Quest (Minto) for hosting a soybean seeding window experiment in Dauphin.
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- Keith Murphy of Murphy et al. for hosting the soybean iron deficiency chlorosis variety evaluation trial.
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PESAI WADO PCDF Agriculture and Agri-Food Canada CMCDC AG-QUEST Celebrating 35 Years of Research You Can Trust

We would also like to recognize our industry partners who have provided product for testing or seed and inputs for crop management:

BASF We create chemistry
NorthStar Genetics
LINNAEUS PLANT SCIENCES INC.
VERDESIAN
DEKALB
CORTEVA agriscience
syngenta
BrettYoung
Western Harvest
NutriAg

Soybean Seeding Depth Evaluation

(Arborg and Carman, MB • 2017-2019)

The objective of this study was to identify the optimum seeding depth for soybeans in Manitoba. The current recommendation is to seed soybeans between 0.75 and 1.5 inches based on guidelines from other regions. Dry soil conditions have often led agronomists and farmers to chase moisture and seed soybeans at >2 inches. Observations on the success of this practice have been variable - delayed emergence is a frequent observation and reduced emergence has occurred in some but not all cases. On the other hand, very wet soil conditions in spring have led some farmers to consider broadcasting and incorporating soybean seed. The yield impact of very shallow and deep seeding is currently unknown.

Soybean seeding depths between 0.25 and 2.25 inches were tested at Arborg (clay soil) and Carman (loam soil) from 2017 to 2019 in a randomized complete block design (RCBD) experiment. Trials were seeded with a double disc plot seeder between May 14 and May 24 at 200,000 seeds/ac. The soybean varieties used at Arborg and Carman were DK 23-60RY and DK 24-10RY, respectively. All trials were seeded into tilled stubble, except Arborg 2017 which was seeded into tilled fallow. Data collection included plant population, nodulation and root rot (Carman 2019 only), pod height (2018 and 2019 only), maturity and grain yield. Growing season conditions in all environments were drier than normal with cumulative spring precipitation in May and June equating to 56-145mm (40-87% of normal). At the time of seeding, moist soil was down to 1.25” at both locations in 2018 and an accumulated 25mm of rain occurred between 10 and 22 days after seeding among all environments.

Data from Arborg18, Arborg19, Carman17, Carman18 and Carman19 was combined for initial analysis using Proc Mixed in SAS 9.4 with environment, treatment (depth) and their interaction as fixed effects and block within environment as a random effect. Fixed effects were tested for heterogenous variance by using the repeated statement and comparing AIC fit statistics. Data from Arborg17 was excluded from the combined analysis because only 5 of the 7 treatment levels were present (imbalanced design), which would restrict production of LS Means. The plant density and yield data from all environments were then combined for regression analysis with Proc Glimmix. Due to the imbalanced design and to produce results applicable to all environments, environment was treated as a random effect for the combined regression analysis of the plant density and yield data. To assess the nature of soybean plant establishment and yield response to seed depth, LS means were assessed by regression. The treatment variance was partitioned within the full model into linear, quadratic and lack of fit components and the significance of the response pattern was determined using a F-test. To partition the treatment variance, Proc IML was used to obtain the orthogonal contrast coefficients. Regression coefficients and Efron’s Pseudo R^2 were estimated for the best fit model.

Table 1a. Summary of analysis of variance for main effects and their interactions on soybean plant density, pod height, maturity and grain yield for combined site-years.

Effect	Plant density	Pod height	Days to maturity	Yield (bu/ac)
Seed Depth (D)	***	***	ns	***
Environment (E)	***	***	***	*
E x D	***	ns	ns	*

* Significant at *P* = 0.05, ** Significant at *P* = 0.01, *** Significant at *P* = 0.001, ns = not significant.

Plant density

The effect of seed depth on soybean plant density varied by environment (Table 1a), however, the same general trend was present in all environments. The overall effect of seed depth on established plant density is presented in Figure 1a. **The soybean seed depth range that resulted in maximum plant density was 0.5 to 2.25".** Within this range of seed depth, the current recommended plant stand of 140-160,000 plants/ac was achieved. The actual plant stand ranged from 140-170,000 plants/ac, equating to 70-85% establishment, which is a typical range of establishment for soybeans. Very shallow seeding (0.25") resulted in significantly lower plant density - 81,000 plants/ac on average (equal to 41% establishment), which is only about 50% of a recommended plant stand. Deep seeding (2.25") resulted in 143,000 plants/ac, on average (equal to 71% establishment) and was similar to the seed depth range of 0.5-1.75".

Delayed and/or reduced plant establishment and reduced seedling vigour are factors that we observed in this study which could contribute to yield loss with non-optimal seeding depth (Fig. 1b, 1c). Shallow seeded soybeans (0.25") are prone to moisture fluctuations at the soil surface, resulting in reduced germination and establishment (Fig. 1c). Deep seeded soybeans (2.25") had greater establishment but emergence was delayed, increasing risk to soil pathogens and pests, and seedlings showed hypocotyl swelling, loss of cotyledons and chlorosis during emergence (Fig. 1c). Loss of one cotyledon has little effect on growth but loss of both cotyledons at the V-E stage has been shown to reduce yield by 8-9% (Hanway and Thompson 1967).

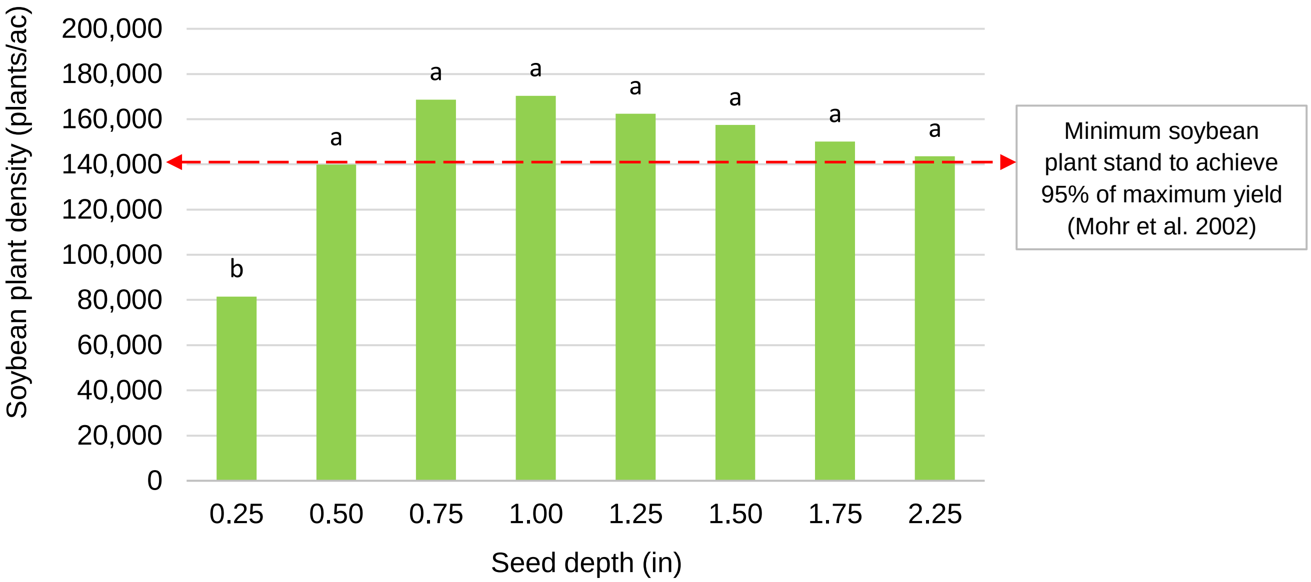

Figure 1a. Effect of seeding depth on soybean plant stand among 6 Manitoba environments (2017-2019). Means that contain the same letter are not statistically different at *P* = 0.05.

Figure 1b. Effect of seed depth from 0.25 to 2.25" (L-R) on soybean plant stand establishment.

Figure 1c. Left: Shallow seeded soybean (0.25”) exhibiting a range of emergence, including failed germination due to wetting followed by drying. Right: Deep seeded soybean (2.25”) exhibiting symptoms of hypocotyl swelling, loss of cotyledon(s) and chlorosis.

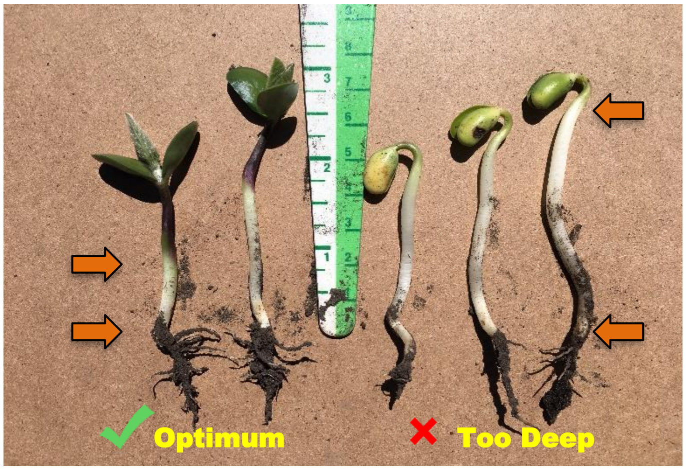

Figure 1d. Soybean seed depth should be measured post-seeding, at the cotyledon stage, by measuring the distance of white tissue on the hypocotyl from where the root hairs are visible to where green tissue begins.

Nodulation and Root Rot

To answer a question that was received from farmers and agronomists, we rated nodulation and root rot at the Carman experiment in 2019. There was no effect of seed depth on nodulation or root rot. Overall, nodulation score ranged from 2.1 to 2.5 out of 4 and root rot score ranged from 0.8 to 1.0 out of 9 among treatments 2-8 (0.5 to 2.25”). In other words, nodulation was good and root rot severity was very low overall. Ratings could not be measured in treatment 1 (0.25”) due to very low plant establishment and therefore inadequate sample size.

Soybean yield

Soybean yield was significantly affected by seed depth, environment and their interaction. Among environments, soybean yield ranged from 21 to 29 bu/ac. Although these yields are below the 10 yr provincial average of 34 bu/ac (MASC 2020), they are reflective of the growing seasons which received only 42 to 77% of normal precipitation from May through August. Provincial soybean yields were also below average from 2017 to 2019 (28-34 bu/ac). At each environment, the overall yield response to seed depth was similar but with varying magnitude, therefore the overall response is presented. The overall quadratic relationship between soybean yield and seed depth displayed in Fig. 1e explains 68% of the variation in soybean yield.

The seed depth range that maximized soybean yield (91-100% of maximum yield) was between 0.75 and 1.75" with yield maximization at 1.25". This study provides evidence that even under dry soil conditions, there is no benefit to chasing moisture and seeding soybeans deeper than the recommended range. Farmers and agronomists should choose seed depths within the range of 0.75 and 1.75" depending on soil type, soil moisture, management practices and equipment. Land rolling may increase the effective seed depth by closing furrows, and equipment often has a 0.5" variation in seed depth among openers or wings. Measuring seed depth during seeding and making adjustments by field is important. A post-emergent assessment to measure actual seeding depth at the cotyledon stage (Fig. 1d) should be adopted to ensure that the target seed depth was achieved.

Compared to other soybean management decisions that we have studied in the soybean and pulse agronomy program, including seeding date, fungicide and variety choice, ensuring seed depth is within the optimum range is likely the most influential to soybean yield, on average. In this study, shallow (0.25") and deep (2.25") seeding reduced soybean yield on average by 19 and 10%, respectively, and ranged from 0-36%. Shallow seeding was more detrimental than deep seeding in this study, likely due to dry soil conditions. **Mechanisms of yield loss with non-optimal seed depth observed in this study include delayed and reduced plant establishment, hypocotyl swelling, loss of cotyledon(s) and reduced seedling vigour.**

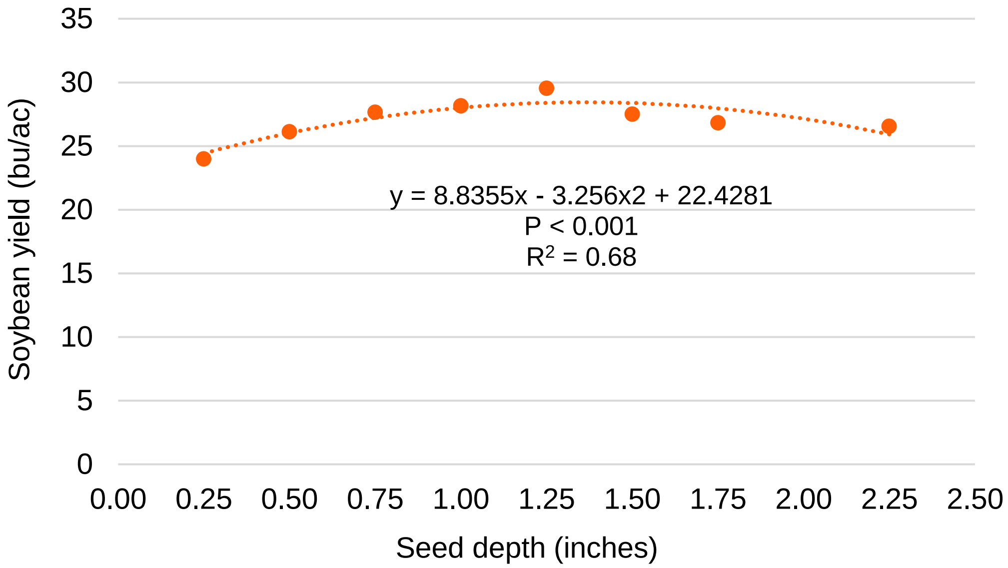

Figure 1e. Relationship between soybean seed depth and soybean yield based on data from 6 site-years in Manitoba (Arborg and Carman, MB from 2017 to 2019).

Pod height

To answer another question posed from farmers and agronomists, “does seed depth affect pod height?”, we measured height to the first pod bearing node. Pod height was significantly affected by seed depth and environment (Table 1a), but the agronomic differences are far more important for the effect of environment than seed depth. Among seed depths, pod height ranged from 3.5 to 3.9 inches and was statistically the same for all seed depths from 0.5 to 2.25” (Fig. 1f), being only significantly reduced with very shallow seeding (0.25”). Among environments, however, pod height ranged from 3.1 to 4.7 inches, which is a 1.5-fold difference. Environmental conditions and genetics are known to influence pod height while management practices have been shown to have little to no impact (Tkachuk 2019). The lowest pod height was observed at Arborg19 which was also the environment with coolest and driest spring growing conditions.

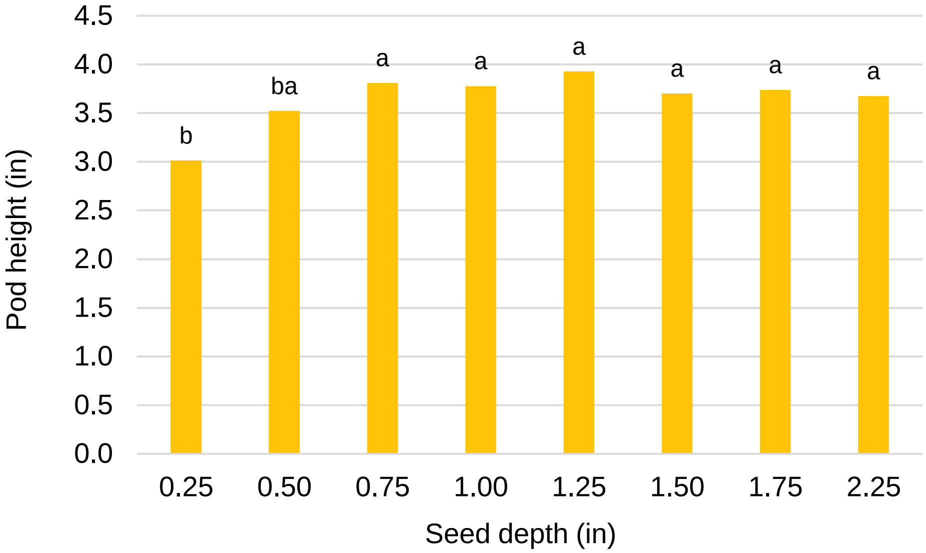

Figure 1f. Effect of seed depth on soybean pod height (4 site-years in Manitoba, 2018-2019).

Days to Maturity

Soybean maturity was affected by environment but not seed depth (Table 1a), ranging from 105 to 127 days from seeding to maturity among environments in 2018 and 2019.

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Defining the Optimum Soybean Seeding Window in Manitoba

(Arborg, Carman, Dauphin and Melita • 2017-2019)

Traditional recommendations are to plant soybeans when soil temperature has warmed to at least 10°C, which is typically May 15-25 in Manitoba (Manitoba Agriculture). However, farmers have started to seed soybeans earlier and work by Dr. Yvonne Lawley and Cassandra Tkachuk supports this trend. They seeded soybeans across a range of soil temperatures from 6-14°C in 2014 and 2015 at Carman, MB and Carrington, ND; the earliest seeding dates maximized yield regardless of soil temperature and it was concluded that calendar date is a superior indicator to soil temperature (Tkachuk 2017). To update soybean seeding date recommendations across a wider range of environments and using defined calendar dates, this study was initiated at Arborg, Carman, Dauphin and Melita in 2017 and continued through 2019. In this study, we seeded soybeans in soil temperatures as low as 0°C.

The objective of this study was to determine the optimum seeding window for soybeans across Manitoba growing regions.

The experimental design was a split plot Randomized Complete Block Design (RCBD), with seeding window as the main plot and variety as the split plot. The four seeding windows tested were “very early” (April 28 to May 6), “early” (May 8 to 14), “normal” (May 16 to 24) and “late” (May 31 to June 4). The short season variety S007-Y4 (MG 00.5) and mid season variety NSC Richer (MG 00.7) were seeded within each seeding window. This experiment was repeated at 4 sites; Arborg (A), Carman (C), Dauphin (D) and Melita (M) over 3 years (2017, 2018 and 2019) for a total of 11 environments. The same seed lot and granular inoculant was used for all sites in each year and soybeans were seeded at 200,000 seeds/ac to target 160,000 live plants/ac. Herbicide and insecticide use followed recommended practices.

Treatment effects were determined using ANOVA with Proc Mixed in SAS 9.4 where seeding date, environment and variety were considered fixed effects and block, always nested within environment, and block x seeding date were considered random effects. Effects were considered significant at $P < 0.05$ and means within treatments were separated using Tukey’s HSD for significant effects. Assumptions of ANOVA were tested prior to final analysis. Proc Corr was used to evaluate correlations among variables and Proc Reg was used for linear regression of oil and protein data.

Table 2a. Summary of analysis of variance for main effects and their interactions on soybean density, days to maturity, grain yield, protein and oil concentration for 11 environments (Arborg, Carman, Dauphin and Melita, 2017-2019).

Source of Variation	Plant density	Days to maturity	Grain yield	Oil	Protein
Environment (E)	***	***	***	***	***
Seeding Date (D)	***	***	***	***	***
Variety (V)	***	***	***	***	**
E x D	***	***	***	**	***
E x V	**	***	***	***	***
D x V	**	**	***	***	**
E x D x V	ns	**	ns	ns	ns

* Significant at $p < 0.05$, ** Significant at $p < 0.01$, *** Significant at $p < 0.001$, ns = not significant

Soybean yield

Overall, soybean yield was statistically similar among the first three seeding windows, which spans April 28 through May 24 (Fig. 2a). There was, however, a significant environment x seeding date interaction, meaning that the effect of soybean seeding window varied by environment. Those differences are explained using relative soybean yield (Table 2a) and demonstrates that soil and weather conditions that vary by site and year can influence the best time to seed soybeans. Since these conditions are often unpredictable and there was no clear trend among regions, the overall effect of seeding window remains important.

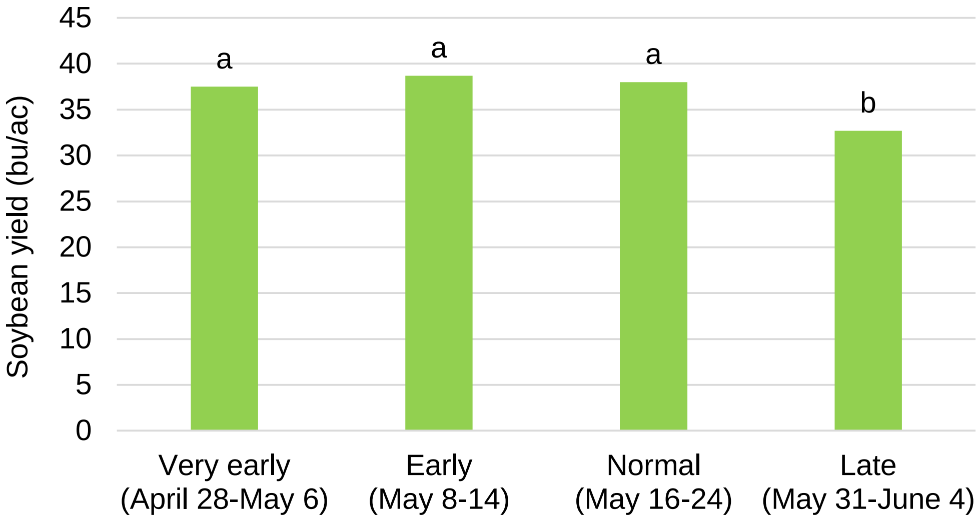

Figure 2a. Soybean yield by seeding window among 11 Manitoba environments from 2017-19 (n=84 observations). Means followed by the same letter are not statistically different at *P* = 0.05.

In 4/11 environments, yield was maximized in the very early seeding window (April 28 to May 6), however, in 1 environment (M19), yield was significantly reduced with very early seeding compared to all other seeding windows. This stark contrast speaks to the risks associated with very early seeding of soybeans in Manitoba - cold soil temperature and exposure to a late spring frost. Cold soil temperatures occurring within the first 24-48 hours of seeding can cause chilling injury (Rees and Specht 2020), reduced or delayed emergence and increased susceptibility to pathogens. The coldest soil temperatures in this study were recorded during the very early seeding window at M19 (0°C), M17 (1.1°C) and A18 (5.8°C), and it was in those environments that yield was reduced by 13-19% with the first (very early) seeding window compared to the second, “early” window, although not always statistically (Table 2a). A late killing spring frost occurred on May 19, 2017 and June 2, 2019 which may have also impacted emerged or emerging seedlings in the very early window, and consequently yield potential.

In 5/11 environments, yield was maximized in the “early” or second seeding window (May 8-14) and in 2/11 environments, yield was maximized in the “normal” seeding window (May 16-24). Soybean yield was reduced by 15% on average with late seeding (May 31-June 4).

Based on the results of this study, seeding soybeans between May 8 to 14 (second week of May), generally maximizes soybean yield in Manitoba while reducing risks associated with cold soil that are common in late April/early May and the risk of seedling exposure to late spring frost. Regional and annual recommendations can vary by considering spring soil temperature, weather forecast and the average date of the last spring frost.

The mid season variety, NSC Richer, produced greater yield than S007-Y4 overall but there were differences among environment and seeding date. Firstly, this yield difference dissipated with later seeding (D x V magnitude interaction), suggesting that if you are seeding in the first half of May (the very early and early seeding windows), additional yield may be captured with a longer season variety. Secondly, despite NSC Richer yielding higher overall, both varieties produced statistically similar yields in 6/11 environments (E x V magnitude interaction). These variety specific results should be interpreted with caution as we only compared two varieties and the yield difference may be due to factors other than maturity grouping. For example, NSC Richer had a statistically higher plant density than S007-Y4 at the very early and early seeding windows, which was particularly evident in 2019 when a seed quality issue with S007-Y4 was noted. An analysis of covariance of yield and plant density showed that the covariate (plant density) was not significant and did not influence the results overall.

Environment	**Seeding window and soil temperature**					Notes
	Very early (0-14°C)	**Early** (6-18°C)	**Normal** (9-23°C)	**Late** (12-23°C)		
Arborg17	100%	92%	92%	82%		Spring frost May 19 (no emergence)
Arborg18	87%	100%	96%	85%		Cold soil (5.8°C) at VE date, spring frost May 19 (no emergence), fall frost Sept 20
Arborg19	100%	95%	97%	84%		Spring frost May 27 (emergence at 1st date)
Carman17	95%	100%	92%	90%		Spring frost May 19 (emergence at 1st date)
Carman18	100%	98%	89%	70%		
Carman19	98%	89%	100%	98%		
Melita17	86% ab	100% a	93% ab	74% b	*	Cold soil (1.1°C) at VE date and frost May 19 (emergence at 1st date)
Melita18	100%	89%	88%	80%		Spring frost May 19 (no emergence)
Melita19	81% b	100% a	97% ab	93% a	*	Cold soil at VE date (0°C) and frost May 27 (no emergence)
Dauphin18	99% a	100% a	97% a	65% b	*	Fall frost Sept 20 (late soybeans did not mature)
Dauphin19	91%	98%	100%	89%		Spring frost May 27 and June 2 (emergence data not available)
Average	**97%** a	**100%** a	**98%** a	**85%** b	*	

Figure 2b. Mean relative soybean yield (% of maximum) by seeding window within each of 11 environments tested in Manitoba from 2017 to 2019. Asterisks (*****) indicate environments where actual yields were statistically different among seeding window (seeding windows that contain the same letter are not statistically different at *P* = 0.05).

Figure 2c. Soybean seedlings in the first seeding window (April 28 to May 6) were emerging and exposed to the last spring frost in 3 out of 11 environments (Carman17, Melita17 and Arborg19), making frost exposure a risk with very early seeding.

Plant density

Plant density was affected by all main effects and several interactions (Table 2a), but mostly were within the recommended range of 120-160,000 plants/ac to achieve 95% of maximum yield (Mohr et al. 2014). The effect of seeding window on plant density varied by environment - at 7/11 environments, plant density was statistically the same among seeding windows. At the other 4 environments (M17, M19, D19 and C19), very early seeding reduced plant density compared to the normal and late seeding window (C19 and D19), the late window (M17) or all other seeding windows (M19). In those environments, plant density in the very early seeding window was <90,000 plants/ac which we would expect to reduce yield and could be a factor in the yield differences among seeding windows in some of those environments (Fig. 2b).

Lower plant establishment/higher seed mortality associated with earlier seeding is likely related to cold soil temperatures, such as those that occurred at M17 and M19. Seed imbibition injury may occur or prolonged emergence could increase susceptibility to soil pathogens or pests, and weed interference. Very early seeding may also result in emerged seedlings being exposed to a late spring frost. This occurred at C17, M17 and A19.

NSC Richer consistently had a higher plant density than S007-Y4, although the magnitude of the difference varied among environments and seeding dates. The difference in plant density between varieties was significant at 2/11 environments (C19 and D19; E x V interaction). In 2019, a seed quality issue was noted - at C19 and D19, plant density of S007-Y4 was below 100,000 plants/ac. Plant density was the same between varieties at the normal and late seeding windows but with very early and early seeding, NSC Richer had a statistically higher plant density compared to S007-Y4 (D x V interaction). This may help explain the D x V interaction for grain yield. It is also possible that the longer season variety utilized the full growing season to maximize yield potential, and that this advantage dissipated as seeding was delayed and the growing season was reduced.

Days to maturity

Soybean maturity is affected by environmental and genetic effects, so it is not surprising that all main effects and interactions were significant. Generally speaking, DTM ranged from 103-129 days among environments and the number days required to reach maturity was reduced by 4-9 days with each successive seeding window. There was a large difference in DTM from the first to last seeding window, ranging from 10 to 30 days depending on the environment. The mid-season variety, NSC Richer, required 122 days to mature on average compared to 117 days for the early variety S007Y4. The difference in DTM between varieties was 3-4 days at the first two seeding dates and increased to 5-6 days at the last two seeding dates (D x V interaction) although these differences sometimes varied by environment (E x D x V). This finding highlights the importance of appropriate variety selection for each environment and seeding date to ensure that soybeans mature before fall frost.

Seed protein and oil concentration

This data provides the first look at the effects of very early seeding on soybean seed protein and oil concentration in western Canada. For seed protein and oil concentration, all main effects and 2-way interactions were significant (Table 2a) with environment accounting for the majority of variation in both variables (data not shown).

Among environments, seed protein ranged from 26.5 to 35.1% with an overall mean of 31.9%. In a previous study where we evaluated late seeding dates, environment was also the primary determinant of soybean seed protein, but the overall protein value of 34.3% was notably higher (MacMillan and Gulden 2020). The effect of seeding window on seed protein overall was significant, however, the effect varied by environment. Seed protein concentrations were the same among seeding dates in 8/11 environments. In 2/3 environments where statistical differences occurred, late seeding produced greater seed protein than very early and early seeding (A17 and M17) and that trend was present in 7/11 environments. Identifying a seeding date that maximizes both soybean yield and protein was identified as a compromise in Wisconsin (Mourtzinis et al. 2017).

The overall average oil concentration in this study was 19.1%, and ranged from 16.0 to 22.4% among environments. This is higher than our previously reported value of 17.8% for Manitoba (MacMillan and Gulden 2020). The opposite trend to seed protein for the effect of seeding date on oil concentration was present in this study – oil values were highest with very early or early seeding and declined as seeding was delayed. This trend was present in 10/11 environments (significant at 8/11). Oil concentration has been related to temperatures during seed-fill such that warmer temperatures are related to higher oil (Naeve et al. 2008). Late seeding, therefore, may result in soybean seed-fill occurring during warmer summer temperatures in Manitoba. Higher seed oil concentration has previously been associated with earlier seeding and shorter season cultivars (MacMillan and Gulden 2020).

Mean oil and protein values for Manitoba soybeans during the study period (2017-2019) was 18.6% and 33.6%, respectively (Canadian Grain Commission). Soybean protein meal between 47.5 and 48.5% is desired by industry, which requires a minimum 33% seed protein and 21% seed concentration on a 13% moisture basis (Brumm and Hurburgh 2006). It is a current priority to understand the environmental and genetic influences that are leading to lower protein in Manitoba soybeans. Previously, we identified that the interactive effects of site and year accounted for most of the variation in seed protein. In this study, when the effects of site-year are separated, site accounts for the majority of variation in seed protein (Fig. 2d). For example, soybeans at the Arborg location, with the shortest and coolest growing season, produced protein levels of 29.8% compared to 34.0% at Carman.

Correlations between soybean yield, protein and oil were examined. A weak negative correlation was identified between yield and oil (r = -0.19, p < 0.001) while yield and protein exhibited a weak positive correlation (r = 0.28, p <.0001). A strong inverse relationship, however, was present between seed oil and protein (Fig. 2d) and occurred at all sites. The weak correlations between yield and quality variables are a positive indication for breeding high-yielding, high-protein soybeans for Manitoba. However, it is also clear from our studies that Manitoba soybeans have a low oil concentration. A focus on increasing seed oil may also be warranted to increase meal protein concentration which may be diluted by the increased residual content in seeds with lower oil concentration.

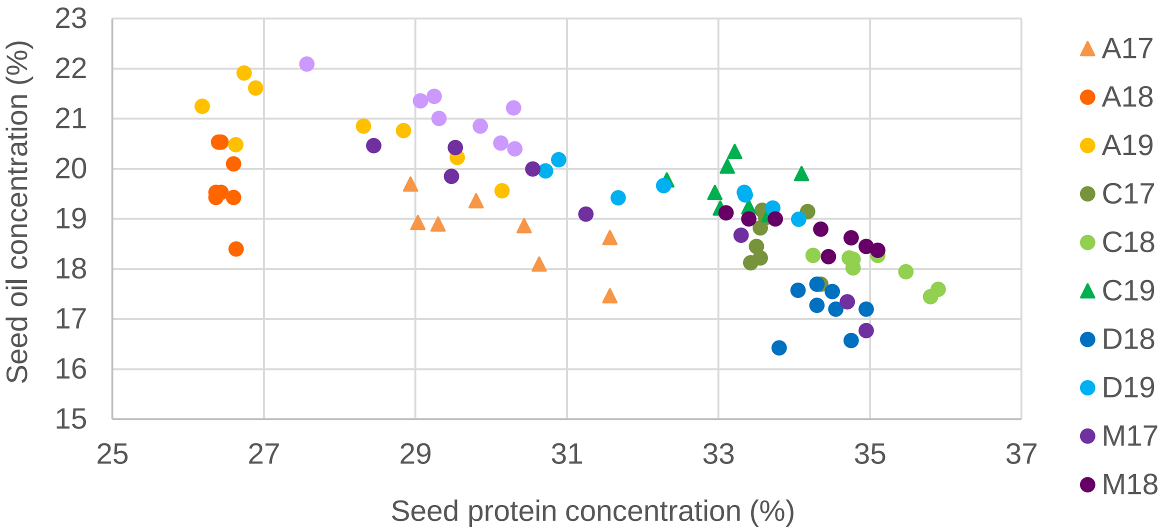

Figure 2d. Relationship between soybean oil and protein concentration based on 13% moisture for each environment studied in Manitoba and averaged across seeding date and variety (n=32) from 2017 to 2019.

Conclusions

Overall, soybean seed yield was statistically the same for seeding dates between April 28 and May 24 and was reduced by 15% on average when seeded between May 31 and June 4. Within the first three seeding windows (April 28 to May 24), environmental differences occurred but with no clear trend by region. Relative soybean yield was maximized when seeding occurred between May 8 and 14, which also avoids risks associated with cold soil and late spring frost. The optimum seeding window is best defined by considering soil and weather conditions for each field in each year.

Soybean Fungicide Product and Timing Evaluation

(Carman, MB • 2017-2019)

The most common diseases found in Manitoba soybeans are foliar leaf diseases; Septoria brown spot, bacterial blight and downy mildew which are present at low severity (<2 out of 5) in the majority (19-100%) of fields surveyed annually from 2014-2019[1]. Frogeye leaf spot was confirmed in Manitoba in 2016 and has been found annually in 3-44% of fields. White mould is found in 0-33% of surveyed fields annually at an average incidence level of ≤10% plants affected while root rot is found in 18-68% of surveyed fields annually at an incidence level of ≤12%. Root rot and white mould occur less frequently but are generally more yield limiting. Foliar fungicides are one management tool available for managing some of these diseases: brown spot, frogeye leaf spot and white mould. In the Manitoba Pulse & Soybean Growers On-Farm Network, the frequency of yield response to foliar fungicide application is 15% (10/66 trials from 2014-2020) and the overall average yield response is 0.7 bu/ac[2].

The objective of this experiment was to conduct an annual assessment of fungicide product and timing in soybeans at Carman, MB. Treatments are comprised of Cotegra (280 ml/ac) and Acapela (350 ml/ac) single fungicide application at R2 and R4 plus a sequential application applied at both R2 and R4 (~14 days after R2). Cotegra is a dual action fungicide product from BASF containing boscalid (group 7) and prothioconazole (group 3). Acapela is a picoxystrobin (group 11) fungicide from Corteva Agriscience. Inoculated soybeans (24-10RY) were seeded mid-May with a disc drill on 7.5” row spacing at 200,000 seeds/ac. Foliar leaf disease and white mould ratings were taken at R2, R4 and R6. Foliar leaf diseases are rated for severity along a 1m length of row in the front and back of each plot using a scale from 0 to 5. Incidence (% of plants affected) of white mould was determined along the same 1m length of row, if present. The experimental design is a randomized complete block with four replicates.

Over 3 years, there was no soybean yield response to foliar fungicide† (Fig. 3a). Foliar fungal leaf disease severity ratings were low (<1.6 out of 5) and white mould was only present at trace levels in 2017 and 2018. Bacterial blight in 2018 and 2019 was rated as moderate (<2.6 out of 5). Dry conditions in all years likely contributed to low disease pressure which was not yield-limiting.

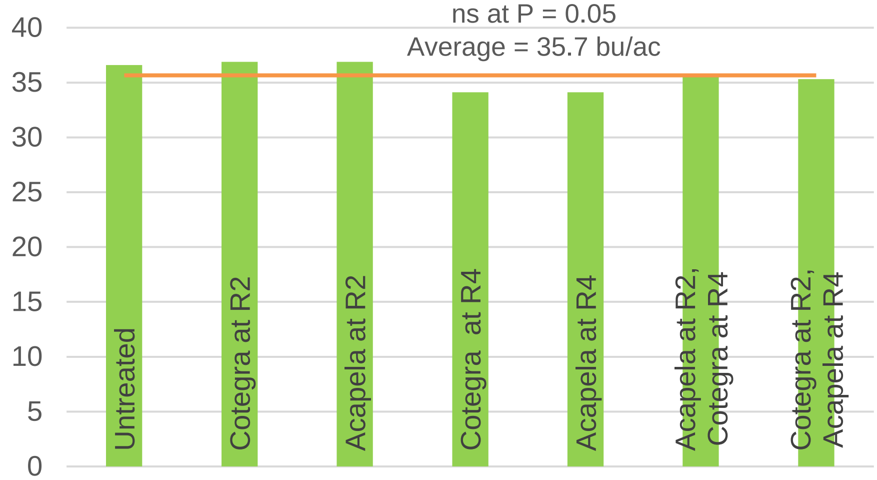

Figure 3a. Soybean yield response to fungicide across 3 years at Carman, MB (2017-2019).

Thank you to BASF and Corteva AgriScience for providing fungicide products for testing.

1, 2, † Data analysis methods and references available at the end of the report.

Soybean Iron Deficiency Chlorosis (IDC) and Yield

(Oak Bluff, MB • 2017-continuing)

Iron deficiency chlorosis (IDC), better known visually as “yellow soybeans”, is a soybean production challenge that reduces yield in Manitoba and throughout the prairies. Soil factors such as calcium carbonate content, salinity, nitrates and excess moisture can prevent the uptake of plant available iron to soybean plants, leading to yellowing of upper foliage. Variety selection is the most effective management option (Fig. 4c). To help farmers and agronomists choose varieties with IDC tolerance, Manitoba Agriculture (MA) coordinates a variety evaluation trial and the soybean and pulse agronomy research team has harvested the trial since 2017.

The objective of this collaboration is to examine the relationship between IDC score and soybean yield in Manitoba. The data produced quantifies the yield impact of yellow soybeans and demonstrates the importance of variety selection in managing this production challenge.

Each year, 80-96 varieties (entries) are seeded in 1m-rows with 3 replicates on an IDC susceptible site near Oak Bluff, MB that is very high in $CaC0_3$ (Table 4a). In late June, each row is evaluated for IDC score according to a scale that ranges from 1-5 (Fig. 4a). A lower score is better – meaning greater tolerance to iron chlorosis. At harvest, the rows were hand harvested for yield and linear regression analysis was conducted for the rating scores and yield data. All ratings were correlated to yield; the overall average rating was used for linear regression.

Figure 4a. IDC rating scale from left to right: 1 = healthy, green, 2 = some yellowing, 3 = interveinal chlorosis, 4 = dead tissue evident, 5 = stunted growing point.

Results

In 2017, IDC scores of entries ranged from 1.5 to 2.9 (Table 4b) and there was a significant linear relationship between iron deficiency chlorosis rating and soybean yield (Fig. 4b). For each 1-unit increase in IDC score, approx. 27.7 bu/ac of soybean yield is lost or for each 0.1-unit increase in IDC score, approx. 2.8 bu/ac of soybean yield is lost.

In 2018, IDC scores of entries ranged from 1.6 to 2.1 and there was no significant linear relationship between iron deficiency chlorosis (data not shown). The occurrence and severity of IDC in the trial was low compared to other years.

In 2019, IDC scores in the variety evaluation trial ranged from 1.5 to 2.3. Unfortunately, due to a wet fall, saturated field conditions and geese damage, we could not harvest the trial.

In 2020, IDC scores of entries ranged from 1.5 to 2.8 and there was a significant linear relationship between iron deficiency chlorosis rating and soybean yield (Fig. 4b). For each 1-unit increase in IDC score, soybean yield was reduced by 24.4 bu/ac or for each 0.1 unit increase in IDC score, yield was reduced by 2.4 bu/ac.

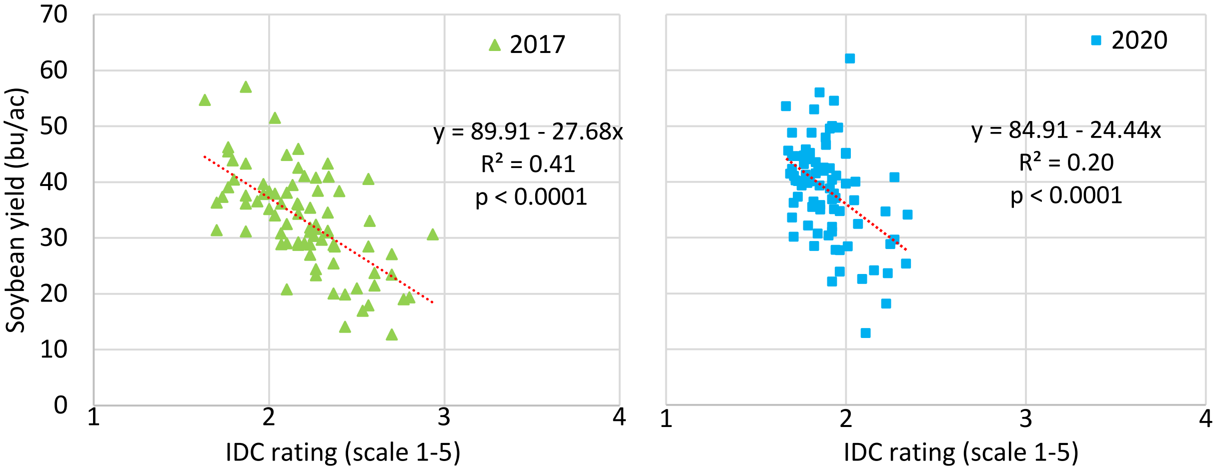

Figure 4b. Effect of average IDC score on soybean yield from the variety evaluation site in 2017 and 2020 (each data point is the mean of 3 replicates).

Discussion and Conclusions

Overall, the effect of IDC on soybean yield depends on the year as severity and duration of symptoms vary. When symptoms occur and persist, the yield impact can be significant and is likely one of the most yield limiting factors for soybean production in Manitoba.

In 2 out of 3 years, a significant linear relationship between overall IDC score and soybean yield was characterized. For each 1-unit increase in IDC score, soybean yield is estimated to be reduced by 24-28 bu/ac. It is important to note that overall, IDC scores are between 1.5 and 3.0, so the effect of a 1-unit difference is substantial (there is also a lot of variability in the linear regression). Another way to look at this data, is that for each 0.1 unit that IDC score increases, soybean yield is reduced by 2.4-2.8 bu/ac, on average. Therefore, in a field where IDC occurs, a variety rated 1.7 would be expected to yield 9-11 bu/ac more, on average, than a variety rated 2.1. In North Dakota, yield loss associated with IDC is estimated at 9 to 19 bu/ac per unit of chlorosis at the 5-6 leaf stage, depending on the year (Franzen and Goos 2016). This is lower than our Manitoba estimates and could be related to the range of IDC scores assigned by evaluators, which can be subjective.

The occurrence of IDC within a field is highly variable and related to heterogenous soil factors that interact with available moisture. In a survey of 53 farmers and agronomists, the frequency of IDC occurring varies from every year to 1 in 4. When IDC does occur, the majority responded that only 10-25% of a field is affected. The study years of 2017-2020 have been drier than normal in Manitoba and IDC has not been a major production issue compared to 2013-2016. This spatial and annual variability makes precision management both an opportunity and a challenge. To explore the opportunity for variable cultivar seeding, we will evaluate variety performance under IDC and non-IDC conditions in the same field beginning in 2021.

To read more about soybean iron deficiency chlorosis, visit "Yield impact of yellow soybeans" or "Iron deficiency chlorosis".

Reference

Franzen, D. & R. J. Goos. 2016. How Much Does IDC Reduce Soybean Yield? https://www.ag.ndsu.edu/cpr/soils/how-much-does-idc-reduce-soybean-yield-05-12-16

Table 4a. Soil characteristics of the soybean iron deficiency chlorosis (IDC) variety evaluation site near Oak Bluff, MB.

	Salinity (mmho/cm, 0-6", 6-12")	**Calcium Carbonate Content**	**Nitrate N** (lbs/ac, 0-12")	**Soil pH** (0-6")	**IDC Risk**
2017	0.46	n/a	36	7.8	High
2018	0.43, 0.55	7.8%	149	8.3	High-Very high
2020	0.36, 0.35	6.7%	89	8.2	High

Table 4b. Summary of mean iron deficiency chlorosis (IDC) scores (scale 1-5) and yields for all entries in each year of the variety evaluation trial near Oak Bluff, MB (2017-2020).

Year	**Variable**	**Mean**	**Range**
2017	IDC rating 1 June 19	1.9	1.5-2.4
n = 80	IDC rating 2 June 22	2.0	1.5-2.5
	IDC rating 3 June 29	2.0	1.6-2.4
	IDC rating 4 July 5 @ V4	2.2	1.7-2.7
	IDC rating 5 July 10 @ V5, R1	2.2	1.6-2.9
	IDC rating overall average	2.1	1.6-2.6
	Yield (bu/ac)	33	13-57
2018	IDC rating 1 June 25 @ V2	1.8	1.6-2.1
n = 96	IDC rating 2 July 3 @ V3	1.8	1.6-2.1
	IDC rating 3 July 9 @ R1	1.8	1.6-2.1
	IDC rating overall average	1.8	1.7-2.0
	Yield (bu/ac)	46	30-65
2019	IDC rating 1 June 26 @ V2	1.8	1.5-2.3
n = 89	IDC rating 2 July 3 @ V3	1.8	1.6-2.3
	IDC rating 3 July 11 @ V4, R1	1.8	1.6-2.1
	IDC rating overall average	1.8	1.6-2.2
	Yield (bu/ac)	not available	
2020	IDC rating 1 June 25 @ V2	1.9	1.7-2.3
n = 80	IDC rating 2 July 2 @ V3	1.9	1.7-2.5
	IDC rating 3 July 10 @ V4	1.9	1.6-2.4
	IDC rating overall average	1.9	1.7-2.3
	Yield (bu/ac)	38	13-62

Figure 4c. IDC-prone field seeded to a tolerant and susceptible soybean variety (L) and the IDC single row variety evaluation site near Oak Bluff, MB (R).

Effect of simulated hail damage on soybean maturity, yield and quality

(Portage la Prairie and Minto, MB • 2015-2018)

Introduction

Hail is a catastrophic weather event that can result in stem bruising, stem breakage, leaf defoliation, stand reduction and secondary effects such as increased susceptibility to lodging and pests. In Manitoba, approx. 5% of crop acres are affected annually, equating to about 4,900 field claims for crop hail damage (Wilcox 2017). On average from 2009-2018, the majority of hail events occurred from July 1 to August 31 and in soybeans specifically, the greatest losses from hail claims occur from V7 to V10, which coincides with flowering and pod fill (Wilcox, personal communication). There were some notable hail events that occurred in western Manitoba in 2013 and 2014 where farmers expressed concerns over hail adjusting procedures. In 2016 alone, there was a record 10,500 field claims for hail damage, affecting nearly 13% of annual crop acres in Manitoba (Wilcox 2017). While soybeans have been grown in Manitoba since the early 2000s, acres steadily increased to 2017 when a record 2.2M acres were seeded (MASC). The surge of the soybean industry surpassed our ability to produce regional information. The data currently used by the Canadian Crop Hail Association and local crop insurance providers to assess hail damaged soybeans is based on data from the United States. Discrepancies between current data and how soybeans recover from hail in Manitoba fields is evident.

The overall objective of this research is to quantify the effect of simulated hail damage on soybean maturity, yield and quality in Manitoba and produce data for western Canada. Specifically, we aim to predict soybean yield loss by level of defoliation and node removal at different growth stages under Manitoba growing conditions. To achieve this objective, two experiments separately evaluating defoliation (exp 1) and stem breakage (exp 2) were conducted at Portage la Prairie and Minto, MB from 2015 to 2018 for a total of 5 site-years. Ironically (and sadly), 3 site-years were lost due to actual hail storms (July 16, 2016 in Minto, August 15, 2016 in Portage la Prairie and June 14, 2018 in Minto).

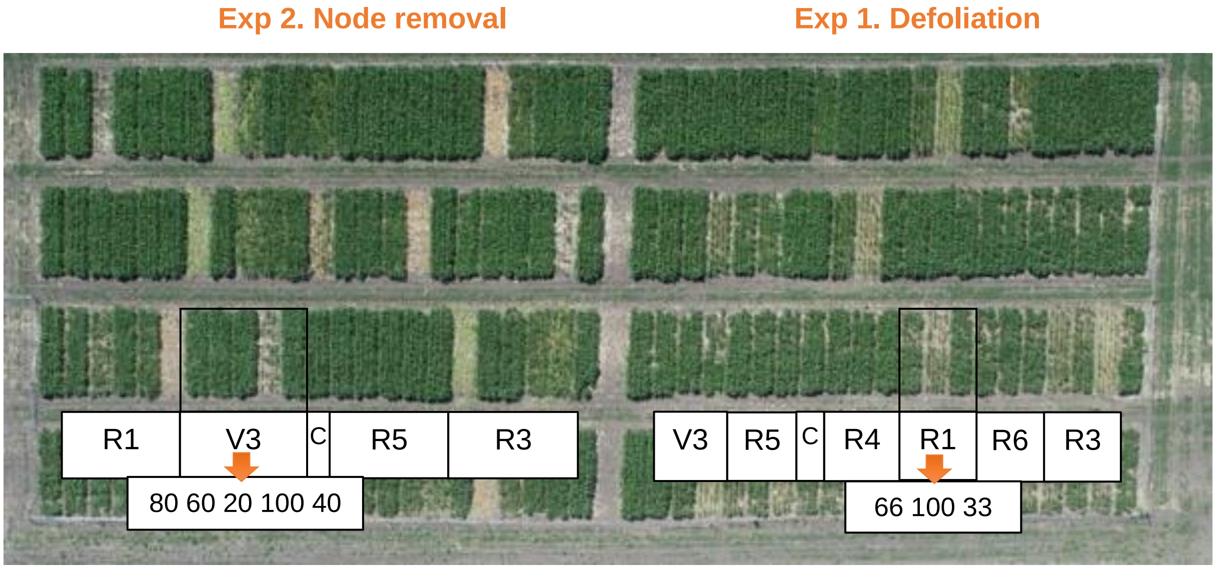

Figure 5a. Soybean node removal (L) and defoliation (R) experiments at Portage 2018. Plot labels given for Replicate 2 (third from the top).

Experiment 1: Soybean yield response to defoliation in Manitoba

Objective

To determine the effect of defoliation at various timings and severity levels on soybean yield and produce region-specific crop insurance data.

Yield loss in short-season soybean at 100% defoliation during V3, R1, R3 and R4 is greater than previously reported for indeterminate soybeans.

Materials and Methods

Trial management and simulated hail treatments
Experiments were located at the Agriculture and Agri-Food Canada research station in Portage la Prairie and the Ag Quest research station near Minto, MB. Soil type at both locations was clay loam and environmental conditions were warm and dry with 41-61% of normal growing season precipitation (127 to 172mm). Experiments were seeded between May 19 and 29 at 200,000 or 210,000 seeds/ac with a plot drill into tilled cereal or corn residue. Row spacing ranged from 20 to 30.5 cm (8 to 12 in). The soybean varieties DK 23-60 RY (MG 00.3) and DK 24-10 RY (MG 00.5) were used at Minto and Portage, respectively. Plots were maintained weed-free using primarily glyphosate but also hand weeding, Edge granular and Pardner herbicides in some years. At Portage 2017, two insecticide applications were made to control soybean aphid at 250 aphids/plant. For the simulated hail treatments at each timing/growth stage, 1, 2 or 3 trifoliate leaflet(s) were manually torn from every trifoliate leaf on every plant in the plot to simulate 33, 66 and 100% defoliation, respectively.

Experimental design and statistical analysis
A 2-way factorial experiment with a control in a split arrangement of an RCBD (main plot = timing/growth stage, sub plot = severity/level of defoliation) with 4 replicates was tested at 5 site-years. Defoliation took place at 6 growth stages (V3, R1, R3, R4, R5 and R6) and 3 severity levels (33, 66, 100) plus a shared control (0), for a total of 19 treatments (6 timings x 3 severity levels + 1 shared control = 19 treatments). The number of observations for each treatment was unbalanced (Table 5a: not all timing x severity combinations were present in each site-year).

Table 5a. Number of observations (n) per treatment.

	Severity Level (%)			
Timing	**0**	**33**	**66**	**100**
V3	20	20	20	20
R1		19	20	20
R3		20	20	20
R4		8	8	8
R5		19	19	19
R6		16	16	16

Statistical analysis
Analysis of variance (ANOVA) on the full model was performed using Proc Mixed, with site-year, severity and timing as fixed effects and block(site-year) and timing*block(site-year) as random effects. Residuals were assessed for normality, outliers and homogeneity of variance. Due to several significant effects, the percent sums of squares (%SS) was obtained through method=type 3 to assess the contribution to variance of each factor. Because the objective of the research was to obtain soybean yield loss data by defoliation level for multiple growth stages that is relevant to Manitoba and western Canada, data from each site-year were grouped and

analyzed separately by defoliation time. For these analyses, severity and site-year were treated as fixed effects and block(site-year) as a random effect. Again, residuals were assessed for normality, outliers and homogeneity of variance. In cases of significant interaction, the slice option was used to partition the interaction variance. For each defoliation time, regression analysis of LS Means was used to characterize the yield response to degree of defoliation (% severity). Treatment variance was partitioned into linear, quadratic and lack of fit components and tested for significance. Proc IML was used to obtain the appropriate coefficients for the orthogonal contrasts. Regression coefficients were obtained using Proc NLMixed and Efron's Pseudo R^2 were estimated for the best fit non-linear models.

Results and Discussion

Overall soybean yield in the nondefoliated control treatments ranged from 44 to 65 bu/ac among site-years, which is above average compared to the provincial average yield of 36 bu/ac in the study years (MASC). Both locations would be considered highly productive.

The three-way analysis of variance of data obtained for yield, yield loss and maturity are shown in Table 5b. In the full model analysis of yield, all main effects and interactions were significant, except the site-year by timing interaction (Table 5b). To account for differences in overall yield among site-years, yield was converted to yield loss [=(1-(Yield of treatment/Yield of control))*100%], and also because differences between treatments was similar among site-years (Muro et al. 2001; Bueckert et al. 2011; Owen et al. 2013). Converting yield to yield loss eliminated the effect of site year, as expected, and site-year interactions were either not significant or accounted for little variation overall.

Table 5b. Summary of three-way analysis of variance for soybean yield, yield loss and maturity (combined over 5 trials in Minto and Portage la Prairie, MB 2015-2018).

	Yield		**Yield loss**		**Maturity**	
	Pr > F	% SS	Pr > F	% SS	Pr > F	% SS
SiteYr	0.0012	12.3	0.9138	0.5	<.0001	79.5
Timing	<.0001	15.6	<.0001	17.6	<.0001	1.1
SiteYr*Timing	0.1871	1.5	0.4439	1.4	<.0001	2.0
Severity	<.0001	44.1	<.0001	49.7	<.0001	2.5
SiteYr*Severity	<.0001	1.7	0.0002	1.1	<.0001	2.2
Timing*Severity	<.0001	8.4	<.0001	9.7	0.0116	2.6
SiteYr*Timing*Severity	<.0001	2.1	<.0001	2.9	<.0001	1.9

Yield Loss and Yield Loss Equations

Soybean yield loss is primarily related to the severity/level of defoliation, which explained 49.7% of yield loss variability followed by timing that defoliation occurred, which explained 17.6% of the variation in yield loss (Table 5b). The third most important factor was the interaction between timing and severity. The effect of severity also varied by site-year and the high level 3-way interaction was significant. It is well known in crop hail research that the effect of hail damage and specifically defoliation varies by growth stage. Therefore, to further elicit the effect of timing (growth stage) and produce data for crop insurance purposes, data were handled separately for each timing and is in agreement with separating defoliation/hail damage effects according to growth stage for a range of crops reported (Muro et al. 2001; Bueckert et al. 2011). This also allows investigation of the high level 3-way interaction, whereby the severity x site-year interaction can be evaluated for each timing.

The following discussion focuses on soybean yield response by growth stage that defoliation occurred (Table 5c). The effect of defoliation on yield loss was consistent among environments at V3, R4 and R6. In other words, the site-year x severity interaction was not significant. At R1, R3 and R5, however, the effect of defoliation severity varied by site-year. Among all growth stages, the lowest level of defoliation did not significantly reduce yield compared to the control. The best fit regression models for soybean yield loss at each growth stage are presented in Fig. 5b and explain 60-92% of the variation in yield loss.

Table 5c. Analysis of variance for the effect of severity, site-year and their interaction on soybean yield loss by growth stage/timing (Minto and Portage la Prairie, 2015-2018).

	V3	**R1**	**R3**	**R4**	**R5**	**R6**
	Pr > F					
Severity	***	***	***	***	***	***
Site-year	ns	ns	ns	ns	ns	ns
Severity x Site-year	ns	*	**	ns	***	ns

*Significant at P <0.05, **Significant at P <0.01, ***Significant at P <0.001, ns = non-significant at P <0.05

At soybean growth stage V3 (vegetative), a quadratic response was significant (Fig. 5bi) and consistent among the five environments. The V stage of soybean was the most tolerant to leaf defoliation with maximum average yield loss of 16.8% occurring with 100% leaf defoliation while 33% defoliation did not reduce yield compared to the control (Table 5d). Generally, soybeans are able to compensate well for leaf loss during vegetative growth and early flower due to rapid leaf re-growth (Board and Kahlon 2011). **Significant yield loss during V3 at 100% leaf loss is a major finding since currently, no yield loss is attributed to defoliation during vegetative stages of soybean** (MASC 2017; Licht et al. 2016; Klein and Shapiro 2011; Hintz et al. 1991).

At soybean growth stage R1 (early flower), the yield response to defoliation varied by environment. A quadratic response occurred at 3 of 5 site-years and a linear response occurred at the others. Overall, the yield response to defoliation at R1 was quadratic (Fig. 5bii), and both 66 and 100% defoliation significantly reduced soybean yield compared to the control (Table 5d). At 100% defoliation during R1, soybean yield was reduced 40% compared to the control.

During R3 (early pod), soybean yield response to defoliation was quadratic overall and for 4 out of 5 environments. The response varied by environment mostly due to the curvature from 0 to 33%, however, that level of defoliation did not significantly reduce soybean yield compared to the control in any of the environments. Consistent with V3 and R1, yield loss of 100% defoliation at R3 in our study (61.7%) is higher than values reported in Nebraska and Iowa (30-50%), but lower than that reported in a high-yielding production system in Mississippi (Owen et al. 2013).

Table 5d. Mean soybean yield loss (%) by defoliation severity level for each growth stage.

Defoliation severity	**V3**	**R1**	**R3**	**R4**	**R5**	**R6**
	% Yield loss †					
0%	0c	0c	0c	0d	0d	0d
33%	0.9c	3.3c	4.1c	13.2c	11.2c	11.1c
66%	7.3b	15.5b	20.2b	27.2b	30.7b	20.6b
100%	16.8a	40.0a	61.7a	74.5a	69.8a	35.9a

† Values within columns followed by the different letters are statistically different at P <0.05.

Soybeans during full pod (R4) and early seed fill (R5) were most sensitive to leaf loss, reducing soybean yield at all levels of defoliation and rising sharply as leaf loss increased (Table 5d). As defoliation level increases, photosynthetic leaf area and light interception is reduced and remaining leaves cannot compensate (Board and Kahlon 2011). During R4 (full pod), soybean yield response was consistent among the two environments where we fit a quadratic model. Yield loss at 100% defoliation during R4 was 70% in this study and is higher than values reported from Iowa (56%) but similar to Nebraska (76%). At R5 (seed fill), soybean yield response was quadratic overall and varied by environment. At two environments, soybean yield responded linearly, where rate of yield loss remains the same across defoliation level. At the other 3 environments, soybean yield showed a quadratic response where the rate of yield loss increased at higher severity levels.

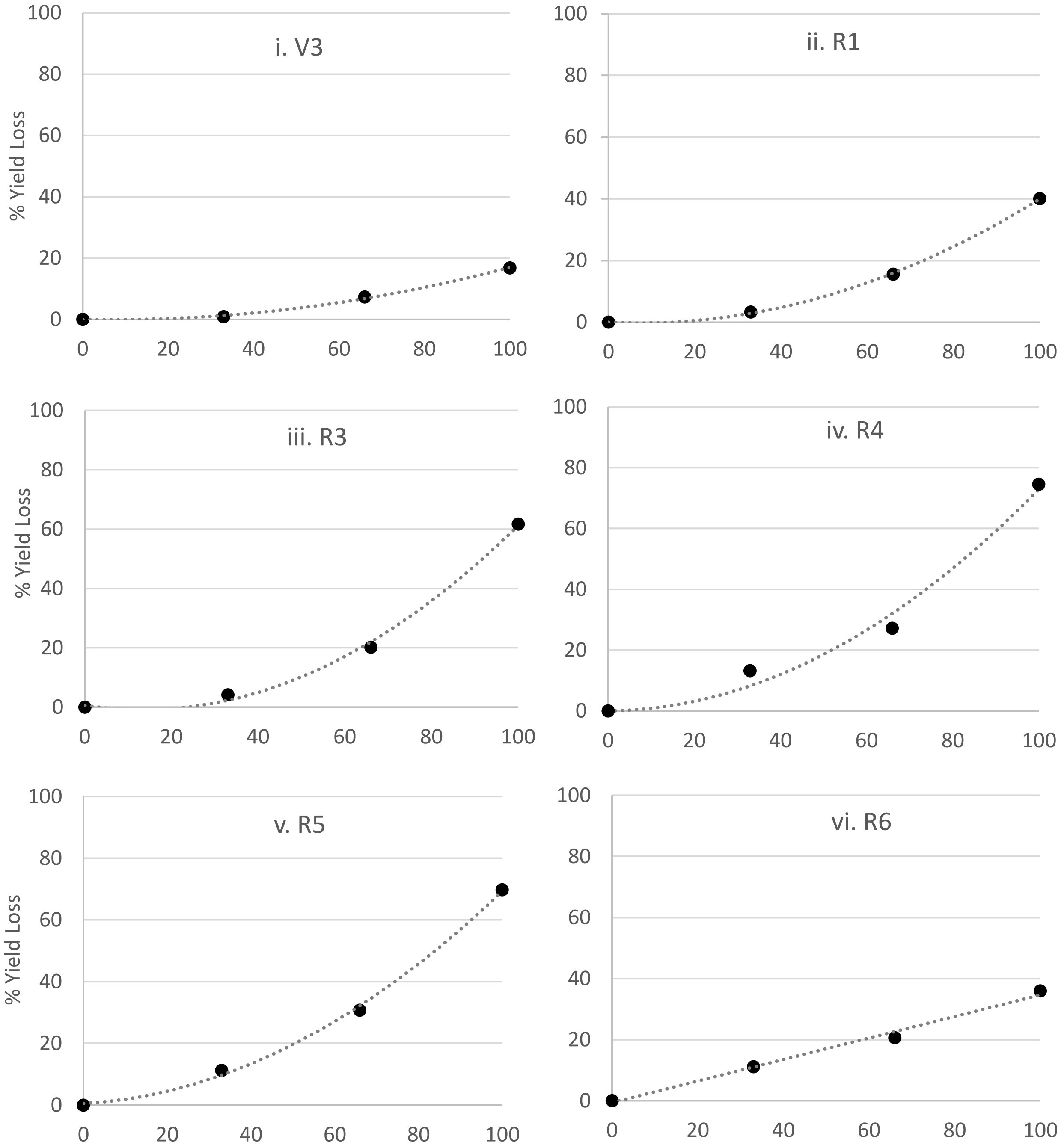

Figure 5bi-vi. Relationship between soybean yield loss and % leaf defoliation at six growth stages in Manitoba averaged across 5 site-years (Minto and Portage la Prairie, MB from 2015-2018).

At R6 (full seed), yield loss at 100% defoliation is substantially lower compared to R3 through R5 and the overall yield response was linear at all environments tested i.e., soybeans are more tolerant to leaf loss from R6 onward. During this later reproductive stage of soybean, seed number has been determined and yield loss is primarily through reduced seed size. In this Manitoba study, 100% defoliation resulted in 36% yield loss which is within the wide range of 25-65% reported from southern growing regions (Licht et al. 2016; Owen et al. 2013; Klein and Shapiro 2011).

Days to Maturity

All main effects and interactions influenced soybean days to maturity. This is not surprising, as soybean maturity is a highly complex trait that is influenced by environment, genetics, management practices and their interactions. The following discussion focuses on the effect of defoliation by growth stage. Generally, soybean maturity was delayed with 100% defoliation during the earlier growth stages of soybean (V3, R1 and R3). This effect diminished as soybean reached seed fill (R5) and the opposite effect was evident when defoliation occurred during R6.

At V3, R1 and R3, a delay in maturity as defoliation increased was evident at most site-years and overall, the highest level of defoliation resulted in a 3- or 4-day maturity delay compared to the non-defoliated control (Fig. 5c). At R5, the overall effect of defoliation was not significant. There was, however, a cross-over interaction among site-years where 100% defoliation hastened maturity, delayed maturity or had no effect. At R6, the overall effect of defoliation was significant and opposite to that of earlier growth stages. The high levels of defoliation (66 and 100%) hastened soybean maturity by 1-2 days compared to 33% defoliation and the control.

Currently, the effect of delayed maturity is not considered by crop insurance providers. Based on this research, 100% defoliation results in an average maturity delay of 3 days at V3 and R1, and 4 days when defoliation occurs at R3, compared to the non-defoliated control. Based on experience with field ratings, it takes 4-12 days (average = 7) for soybeans to dry down from R7 (physiological maturity, 5% brown pod) to R8 (full maturity, 95% brown pod). At R7, soybeans are at low risk of yield or quality loss due to frost. **Therefore, a 3-4-day delay in maturity due to high levels of defoliation would not pose a substantial risk of additional crop damage due to frost, assuming the soybean crop would have normally reached maturity prior to the typical frost date.**

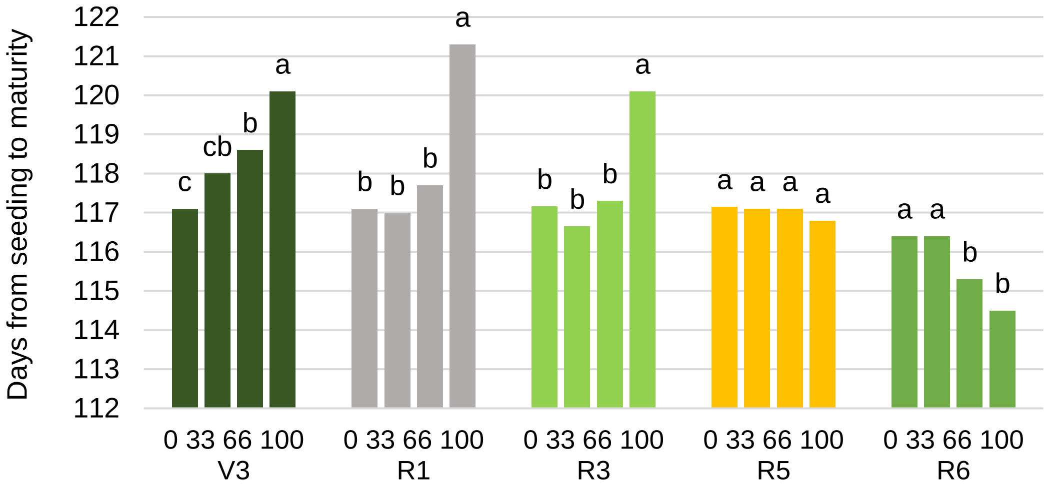

Figure 5c. Effect of leaf defoliation on soybean maturity at each growth stage and defoliation level based on 5 site-years in Manitoba (2015-2018).

Conclusions

This study provides the first comprehensive dataset quantifying the impact of defoliation on soybean yield in Manitoba and western Canada. Results indicate that the response of short-season soybean in western Canada to leaf defoliation is different compared to southern growing regions. Yield loss overall is greater in some circumstances compared to current crop loss values (Fig 5d). Equations for the soybean yield responses in Fig. 5b, will be made available to farmers, agronomists and crop insurance adjusters to more accurately estimate the impact of defoliation on soybean yield in western Canada.

Table 5d. Difference between new soybean yield loss data and current data used by crop insurance providers for each growth stage and defoliation level in Manitoba. High positive values indicate that current data is underestimating soybean yield loss.

	33	**66**	**100**
V3	1	7	17
R1	1	12	28
R3	0	8	29
R4	6	8	19
R5	1	4	-5
R6	9	15	13

% difference (new data-current data)

🟩 <5%

🟨 5-10%

🟥 >10%

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Agronomy Journal

ARTICLE

Agronomy, Soils, & Environmental Quality

Effect of seeding date, environment and cultivar on soybean seed yield, yield components, and seed quality in the Northern Great Plains

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Abstract

Western Canada grows more than 25% of Canadian soybeans [*Glycine max* (L.) Merr.] and is the new northern extent of the North American soybean-growing region. Canada is the seventh largest soybean-exporting country, yet little information on yield and quality in modern cultivars exists for that region. The objective of this study was to determine the impact of delayed seeding on soybean seed yield, yield components, maturity, and seed quality in Manitoba, located in the eastern northern Great Plains, and provide the first characterization of the relative influence of environment, seeding date and cultivar on those variables. Field studies were conducted from 2015 to 2017 at three locations in southern Manitoba to evaluate the performance of three soybean cultivars at three seeding dates from 24 May to 24 June. Up to 90% of total variation in the response variables was explained by environment, seeding date, cultivar and their interactions, with environment often consuming the majority of total sums of squares. Among environments, seed yield ranged from 1610 to 3590 kg ha^{-1}, seed number from 1719 to 3828 seeds m^{-2}, seed weight from 125 to 169 g 1000 seeds^{-1}, oil concentration from 16.1 to 18.7% and protein concentration from 32.8 to 35.3%. Overall, very late seeding reduced yield, seed weight, and oil but did not affect protein. This study demonstrates that environmental conditions in Manitoba have a large influence on soybean performance compared to seeding date or pedigree and that protein concentration varies at a finer geographical scale than previously reported.

1 | INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] land area has increased sixfold in the province of Manitoba since 2002, becoming the third largest crop grown in the province, and contributing 32% to Canadian soybean production in 2017 (Statistics Canada, 2018). Short-season breeding advances in recent decades (Cober & Voldeng, 2012) in the public and private sector have increased the availability of soybean cultivars in the maturity groups (MG) 00 and 000 which has facilitated the expansion of soybean land area in this region. Relatively high crop water use, adaptability to various soil and tillage

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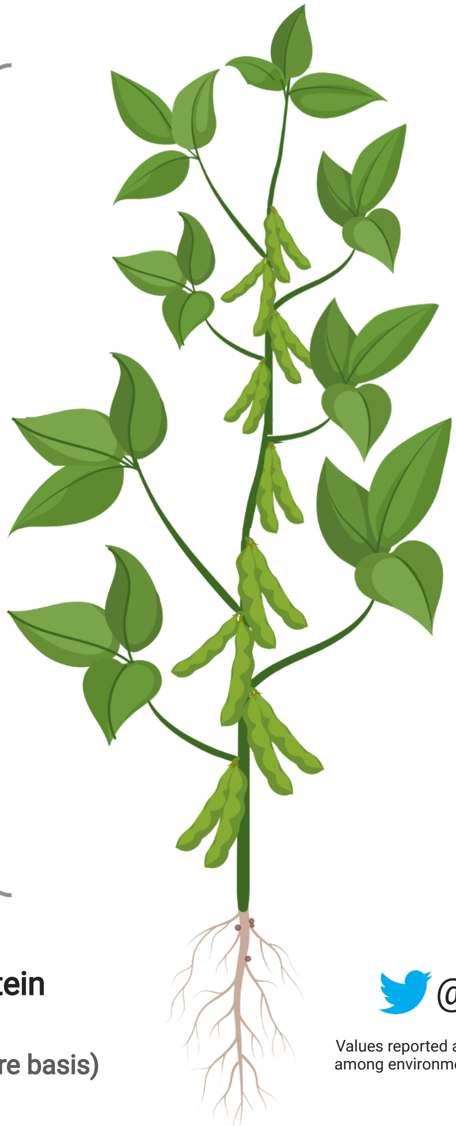
Abbreviations: C, cultivar; E, environment; MG, maturity group; SD, seeding date.

Soybean yield, yield components and seed quality in western Canada

A look at numbers from a recent Manitoba study



73 cm
(59-91)

29 pods/plant
(17-40)

67 seeds/plant
(38-88)

143 g/1000 seeds
(125-169)

39.8 bu/ac
(24-54)

34.3% Protein
17.8% Oil
(13% moisture basis)

@kpmacmillan

Values reported are overall means with range of means among environments (8 site-years) reported in brackets

MacMillan KP and RH Gulden. 2020. Effect of seeding date, environment and cultivar on soybean seed yield, yield components and seed quality in the northern Great Plains. Agronomy Journal 112:1666-1678. https://doi.org/10.1002/agj2.20185.
Created with BioRender.com

Developing an Integrated Weed Management System for Soybean

(Portage la Prairie, MB • 2019-2021)

A large, multi-province study that aims to develop recommendations on integrated weed management in soybean is being led by Dr. Charles Geddes, Weed Scientist with Agriculture and Agri-Food Canada in Lethbridge, AB. Soybeans are a relatively non-competitive crop species and with the widespread historical reliance on glyphosate for weed control, both weed competition and the development (and spread) of glyphosate resistant weeds are major concerns for soybean production in western Canada. **Overall, this study is evaluating eight cultural weed management strategies for their effectiveness in reducing selection pressure in soybean in western Canada**. We are collaborating with Charles by hosting two of the five experiments evaluating four management practices at Portage la Prairie (denoted by *).

- Seeding date* (mid May, late May, early June)
- Variety* (up to 7 with varying leaf shape, branching, height, maturity etc.)
- Preceding crop type* (wheat, canola, corn, soybean)
- Residue management* (tilled vs. direct seed)
- Row spacing (9 vs. 27")
- Seeding rate (160,000 vs. 240,000 seeds/ac)
- Fall rye cover crop (with vs. without, terminated with pre-seed herbicide)
- Frequency and sequence of herbicide tolerant soybean and canola crops in rotation

Measurements being collected aim to explain differences in soybean competitive ability brought about by the various management factors and include soil moisture, canopy closure, weed community, soil temperature, soil nutrient supply, plant height, crop and weed biomass and yield.

In the first experiment (variety x seeding date), multiple varieties with different characteristics are being tested in multiple seeding dates and under weedy and weed-free conditions. The overall objectives are to determine the impact of seeding date and variety (and associated traits) on the ability of soybean to compete with and withstand weed competition. We will also be able to determine if weeds impact soybean traits. Preliminary results indicate that canopy closure (a measure of crop competitiveness) occurred within about 30 days at Portage with few differences among varieties. Differences among varieties in canopy closure were more apparent late in the season suggesting that varietal differences may influence late season weed establishment more so than early in the season. Canopy closure took longer and variety differences were more apparent at Saskatoon and Lethbridge. In regards to yield, soybean varieties that performed well under weed-free conditions also performed well under weedy conditions.

In the second two-year experiment (preceding crop x residue management x seeding date), we are testing the impact of stubble type, residue management and seeding date on the ability for soybean to compete with and withstand weed competition. In the first year, we seeded four crop types (wheat, canola, soybean and corn) and then managed the residue with or without tillage. The following spring, soybeans were seeded at three seeding dates into each preceding crop-residue management combination. No results are available for this study as the first soybean test crop was harvested in fall 2020.

What is the importance of testing under weedy and weed-free conditions? Comparing both systems allows researchers to a) quantify yield loss due to weed competition in a particular treatment and b) test weed management practices under both high and low weed pressure cropping systems.

Optimizing nitrogen rates for pinto and navy beans in Manitoba

(Carman and Portage la Prairie, MB • 2017-2019)

Despite being a legume, dry beans (*Phaseolus vulgaris*) are relatively poor N-fixers compared to soybean or field pea, for example. They produce less than 45% of their N requirements through biological nitrogen fixation (BNF) and their efficiency can be highly variable depending on cultivar and environment (Walley et al. 2007). Application of nitrogen (N) fertilizer is common practice in dry bean production systems in Canada and the United States, although recommendations vary by region. In Ontario, no supplemental N is recommended while in North Dakota, a total N (soil + fertilizer N) rate of 70 lbs/ac is used for non-inoculated beans and 40 lbs/ac for inoculated beans (Franzen 2017). Currently, N recommendations in Manitoba are to achieve 70-120 lbs N/ac total N supply (soil + fertilizer N) for a yield goal of 2,400 lbs/ac with different recommendations for wide and narrow row production systems to account for N mineralization associated with inter-row cultivation (Manitoba Soil Fertility Guide 2007). This equates to 2.9 to 5.0 lbs N/cwt which is comparable to N uptake rates of 3.9 to 4.7 measured in Manitoba (Heard 2005). Inoculation is not a standard practice in Manitoba since inoculant efficacy is highly variable and formulations are not widely available. Currently, about 80-90% of dry bean farmers are applying N at an average ate of 60-90 lbs N/ac (MPSG 2014; Heard 2016). In 2019, two inoculant products became available and we have been testing them in another experiment (see page 40). Since the last investigation of dry bean N fertility and inoculation in Manitoba which dates back to 1996-2003 (McAndrew, unpublished), cultivars have changed, yields have increased, some inoculants have become available and dry bean field history has increased. This provides justification to re-visit N recommendations.

This study aimed to compare five rates of N fertilizer (0, 35, 70, 105 and 140 lbs N/ac) in Windbreaker pinto beans and T9905 navy beans at Carman and Portage la Prairie, MB. Results of this study will contribute to 4R nutrient management practices by attempting to identify the agronomic and economic optimum N rate for dry beans in Manitoba.

The experimental design is a factorial arrangement of a split plot RCBD with 4 blocks (main plot = bean type, split plot = N rate). The method of fertilization is spring broadcast and incorporation of urea prior to planting dry beans on 15” row spacing. Non-inoculated beans were seeded into tilled wheat stubble with background N levels of 23-56 lbs N/ac between May 21 to June 1 and were hand harvested between August 23 and September 27. Field cropping history did not include dry beans for at least 5 years previous. Data collection included plant population, days to flowering, R1 Biomass, nodulation score, disease ratings, maturity, pod height and yield. The Portage17 trial was not taken to harvest due to poor bean establishment (<40% of target population achieved) and non-uniformity. Plant establishment was also poor at Carman19 and despite re-seeding, navy bean plant density was <30% of an acceptable stand. Due to confounding effects and spatial variability, navy beans were not harvested at Carman19.

Data was analyzed initially using ANOVA in PROC Glimmix in SAS 9.4 with nitrogen rate, bean type and environment as fixed effects, and block nested within environment as a random effect. Because the effect of N rate on bean yield and return to N was consistent among environments (no interaction) and the missing data for navy beans at Carman 2019 (imbalanced design) precludes production of LS Means, data analysis proceeded with environment as a random effect. Assumptions of ANOVA were evaluated prior to final analysis. For significant effects, LS Means were separated using Tukey’s HSD at P = 0.05.

Table 8a. Soil characteristics, applied fertilizer and weed control at each environment/site-year.

	Portage17	Portage18	Portage19	Carman17	Carman18	Carman19
Soil texture†	Clay loam	Loam	Clay loam	SCL	SCL	VFSL
Nitrate-N (0-24”, lbs/ac)	26	23	25	40	56	33
P_20_5 (0-6”, ppm)	10	15	7	42	11	14
K_2O (0-6”, ppm)	225	382	202	275	203	266
SO_4 (0-24”, lbs/ac)	44	336	466	62	100	56
Zn (ppm)	n/a	1.44	0.79	2.4	1.7	1.24
Soil OM %	n/a	6.3	4.3	1.8	4.6	3.0
Soil pH (0-6”, 6-24”)	n/a	8.1, 8.5	8.2, 8.5	5.2, 7.6	5.7, 7.2	5.7, 7.3
Soluble salts (0-6”, 6-24”, mmhos/cm)	n/a	0.65, 0.68	0.48, 0.68	0.08, 0.00	0.26, 0.43	0.07, 0.25
N-P-K-S	N as Urea according to treatment and 15 lbs P_20_5/ac as MAP applied with seed					
Weed control	Pre-plant: Edge	Pre-plant:, Trifuluralin	Pre emerge: Edge granular; In-crop: Viper + Basagran Forte	Pre-plant: Treflan liquid EC; In-crop: Viper + Basagran + UAN, Centurion	Pre-plant: Treflan liquid EC; In-crop: Viper + Basagran Forte + UAN, Poast	Pre-plant: Treflan liquid EC; In-crop: Viper ADV + Basagran Forte + UAN

† SCL = sandy clay loam, VFSL = very fine sandy loam

RESULTS

Growing season weather conditions and soil characteristics

The 2017-2019 growing seasons at Carman and Portage la Prairie were dry and warm; May through August growing season precipitation was 42-69% of normal and mean daily temperature was generally above average with the exception of Carman17 and Carman19 which were more seasonal. Lack of soil moisture could influence soil N processes in several ways, including being detrimental to effective nodule development. Dry soil conditions may also promote root exploration of deep N while increasing mineralization following soil wetting. Soil residual nitrate-N levels were generally low across all environments, ranging from 23-56 lbs N/ac. At Carman, soil pH in the top six inches is slightly acidic (pH 5.2 to 5.7) and could be limiting for nodule development.

Plant density

Nitrogen rate did not affect plant establishment (Table 8b). Average plant density was 71,000 plants/ac for pinto beans and 58,000 for navy beans. The minimum recommended plant density for pinto beans is 70,000 plants/ac and 90,000 plants/ac for navy beans (MPSG), although research in this area is ongoing. In each year of the study, navy bean seed germination and plant establishment were low.

Disease and Crop Development

Environmental conditions during the study period were not conducive to white mould development and the disease was only present at very low levels in 2 out of 5 environments. Days to flowering and maturity was longer for navy beans than pinto beans (Table 8b) and while there were some statistical differences among N rates, all N treatments flowered and matured within 1 day of one another, on average.

Table 8b. Analysis of variance and mean values for plant density, nodulation, days to flower, days to maturity, yield, return to N and total N supply across 5 Manitoba environments (Portage la Prairie and Carman, 2017-2019).

	Plant density	Nodulation	Days to Flower	Days to Maturity	Yield	Return to N	Total N Supply
	Plants/ac	0-4	Days	Days	lbs./ac	$/ac	lbs./cwt
Bean (B)							
Pinto	70,892	0.6a	52b	93b	3162a	1009a	3.7b
Navy	58,261	0.4b	54a	97a	2734b	923b	4.2a
Nitrogen Rate (N)							
0	64,609	0.8a	53	95ab	2712b	922	1.7e
35	65,427	0.7ab	53	95ab	2911ab	971	2.9d
70	67,282	0.4bc	53	95b	2990ab	983	4.1c
105	62,935	0.4c	53	95ab	2962ab	955	5.2b
140	62,629	0.3c	54	96a	3171a	1010	6.0a
ANOVA							
Bean type (B)	ns	***	***	***	***	**	***
Nitrogen rate (N)	ns	***	ns	*	**	ns	***
B x N	ns	ns	*	ns	ns	ns	ns

* Significant at 0.05 p level, ** Significant at 0.01 p level, *** Significant at 0.001 p level, ns = not significant

Nodulation

Nodulation (nod) score was affected by bean type and N rate (Table 8b). Application of N fertilizer significantly reduced nod score for both bean types from 0.8 in the 0N control to 0.3 in the 140N treatment, on average. Nodule development is presumably a result of native rhizobia populations since beans were not inoculated. Nodulation in this study was low overall based on our rating scale where 0 = no nodules, 1 = <5 nodules/plant and 2 = 5-10 nodules/plant. Low nodulation in dry bean is not uncommon and there is no known relationship between nodule traits (number and size) and N fixation or yield. Recently, 3-19 nodules/plant was reported for dry bean depending on cultivar, environment and N strategy (Buetow et al. 2007; Hossain et al. 2017). In this study, pinto beans had a higher overall nod score (0.6) than navy beans (0.4).

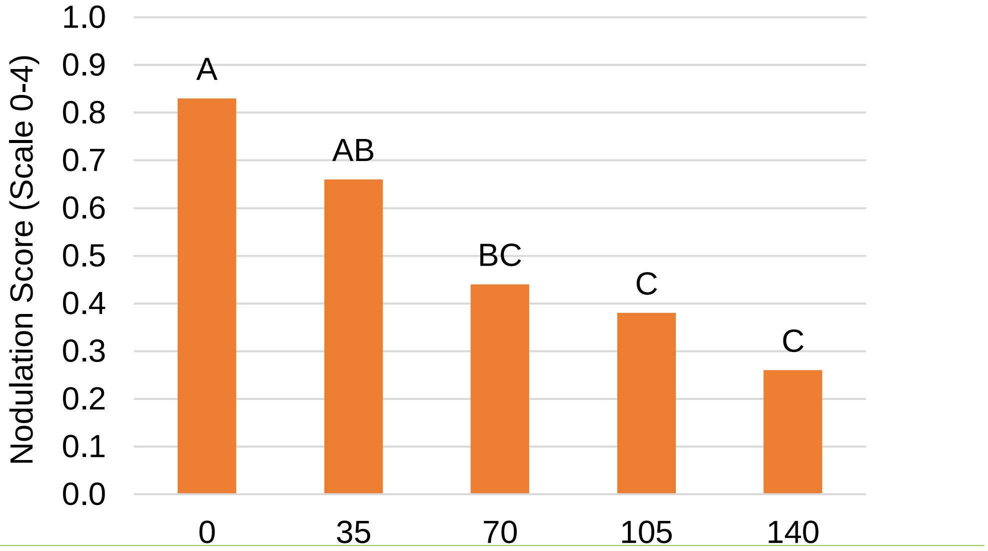


Figure 8a. Effect of N rate (lbs/ac) on nodulation across 5 environments in Manitoba (n=40).

Yield Response

Bean yield was affected by bean type and N rate. The average bean yield at the 0N rate was 2712 lbs/ac and was significantly increased at the 140N rate by 15% to 3171 lbs/ac. Nitrogen rates of 35, 70 and 105 lbs N/ac produced bean yields similar to all other treatments. The lowest N rate to match maximum biological yield was 35 lbs N/ac.

In the analysis of yield as a % of the control, which reduces environmental variability, yield increase from N application across both bean types ranged from 12-23% with the lowest N rate (35 lbs N/ac) again providing maximum yield. At the 35N rate, N supply (soil + applied N) ranged from 60-90 lbs N/ac or 2.8-3.4 lbs/cwt seed among environments.

In complementary on-farm trials with the Manitoba Pulse & Soybean Growers, there was no yield response to supplemental N in 4 trials conducted in 2019 and 2020.

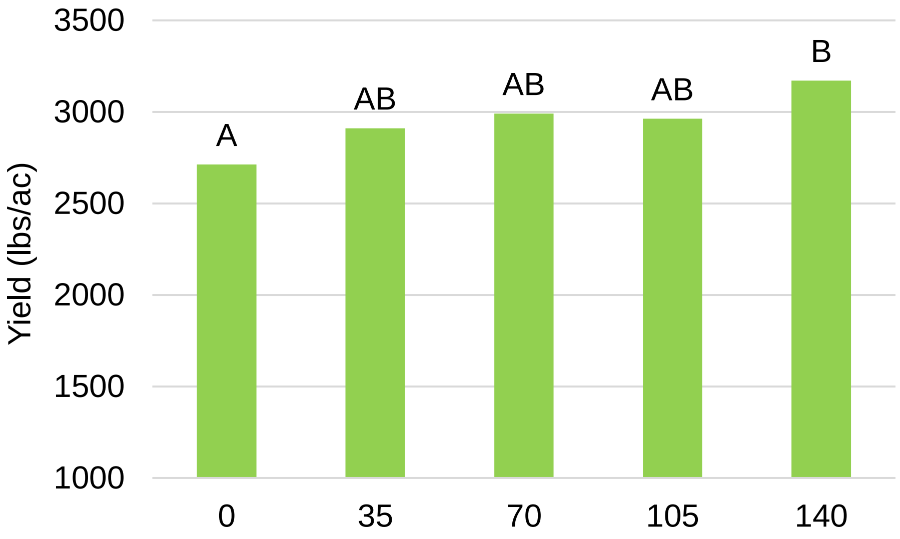


Figure 8b. Bean yield (lbs/ac) response to nitrogen rate (lbs/ac) at 5 site-years in Manitoba from 2017-2019. Means followed by different letters are statistically different at *p* < 0.05.

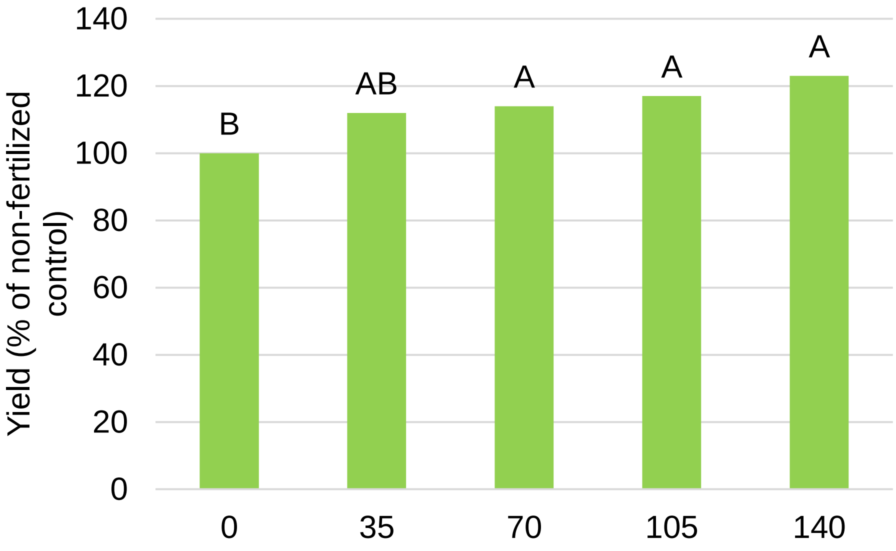


Figure 8c. Bean yield (% of non-fertilized control) response to N rate (lbs/ac) at 5 site-years in Manitoba from 2017-2019. Means followed by different letters are statistically different at *p* < 0.05.

Return to N ($/ac)

An economic analysis of N fertilization was conducted by calculating the return to N for each N treatment: Return to N ($/ac) = [Yield (lbs/ac) x Price ($/lb)] – [N rate (lbs/ac) x Cost of N ($/lb)]. Return to N was statistically the same for all rates of N application (Fig. 8d).

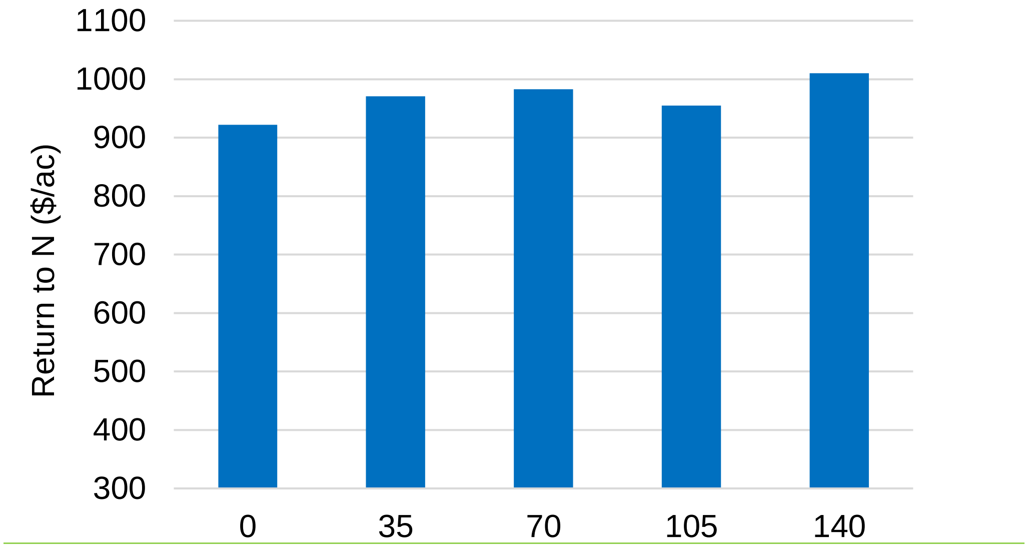


Figure 8d. Return to N ($/ac) was not statistically different among nitrogen rates (2017-2019). Assumptions: cost of N = $0.49/lb, navy beans = $0.35/lb, pinto beans = $0.33/lb.

Nitrogen (N) Supply

Nitrogen uptake of dry bean in Manitoba is estimated at 3.9 to 4.7 lbs N/cwt seed (Heard and Brolley 2008) and current N guidelines recommend 2.9-4.0 lbs available N/cwt seed. In this study, the N supply (soil + fertilizer N) per cwt (100 lbs of bean seed) was affected by N rate and bean type. As N rate increased, N supply increased and overall, navy beans had a higher N supply than pinto beans (due to overall lower yield). The N supply at the 0, 35, 70, 105 and 140N rate was 1.7, 2.9, 4.1, 5.2 and 6.0 lbs N/cwt, respectively. The two highest rates of N provided more N than what is required by dry bean and would be considered agronomically inefficient. Nitrogen is a highly dynamic nutrient in the environment and N supply does not tell the entire story since we presume that BNF (and other processes) contributes to the N requirements of dry bean. Although lower than other grain legumes, dry beans have been shown to fix 38% of their N requirements, on average (range 17-92), through BNF (Walley et al. 2007) across western Canada and more recently, 54% in Ontario studies (Wilker et al. 2019). Current Manitoba recommendations do not account for BNF contributions.

Nitrogen Balance

Estimated N uptake, total N supply and resulting N balance was determined for the 0N and 140N treatments (data not shown). Post-harvest composite soil samples were collected at Portage18, Carman19 and Portage19 from the 0N control and 140N plots.

Total N uptake in the 0N treatment was predicted at 64-169 lbs N/ac and total N supply ranged from 23-56 lbs N/ac as soil N, leaving an N deficit of 8-131 lbs N/ac depending on the environment. Residual nitrate-N from pinto and navy bean plots in the 0N control treatment ranged from 19-59 lbs/ac. This suggests that there was sufficient N supply remaining after harvest and that the N deficit for the 0N control, which ranged from 68-131 lbs/ac or 67-85% of N uptake in those environments where post-harvest soil samples were collected, was acquired through other processes such as biological nitrogen fixation, deep nitrogen (root exploration >24”), mineralization, or a combination. Measurements, however, were not taken to allow consideration of nitrate-N from >24”, nitrogen derived from BNF nor mineralization.

In the 140N plots, N uptake was predicted at 90-176 lbs/ac and N supply was 163-196 lbs/ac, providing sufficient synthetic N to meet crop demand. At both sites in 2019, post-harvest N was low (21-34 lbs/ac), suggesting that fertilized beans utilized applied N. At Portage18, however, post-harvest N in the 140N treatment was very high (124 lbs/ac), suggesting the fertilized beans did not utilize the full N supply and also likely acquired N through other processes.

DISCUSSION

Dry bean yield response to N fertilizer was consistent across environments (data not shown) and bean type. Yield was only significantly increased over the non-fertilized, non-inoculated control at the 140N rate. The lowest rate of N to reach maximum yield was 35 lbs N/ac. There were no significant differences between treatments for return to N ($/ac) indicating that the economic optimum N rate is 0 lbs N/ac. Based on these results, addition of supplemental N may not be warranted in Manitoba dry beans but additional work is needed to account for the N requirements of dry bean.

Dry bean yield in the 0N control was exceptional - 2700 lbs/ac on average (range 1400 to 3200 lbs/ac), providing 86-93% of maximum yield. Only 15-33% of predicted N uptake in the control was supplied through residual soil nitrate-N indicating that beans likely acquired N through a combination of biological nitrogen fixation, mineralization and deep nitrogen (>24”).

Dry beans in this study did produce effective nodules and despite low nodulation overall, nodulation was reduced in a step-wise fashion as N rate increased. Notwithstanding the overall yield responses to N rate being consistent among environments, the effect of N rate and environment on nodulation was more complex (data not shown). This is important in understanding the processes contributing to N requirements of dry bean and the overall magnitude of yield response to N in different environments. Consideration has not previously been given to N fixation in dry beans but our work suggests that BNF is contributing to the N requirements of dry bean in Manitoba and is supported by %NDFA values in the literature. We aim to characterize the N fixation capacity of current cultivars in Manitoba environments in the future. Variation in BNF among dry bean cultivars also suggests that higher BNF should be a priority for breeders among other selection traits.

A clear N management strategy for dry bean has not emerged from this study at this point. Due to the specificity among dry bean cultivars and environments, the optimum N strategy may not be a one size fits all approach. For now, one of the most important steps in determining a dry bean N management strategy is to know if dry beans are developing nodules in specific field environments. Assessing nodulation must be part of routine crop scouting in dry beans. Farmers and agronomists should also implement a replicated on-farm trial to compare at least 3 rates of N including a 0N control.

Results of this study are being reviewed in conjunction with results of the inoculant evaluation study (page 43) and on-farm N fertility trials to revise N management recommendations for Manitoba dry beans.

Effect of Preceding Crop and Residue Management on Dry Bean

(Carman and Portage la Prairie, 2017-2020)

Crop sequence within a rotation can influence yield through various agronomic factors, such as nutrient cycling, residue, soil moisture and pest pressure. Currently, farmers in Manitoba are seeding dry beans most commonly following wheat > corn > canola > dry bean and oat (MPSG). Long term data from Manitoba crop insurance suggests that crop yield response may vary by previous crop type. From 2010-2015, 21% of navy bean acres were planted into spring wheat stubble, 35% into canola stubble, 13% into navy bean stubble and 8% into corn stubble and relative navy bean yield produced by those previous crop types was 109%, 93%, 86% and 103%, respectively (MASC). There is currently no research data available for Manitoba on the effect of preceding crop and residue management on dry bean yield and productivity. **The objective of this experiment was to determine the effect of preceding crop type and residue management on dry bean productivity.**

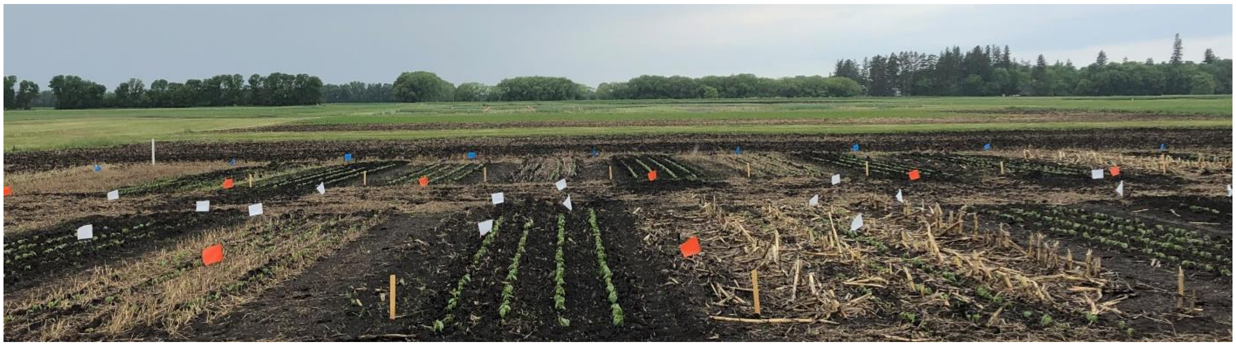


Figure 9a. Pinto bean establishment at Carman on June 11, 2019 in various combinations of crop residue (wheat, corn, canola, bean) and residue management (tilled vs. direct seed).

Materials and Methods

A two-year study was conducted at Carman, MB (loam to sandy clay loam soil) and Portage la Prairie, MB (clay loam to clay soil) in 2017-18, 2018-19 and 2019-20. Field history of the study sites did not include dry bean in at least the 5 years previous. In year 1, four test crops (wheat, canola, corn and pinto bean) were seeded and managed according to current best practices. After harvest, each test crop plot was split into a tilled and direct seed treatment resulting in 8 treatments. Tillage was performed in the tilled treatments in fall and spring (except fall 2018) using a field cultivator, roto-tiller or disc cultivator depending on soil and residue conditions. In year 2, Windbreaker pinto beans were seeded into each preceding crop-residue management treatment between May 16 and 29 at 100,000 seeds/ac on 12 or 15” row spacing. Plots were fertilized by preceding crop type to 90-120 lbs N/ac total soil + fertilizer N and all treatments received 10 lbs P_20_5/ac seed placed. Weed control consisted of pre-emergent glyphosate (group 9) + Pursuit (group 2) or Dual II Magnum (group 15) and in-crop Basagran + Viper (group 6 + 2) and Poast (group 1). All growing environments were dry (42-69% of normal growing season precipitation) with seasonal to above seasonal temperatures.

Experimental design was a split-plot RCBD with 4 replicates. ANOVA was conducted using Proc Mixed in SAS 9.4. Crop residue, tillage and environment were considered fixed effects and block(environment) and residue*block(environment) were considered random effects. Effects were considered significant at *P* < 0.05 and LS means for significant effects were compared using Tukey’s HSD. Assumptions of ANOVA were assessed for all variables prior to final analysis i.e., residuals were assessed for normality, homogeneity of variance and outliers. Nodulation score data and broadleaf weed data was transformed using square root function. Data analysis was performed on transformed data and data prior to transformation is presented.

Table 9a. Summary of analysis of variance for the effect of preceding crop type, residue management (tillage), environment and their interactions on measured variables in pinto bean at Carman and Portage la Prairie in 2018, 2019 and 2020.

Effect	Plant population	Grass weed density	Broadleaf weed density	Nod Incidence	Nod Score	Root rot severity	Maturity	Yield
Environment (E)	ns	ns	*	*	***	***	***	**
Crop residue (C)	**	*	*	ns	**	*	**	ns
Tillage (T)	*	***	*	ns	ns	ns	ns	ns
E x C	*	ns	ns	ns	ns	*	ns	ns
E x T	ns	ns	ns	ns	**	ns	ns	*
C x T	ns	**	*	ns	ns	ns	ns	ns
E x C x T	ns	ns	*	ns	ns	ns	ns	ns

* Significant at $P < 0.05$, ** Significant at $P < 0.01$, *** Significant at $P < 0.001$, ns = not significant

Plant population

Pinto bean plant population was affected by tillage, preceding crop and the effect of preceding crop varied by environment (Table 9a). Overall, pinto beans seeded into tilled residue (74,000 plants/ac) resulted in a slightly higher plant population than direct seeded beans (70,000 plants/ac). Pinto beans seeded into canola stubble (76,000 plants/ac) resulted in a higher plant population than corn stubble (68,000 plants/ac) overall, but the trend was not consistent among environments. All plant populations were near the target plant stand of 70,000 plants/ac. An important finding is that bean plant stands following corn were similar in both direct seed and tilled treatments since corn residue management can be challenging. Seeding equipment varied by environment but all used double- or single-disc openers and seeding took place between the preceding corn rows as to avoid root balls. Minimal hair pinning occurred in corn stubble but was sometimes a problem where wheat residue was not standing or well distributed.

Figure 9b. Pinto bean establishment in corn residue at Carman on May 31, 2018 (L) and on June 18, 2019 (R) in direct seed (inset, L) vs. tilled corn residue (inset, R).

Weed density

At Carman, there are suspected group 1 and 2 herbicide resistant (HR) foxtail and wild oat populations. Differences in grass weed density among treatments became evident *post-seeding* which may be attributed to differing herbicide strategies and selection in the preceding test crops, tillage effects and limited herbicide options for direct-seed beans. To capture these differences, weed community and density data was collected prior to in-crop herbicide application in all years at Carman only. The grass weed community consisted primarily of green foxtail but also yellow foxtail, barnyard grass, wild oat and volunteer wheat. The broadleaf weed community included wild buckwheat, lambsquarters, redroot pigweed, volunteer canola, wild mustard, smartweed and dandelion. At Portage, there were visual differences in the *pre-seed* weed community where winter annuals and perennials (dandelion, Canada Thistle, stinkweed and narrow-leaved hawk's beard) were present more clearly in the direct seed treatments. They were managed well with the pre-emerge herbicide application.

The density of grass weeds in pinto beans was significantly affected by crop residue, tillage and their interaction (Table 9a). **Grass weed density was higher when pinto beans followed wheat (47 plants/ft^2) compared to pinto beans following corn (13 plants/ft^2) and was consistent in both tilled and direct seed systems. In all preceding crop types, grass weed density was higher in tilled residue (43 plants/ft^2) compared to when pinto beans were direct seeded (24 plants/ft^2)** although these differences varied in magnitude (C x T interaction).

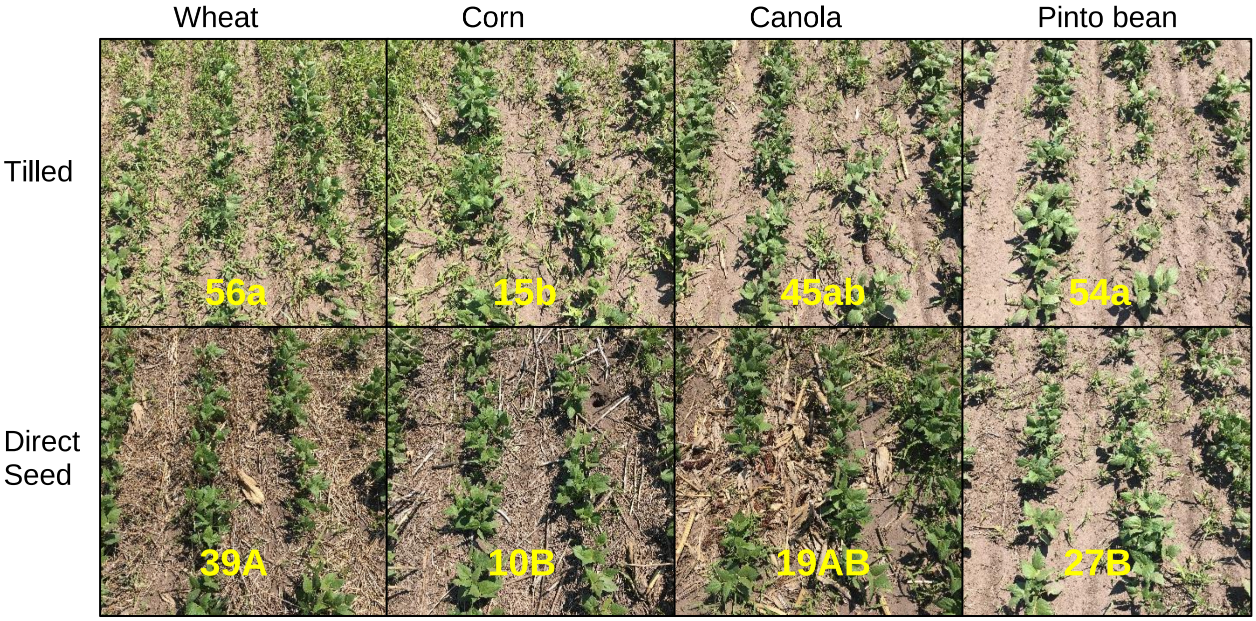


Figure 9c. Pinto beans seeded May 23, 2018 into split plots of tilled and direct-seeded wheat, corn, canola and bean stubble at Carman, MB. Overall grass weed density (weeds/ft^2) by treatment indicated in yellow text. Preceding crop means followed by the same letter within a tillage system are not significantly different at $P < 0.05$ (crop residue x tillage interaction means).

We speculate that HR grass weed populations were selected for with the preceding wheat and bean crop where group 1 and 2 herbicides did not provide full control. A fall or spring soil incorporated herbicide is a common strategy ahead of dry beans that would provide control of group 1 and 2 resistant grass weed populations, however, these soil-applied herbicides do not fit well in direct seed systems and are not registered for all bean types. In this study where we compared tilled and direct seed residue management systems, we used a pre-emerge application of glyphosate + Pursuit in 2017 and then glyphosate + Dual II Magnum in 2018 and 2019. The effect of preceding crop and tillage was consistent among environments despite varying herbicide strategies. Group 2 resistant populations and lack of rainfall may have reduced efficacy of the pre-emerge products. Adequate weed control/suppression was achieved with the in-crop application of Basagran + Viper ADV and Poast (2017 only), suggesting partial resistance among the grass weed populations. Visually, the foxtail was chlorotic and growth was suppressed sufficiently for the dry bean canopy to get ahead.

Dry beans are generally poor weed competitors and have higher yield loss associated with weed interference compared to other field crops (Soltani et al. 2018). These findings have important implications for weed management in pinto beans, especially with increasing herbicide resistance and limited control options in dry beans. In the most recent Manitoba Weed Survey (2016), green foxtail, barnyard grass, wild oats and yellow foxtail all comprise the top ten in relative abundance, ranking 1, 3, 4 and 6, respectively (Beckie et al. 2016). In 2016, over 68% of surveyed fields had HR weeds compared to 48% in 2008. Most wild oat populations sampled were HR to group 1 (78%), group 2 (43%) or both (42%). Among green foxtail populations sampled, HR to group 1 (44%), group 2 (6%) and group 1 and 2 (2%) was found. The 2016 survey was the first to document HR in yellow foxtail, where 42% were HR to either group 1 (32%), group 2 (17%) or both (8%). Lastly, group 2 resistant barnyard grass was found in 27% of fields that contained the weed, which was also the first documentation.

In fields where grassy weeds are a problem, especially herbicide resistant populations, consideration to where pinto bean falls in crop rotation and how crop residue is managed can help reduce in crop weed competition and selection pressure. Results of this study suggest that seeding pinto beans following corn and direct seeding overall generally reduces grass weed density although soil incorporated herbicides remain an important tool.

The response of broadleaf weed density was not as apparent and was more complex - the interaction among residue and tillage varied by environment (3-way interaction). At 2 out of 3 environments, broadleaf weed density was similar regardless of treatment. At Carman18, however, pinto beans seeding into tilled corn residue had more broadleaf weeds (2 plants/ft2) compared to pinto beans direct seeded into corn residue (0.8 plants/ft2). The broadleaf weed community at Carman was controlled well with in-crop herbicide application.

Nodulation Incidence (% of plant roots with nodules) and Nodulation Score (scale 0-4)

The % of bean roots with nodulation varied significantly among environments, ranging from only 18% at Carman18 to 99% at Portage18. All other environments ranged from 38 to 58% and were statistically similar to all environments. Nodulation score among environments was low, ranging from 0.4 to 1.6. Nodulation incidence nor score was expected to be high in this study because pinto beans were fertilized to meet N requirements, which is the current recommended practice. Pinto beans following bean stubble resulted in higher nodulation score (0.9) compared to all other stubble types which ranged from 0.7 to 0.8. The effect of tillage on nodulation score varied by environment – at 5 out of 6 environments, residue management did not affect nodulation. At Portage20, direct seeded beans had a higher nodulation score (0.9) than beans seeded into tilled residue (0.7).

Root Rot (severity scale, 0-9)

Overall, the mean root rot score in this study was 3.3 with a range of 1.9 to 4.5. A root rot score ≥4 with 50% of the lower stem and root area infected would be expected to reduce growth and limit yield (McLaren 2019). In this study, preceding crop, environment and the interaction between tillage and environment significantly affected root rot severity.

Root rot severity was highest in pinto beans that were seeded into bean stubble (3.3) and lowest in pinto beans following corn (3.0). Wheat and canola stubble resulted in similar root rot severity as all crop residue types (Fig 9e). Environment accounted for the greatest range in root rot severity, from 2.5 to 3.7. The effect of residue management varied by environment - at 5 out of 6 environments, tilled and direct seed systems did not influence root rot severity. At Portage20, however, pinto beans seeded into tilled residue had a higher root rot score (3.7) compared to direct seeded beans (3.3).

According to Manitoba disease surveys, the % of dry bean fields with root rot and disease severity increased over the 5-year period from 3.3 in 2004-2008 to 4.5 in 2014-2018 (McLaren 2019). The most prevalent root rot pathogen(s) found in bean fields are *Fusarium* species.

Fig 9d. Root rot severity scale from 1-4 (L-R) where lower stem is rated for % infected area.

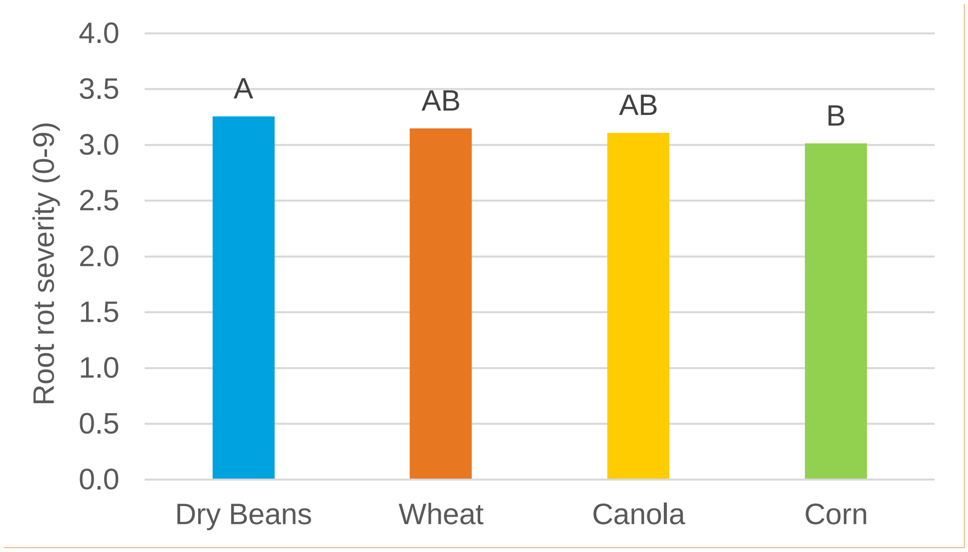


Fig 9e. Effect of preceding crop on pinto bean root rot severity (n=48). Means that contain different letters are statistically different at $P < 0.05$.

White Mould

White mould, caused by *Sclerotinia sclerotiorum*, was present in only 2 out of 6 environments. At Carman20, it was present randomly in 5 out of 32 plots at 2-8% incidence. At Portage18, white mould incidence ranged from 5-11% among treatments and there was no significant effect of preceding crop or residue management. White mould can be an economically important disease of dry bean when weather conditions are favorable. The growing conditions for the duration of this study were dry and not favorable for white mould development. In years where rainfall and available soil moisture is high prior to and during flowering (late June and July in Manitoba), we would have expected higher white mould incidence overall and potentially higher in beans following beans and canola which are also host crops to Sclerotinia.

Maturity

The number of days required from seeding to R9 (80% pod colour change) was significantly affected by the main effects of preceding crop and environment. Among environments, pinto bean maturity ranged from 80 to 105 days to maturity (DTM). The effect of preceding crop was consistent among all environments (no interactions) such that pinto beans matured in 93 days following corn compared to 90 days following beans. Bean maturity in wheat and canola was similar to all preceding crops.

Earlier maturity that does not sacrifice yield might be favorable, particularly as dry bean production expands into shorter growing areas of Manitoba and timely harvest to maintain seed quality remains a priority.

Yield

Pinto bean yields were high in this study and significantly affected by environment and an interaction between residue management and environment only. There was more than a twofold range in yield (1788 to 3888 lbs/ac) among environments which were typically greater than the 5-year provincial average pinto bean yield of 1891 lbs/ac (MASC).

Preceding crop did not affect pinto bean yield in this study (Fig. 9f), suggesting that dry beans offer flexibility in a crop rotation. A previous study in Alberta also found no differences in bean yield following wheat, barley and canola and few differences among tillage system (Blackshaw et al. 2007). In this study, the effect of residue management varied by environment (Table 9a). **In 2 out of 6 environments (C18 and C19), direct seeded beans out-yielded beans seeded into tilled stubble by 10-17% (Fig 9g).** This effect was consistent across preceding crop types (wheat, canola, corn and pinto beans). At the remaining environments, yield was similar between residue management strategies. The soil texture at Carman is lighter than Portage and may have benefited from moisture conservation with direct seeding.

Figure 9f. Overall pinto bean yield by preceding crop type across tillage system and environment from 2017 to 2019 at Carman and Portage la Prairie, MB (n=48).

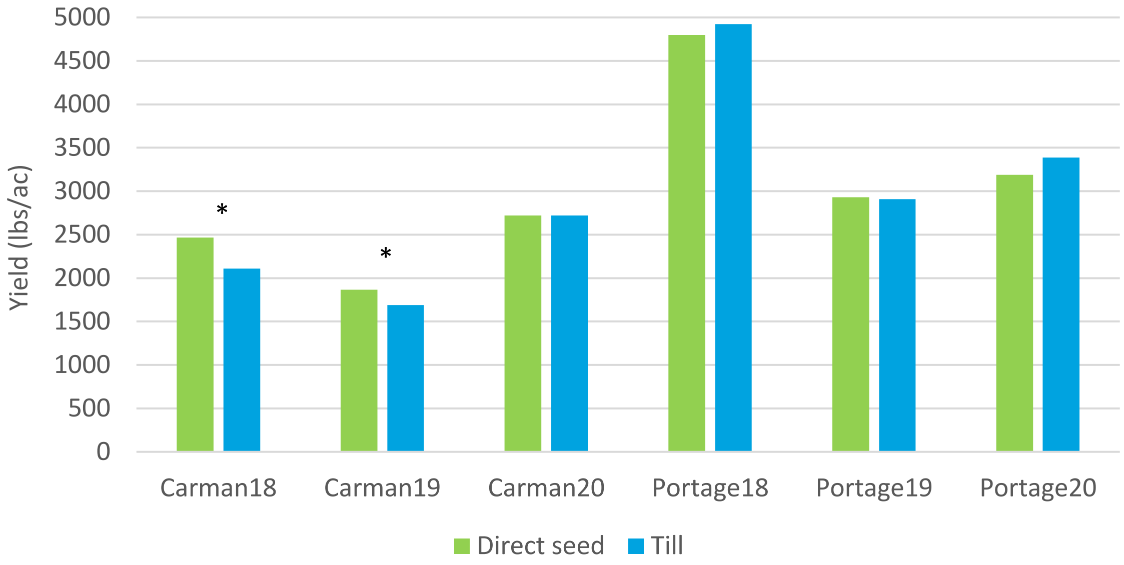


Figure 9g. Effect of residue management on pinto bean yield at each environment averaged across preceding crop type (n=16). Asterisk (*) denotes significant difference between residue management/tillage at *P* < 0.05.

Conclusions

Pinto beans produced similar yield following wheat, canola, corn and bean stubble while direct seeded pinto beans increased yield by 10-17% in 2 out of 6 environments compared to seeding into tilled residue. Results indicate that dry beans can be successfully established following a range of crops and under direct seed conditions in Manitoba crop rotations. Bean establishment and yield were not compromised by crop sequence or residue management but some important and clear agronomic effects on weed density, root rot severity and maturity were identified. These crop sequence and tillage effects may be exacerbated under certain environmental or field conditions and should be considered in cropping system planning. For example, fields with a long history of bean production or fields prone to wetness may see greater effects of root rot and other diseases. It is possible that the dry growing season conditions experienced through the duration of the study (39-69% normal precipitation) and lack of dry bean field history masked additional agronomic effects that could otherwise influence bean yield (e.g. white mould). The drier conditions were favorable for bean yields in this study and likely highlighted the resilience of pinto beans to direct seed conditions when residue management and seeding equipment facilitate good crop establishment.

Evaluation of Dry Bean Inoculants

(Carman and Melita, MB • 2019-continuing)

Dry beans are known as relatively poor N fixers compared to soybean, pea and faba bean, meeting <45% of their N requirements through biological nitrogen fixation (Walley 2017). Additionally, dry bean association with rhizobia can be highly specific, being shown to vary with environment and cultivar. This makes N management strategies for dry beans very complex. In previous western Canadian studies, there have been few responses to inoculant (McAndrew et al. 2000) and with limited acreage and a range of market classes, there are typically none or few inoculant products available specifically for use in dry beans. Supplemental N fertilizer is being used by the majority of farmers in Manitoba; a survey of 116 Manitoba dry bean farmers in 2016 demonstrated that about 90% of farmers apply N fertilizer at an average rate of 60-90 lbs N/ac (Heard 2016). Based on observations of bean nodulation and an unclear response to N fertilizer in our other Manitoba studies, we hypothesized that nodulation is contributing to N requirements of dry bean in Manitoba and we sought to investigate further. In 2019, two inoculant products became available in limited quantities to Manitoba farmers and we acquired product for independent testing in small-plot trials.

The objective of this experiment is to determine if recently available inoculants improve nodulation and yield in pinto, navy and black beans compared to non-inoculated, non-fertilized checks. The experimental design is a 2-way factorial arranged as a completely randomized complete block design with 4 replicates. The first factor is bean type/market class and the second factor is inoculation strategy with the resulting treatment list:

	Bean type	**Variety**	**Inoculant**
1.	Navy beans	T9905	Check (non-inoculated, non-fertilized)
2.	Navy beans	T9905	BOS self-adhering peat inoculant
3.	Navy beans	T9905	Primo GX2 granular inoculant
4.	Pinto beans	Windbreaker	Check (non-inoculated, non-fertilized)
5.	Pinto beans	Windbreaker	BOS self-adhering peat inoculant
6.	Pinto beans	Windbreaker	Primo GX2 granular inoculant
7.	Black beans	Eclipse	Check (non-inoculated, non-fertilized)
8.	Black beans	Eclipse	BOS self-adhering peat inoculant
9.	Black beans	Eclipse	Primo GX2 granular inoculant

Primo GX2 is a multi-action granular dry bean inoculant offered by Verdesian (contains *Rhizobium leguminosarium* biovar *phaseoli* 1x10^8 CFU/g and *Azospirillum brasilense* 1x105 CFU/g). BOS self-adhering peat inoculant is offered by NutriAg (contains *Rhizobium leguminosarium* biovar *phaseoli* 8x10^8 CFU/g).

Figure 10a. Dry bean inoculant treatments at Melita, MB in 2020 (B=black, N=navy, P=pinto).

At Carman19, beans were seeded May 29 into tilled oat stubble with a Wintersteiger Monoseed Great Plains planter (15” rows). At Carman20, beans were seeded June 4 into tilled wheat stubble with the same planter. At Melita20, beans were direct seeded into harrowed wheat stubble May 27 with a Seedhawk drill (9.5” rows). See Table 10a for soil analysis, fertilizer and weed management. Insecticide was sprayed for cutworms at Carman19 and grasshoppers at Melita20 and Carman20. Beans were hand harvested at Carman and combined at Melita. To avoid contamination, non-inoculated treatments were seeded first followed by the Primo seed placed granular inoculant treatments (granular inoculant in separate boxes) and lastly, the BOS self-adhering peat inoculant treatments. At both locations, all seed was metered the same way.

Table 10a. Soil characteristics, applied fertilizer and weed control at each site-year.

	Carman19	**Carman20**	**Melita20**
Soil texture	Very fine sandy loam	Sandy clay loam	Loam
Nitrate-N (0-24, lbs/ac)	33	12	76
PO_4-P (0-6, ppm)	14	6	6
K_2O (0-6, ppm)	266	183	254
SO_4 (0-24, lbs/ac)	56	58	480
Zn (ppm)	1.24	n/a	0.83
Soil OM %	3.0	n/a	3.8
Soil pH (0-6, 6-24)	5.7, 7.3	6.0, 7.9	7.7, n/a
Soluble salts (0-6, 6-24 mmho/cm)	0.07,0.25	0.11,0.25	0.92, 1.62
N-P-K-S applied at seeding	None	2-15-0-0	10-35-20-8-2 Zn
Weed control	PPI Treflan, Basagran Forte + Viper in-crop	PPI Treflan, Select + Amigo in-crop, Basagran + Viper in-crop	Pre-emerge glyphosate, in-crop Basagran + Arrow

Proc Glimmix in SAS 9.4 was used for ANOVA with bean, site-year, and inoculant as fixed effects and block(site-year) as a random effect using a normal distribution for the measured variables. Residuals were evaluated for normality, heterogenous variance and outliers. For plant population, three putative outliers were identified and removed for analysis. Means separation was conducted using Tukey’s HSD with the lines statement for significant effects ($P \leq 0.05$).

Results and Discussion

At Carman19, very poor establishment of navy beans (<16,000 plants/ac) resulted in no harvestable results. For this reason, Carman19 data was analyzed separately. **There was no significant effect of inoculant treatment on nodulation incidence, nodulation score or yield at Carman19.** The following results and discussion are for Carman and Melita in 2020.

Overall, inoculant treatments had the same effect across bean types for nodulation and yield (inoculant x bean type interaction is ns; Table 10b) – this is encouraging news since specificity between market classes and N responses is common. As expected, plant populations and yields typically varied by bean type and site year, or their interactions.

Table 10b. Effect of inoculant, site-year, bean type and their interactions on bean population, nodulation, maturity and yield (Portage la Prairie and Melita, MB in 2020).

	Plant population	**Nodulation Incidence**	**Nodulation Score**	**Days to maturity**	**Yield (lbs/ac)**
Inoculant (I)	*	*	***	ns	***
Site-year (S)	***	ns	**	*	ns
Bean (B)	***	ns	ns	***	***
Inoculant x Bean	**	ns	ns	ns	ns
Inoculant x Site-year	ns	ns	**	ns	***
Bean x Site-year	**	*	*	ns	***
I x B x S	**	ns	ns	ns	ns

* Significant at 0.05 p level, ** Significant at 0.01 p level, *** Significant at 0.001 p level, ns = not significant

Plant population

All established plant populations were at or above the target, with the exception of navy beans at Carman20 (Table10c) and inoculated navy beans at Melita20. Plant populations varied by bean type, as expected, due to different seeding rates and targets. Site-year also affected plant population with higher establishment overall being achieved at the Melita site although differences between bean types varied in magnitude (bean x site-year interaction, Table 10b). Surprisingly, the effects of inoculant and inoculant x bean type were significant as was the 3-way interaction. At Carman, there was no significant effect of inoculant among bean types for plant population. In contrast, at Melita, the BOS inoculant (171,000 plants/ac) resulted in a higher plant population in black beans compared to the other inoculant treatments (137-142,000 plants/ac); in pinto beans, both inoculant treatments increased plant population (101-111,000 plants/ac) compared to the check (84,000 plants/ac) while in navy beans, both inoculant products reduced plant population (82-86,000 plants/ac) compared to the check (107,000 plants/ac). It is unclear how inoculant product affected plant establishment at the Melita site – seed for each treatment was metered using the same mechanism and any growth-promoting effects we would expect to be consistent among environments. It is also unclear how the established plant stands for black beans at Melita were higher than the seeding rate. The flow of seed may be affected by the speed of the seeding operation resulting in non-uniform plant stands which in addition to sampling bias may have influenced the results.

Table 10c. Seeding rate, target plant population and interaction mean for the effect of bean type by site-year on average plant population.

	Seeding rate (seeds/ac)	**Target** (plants/ac)	**Carman20** (plants/ac)	**Melita20** (plants/ac)	**% est.**
Pinto	100,000	70,000	87,610	98,599	87-99
Navy	130,000	90,000	73,893	91,651	57-85
Black	130,000	90,000	117,551	150,123	78-115

Nodulation Incidence (% of bean plants with nodules)

Across bean types, 77-80% of bean plants developed N-fixing nodules. There was a significant difference among inoculants – Primo GX2 inoculant resulted in a more nodulated bean plants (87%) compared to the check (72%) and similar to the BOS inoculant (77%). Within site year, there were differences in ranking of bean type for nodulation which contributed to the bean x site-year interaction (Table 10b) i.e., at Melita20, pinto>black>navy while at Carman20, black>navy>pinto but these differences within site year were not statistically significant.

Figure 10b. Black bean roots (L-R) that were rated for nodulation from the Primo GX2 (score = 1.4), Check (score=1.6) and BOS (score = 1.5) treatments in rep 2 at Carman in 2020 (there were no significant differences between inoculant treatments).

Nodulation Score (number of nodules per plant root, scale 0-4)

The effect of bean type on nodulation varied by site year and there was no overall effect of bean type (Table 10b). At Melita20, pinto beans (score = 2.9) had a significantly higher nodulation (nod) score than navy beans (score = 2.2) while black beans (score = 2.4) were similar to both. At Carman20, nod score among bean types was statistically the same and would be considered low (range 0.9 to 1.4). Since the trend at Carman was opposite to that of Melita (black > navy > pinto), the overall effect of bean type was not significant.

Nodulation across all bean types was significantly greater at Melita (avg 2.5 = fair to good) compared to Carman (avg 1.2 = poor). At Carman, we have observed historically low nodulation in our dry bean studies, which may be related to relatively low soil pH which is known to inhibit nodulation. Most Manitoba soils have a neutral (pH 6.6-7.3) to alkaline pH (pH >7.4) but there are areas with slightly acidic soil (pH 6.1-6.5). Further investigation is required.

Figure 10c. Black bean root with 20-40 nodules.

The effect of inoculation on nod score was significant overall but varied by site-year (Fig 10d). At Carman, nodulation was statistically the same in all inoculant treatments (range 1.0-1.3) while at Melita, Primo GX2 inoculant (3.6) resulted in significantly higher nod score than both BOS inoculant (2.0) and the untreated check (1.8), which were similar to one another. A nod score of 3.6 would be considered good to excellent, with 20-40 nodules per plant. We have not seen this high of nodulation score in any of our dry bean studies, thus far. That being said, there is no known relationship between nodule traits (e.g., number, weight) and bean yield. More work is needed in this area to understand how nodule number, weight and/or function may relate to N fixation capacity and yield. In this study, both low and high nod scores produced excellent yield.

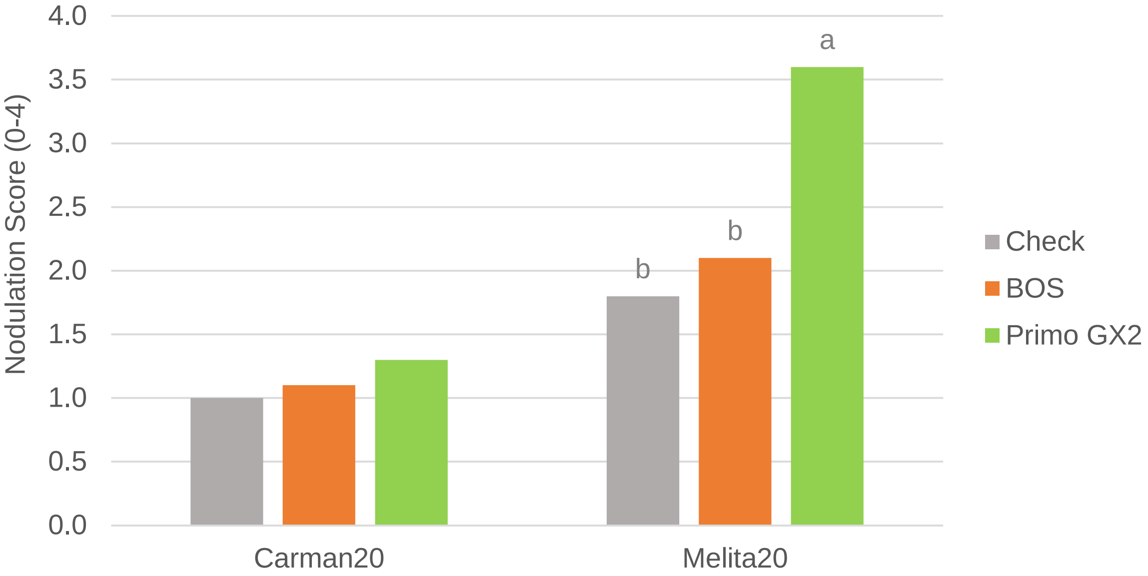


Figure 10d. Bean nodulation score by inoculant treatment at each site-year in 2020 (averaged across bean types). Means within site-year followed by diff. letters are statistically different at P<0.05.

Days to Maturity (DTM)

Days to maturity varied by bean type and site-year (Table 10b). On average, navies took 94 days to reach R9 (80% pod colour change) compared 92 days for blacks and 88 days for pintos. On average, at Melita20, DTM was 92 compared to 90 at Carman20.

Yield (lbs/ac)

A yield response to inoculant treatment was detected but this effect varied by site-year (Table 10b and Fig. 10e). At Carman20, there were no statistical differences in yield among inoculant treatments. At Melita20, however, Primo GX2 resulted in a significantly higher yield compared to the BOS inoculant and non-inoculated check. The yield response was an impressive 743 lbs/ac, on average, or 34% above the check.

Yield among bean types varied by site-year – at Carman20, pinto beans produced higher yield (3450 lbs/ac) compared to navy (2440 lbs/ac) and black beans (2550 lbs/ac). At Melita20, however, all bean types produced similar yields (2760-2860 lbs/ac). In Manitoba, on average, pinto > navy > black bean yields but there is annual variation in this trend. The 2020 provincial average pinto, navy and black bean yields were 2309 lbs/ac, 1854 lbs/ac and 1897 lbs/ac, respectively. The 5-year provincial average (2015-2019) bean yields for those bean types are 1891 lbs/ac, 1719 lbs/ac and 1683 lbs/ac, respectively (MASC).

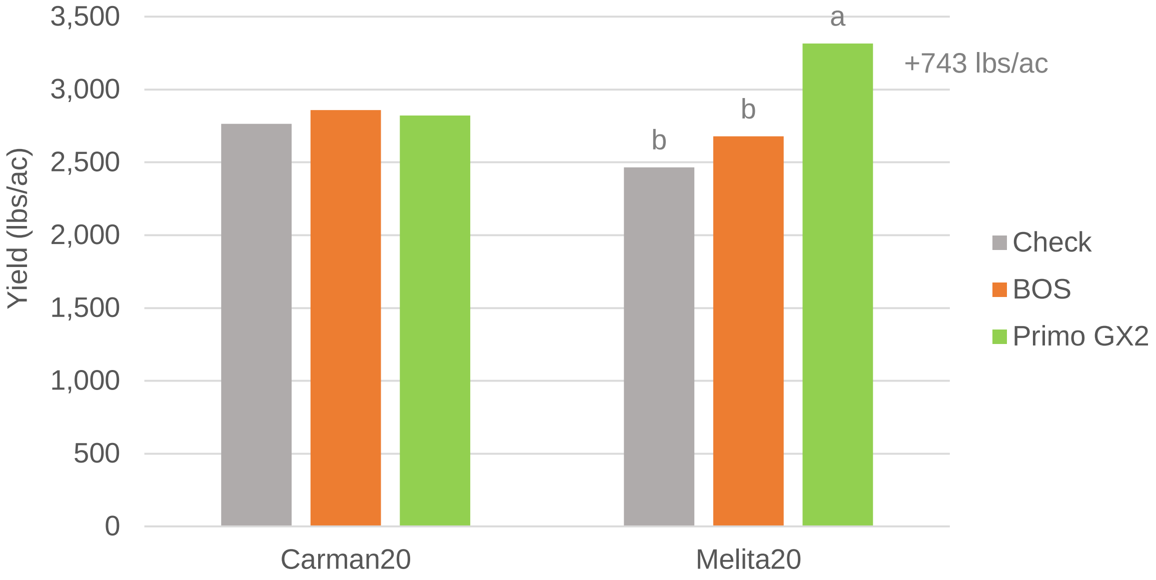


Figure 10e. Dry bean yield by inoculant treatment at each site-year in 2020 (n=12). Means within site-year followed by different letters are statistically different at P < 0.05.

Conclusions

A significant nodulation and yield response to Primo GX2 granular inoculant was detected across all bean types at the Melita site in 2020. There was no detectable response at Carman in 2019 nor 2020. We will continue to evaluate available dry bean inoculant products in 2021 to increase the number of environments. It is important to note that rhizobia interaction and N responses in dry beans can be specific to cultivar and environmental conditions. Nodule assessment in dry beans should be part of a regular crop scouting routine. This study will contribute to updated N recommendations for dry beans in Manitoba.

Thank you to NutriAg and Verdesian for providing inoculant products for testing.

Yellow Pea Growth Stages and Effect of Intercropping on Pea Aphid Populations in Manitoba

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Introduction

- The pea aphid, *Acyrthospihon pisum* Harris (Hemiptera: Aphididae) was first reported in Illinois, US in 1878 and spread throughout North America. It is one of the important insect pests of field peas, *Pisum sativum* L., in Canada that could potentially cause economic damage (Ali-Khan and Zimrner 1989).
- The economic threshold in peas at $0.21/kg ($5.71 per bushel) and average control cost of $16.63-$22.86/ha ($6.73-$9.25/acre) is 2 to 3 aphids per 8-inch (20 cm) plant tip, or 9 to 12 aphids per sweep, at flowering (Manitoba Agriculture 2020).
- Demand for yellow pea production is growing in Manitoba and western Canada. There is also growing interest in intercropping and relay cropping practices, which have the potential to improve crop productivity through mechanisms such as resource use efficiency and pest suppression.
- Characterization of pea growth and development, arrival date of pea aphid and the effect of intercropping and relay cropping with field peas on pea aphid populations have not been studied in Manitoba.

Objectives

From a sub-set of treatments within broader intercrop and relay crop agronomy experiments, we set out to:

- To characterize field pea growth and development in Manitoba.
- To determine the approximate arrival days of pea aphids in Manitoba.
- To quantify aphid populations among the intercropping and relay cropping treatments compared to monocrop peas.

Materials and Methods

Fig.1. Plot arrangement in Prairies East Sustainable Agriculture Initiative Research Station, Arborg 2020.

- Randomly selected pea plants in the front and back of each plot were inspected once a week for pea aphids (4-5 plants x 4 rows = 16-20 plants/plot; Table 01). As plants grew taller and bushier, aphids were counted on the terminal 20 cm tip. The total number of aphids was recorded per plant for 9 weeks beginning in early June each year.
- Vegetative and reproductive stages according to the "Field Pea Growth Staging Guide" from Manitoba Pulse & Soybean Growers were recorded on 5 randomly selected pea plants per plot on the aphid sampling days (weekly). Pea monocrop seeding dates were May 3-21.
- Crop treatments and agronomic practices varied by site-year and followed best management practices if available. Most intercrop and relay crop treatments were experimental, therefore agronomic practices are being tested. Detailed agronomic and yield data will be available in the Soybean and Pulse Agronomy 2020 Annual Report in winter 2021.
- Field locations: University of Manitoba Ian N. Morrison Research Farm in Carman (2018-2020) and Prairies East Sustainable Agriculture Initiative (PESAI) Research Station in Arborg in 2020 (Fig. 1).
- Data analysis: Aphid numbers were analyzed with the Kruskal-Wallis rank-sum test followed by the Dunn test as a post hoc test on each sample day. The Welch's Heteroscedastic F Test followed by the pairwise comparisons using the Bonferroni Corrections were used to analyze the aphid numbers after combining the same crop treatments in Arborg.

Table 1. Selected treatment list, replicates, and inspected plants of the study in each location and year.

Year-Location	Treatments	No. of reps/trt	Total plants/plot	Total inspected plants/treatment
2018-Carman	Pea, Pea-Canola, Pea-Winter Camelina, Pea-Oats	3	16	48
2019-Carman	Pea, Pea-Canola, Pea-Winter Camelina, Pea-Fall Rye (single row), Pea-Flax (½ rate)	3	20	60
2020-Carman	Pea, Pea-Spring seeded Camelina*, Pea-Fall Rye (single row), Pea-Fall Rye (twin row), Pea-Winter Wheat (single row), Pea-Winter Wheat (twin row) *error = winter camelina seeded in spring	4	20	80
2020-Arborg	Pea, Full pea-Canola(½ rate), Pea(⅔ rate)-Canola(½ rate), Pea(⅔ rate)-Canola(⅔ rate), Full pea-Flax(¼ rate), Full pea-Flax(½ rate), Full pea-Flax(¾ rate), Full pea-Oat(¼ rate), Full pea-Oat(½ rate), Full pea-Oat(¾ rate)	3	20	60

Results and Discussion

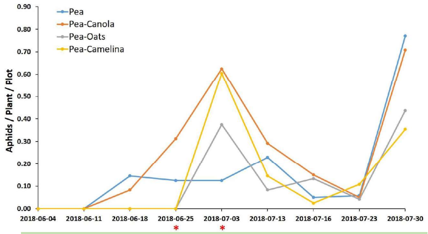


Fig. 2. Pea aphid counts on each sampling day in Carman in 2018. (* $P < 0.05$; counts significantly different among the treatments)

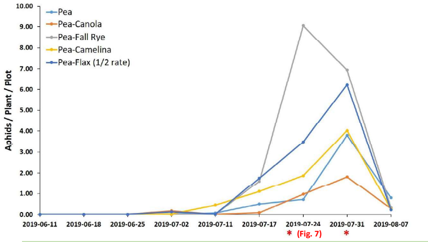


Fig. 3. Pea aphid counts on each sampling day in Carman in 2019. (* $P < 0.05$; counts significantly different among the treatments)

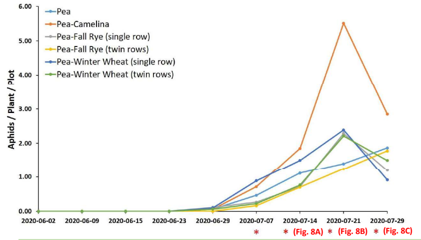


Fig. 4. Pea aphid counts on each sampling day in Carman in 2020. (* $P < 0.05$; counts significantly different among the treatments)

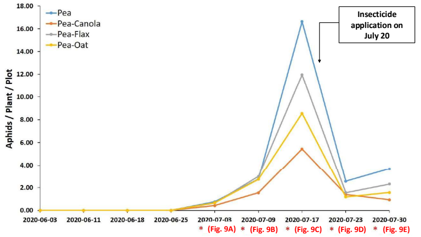
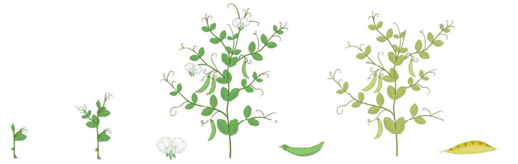


Fig. 5. Pea aphid counts on each sampling day in Arborg in 2020.
(* $P < 0.05$; counts significantly different among the treatments)

Natural enemies observed during aphid sampling:
Common harvestman spiders, Seven-spotted lady beetles (adults & larvae), Rove beetles, Syrphid Flies (adults & larvae), Damsel Bugs, Minute Pirate bugs, Green Lacewings (adults, larvae, & eggs), Brown lacewings (adults & larvae).



	V2-3	V4-5	V8	R2	R3	R4	R5	R6	Harvest
Average days from seeding	**19** (17-21)	**29** (24-34)	**38** (30-46)	**52** (49-55)	**58** (52-64)	**66** (61-70)	**73** (70-77)	**80** (74-84)	**93** (90-97)

Fig. 6. Yellow pea development in Manitoba based on weekly observation of monocrop peas from 4 site-years. Average days from seeding (range in brackets) is the average of 2 to 4 site-years (not all growth stages were captured in each site-year). Created with BioRender.com.

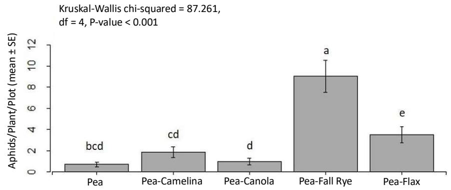


Fig. 7. Aphid counts on each treatment on July 24 in Carman in 2019.

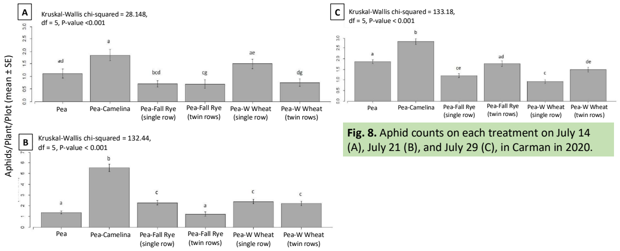


Fig. 8. Aphid counts on each treatment on July 14 (A), July 21 (B), and July 29 (C), in Carman in 2020.

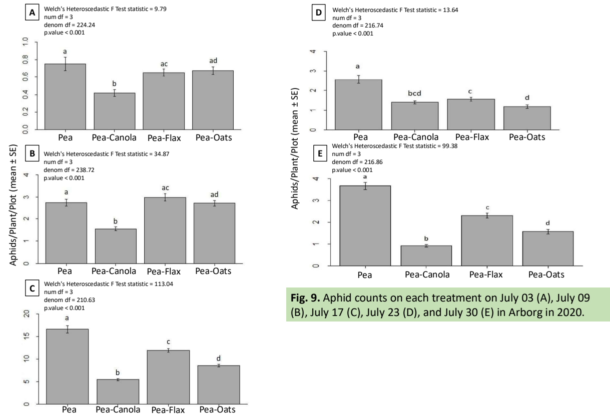


Fig. 9. Aphid counts on each treatment on July 03 (A), July 09 (B), July 17 (C), July 23 (D), and July 30 (E) in Arborg in 2020.

- At Carman 2018 **(Fig. 2)**, pea aphids were present 2 weeks earlier (June 18, R1) in pea-canola and pea monocrop compared to pea-winter camelina and pea-oat intercrops (July 3, R3-4). Statistical differences occurred June 25, when aphid counts were higher in pea-canola intercrop compared to pea-oat and pea-w. camelina, and July 3, when aphids counts were higher in pea-w. camelina compared to pea monocrop. There was low establishment of canola in the pea-canola intercrop. Pea aphid populations did not reach threshold.
- At Carman 2019 (**Fig. 3**), aphids were detected July 2 and were present at low levels with no statistical differences among treatments throughout the susceptible stage of pea (R1 through R3). On July 24, pea-fall rye had higher aphid counts (above threshold) than all other treatments except pea-flax (**Fig. 3 & 7)** and could be related to inhibited pea development (peas remained at R1-2 at harvest; no pea grain yield in pea-fall rye intercrop).
- At Carman 2020 (**Fig. 4**), aphids were detected June 29 and remained below threshold through July 14 during the susceptible stage of pea (R1 through R3). Statistical differences occurred July 7, 14, 21 and 29. At each of those dates, pea- s. camelina had the highest pea aphid population and could be related to the development of camelina which did not reach maturity. Winter cereal row spacing may be an influencing factor (**Fig. 8**) but the twin row system is not recommended due to pea lodging.
- At Arborg 2020 (**Fig. 5**), aphids were present July 3 and reached threshold in all treatments (2.3-3.3 aphids/plant) by July 9, except pea-canola (1.3-1.9 aphids/plant) which was significantly lower than all other treatments **(Fig. 9B)**. A spray product error was made July 10 resulting in pea aphid control not occurring until July 20. Aphid numbers remained above threshold July 17 with greater differentiation among treatments **(Fig. 9C)**. Following control, aphid numbers decreased overall (**Fig. 9D**) but remained at threshold in the pea monocrop **(Fig. 9E)** and on July 30, pea-canola continued to have significantly fewer aphids per plant.

Conclusions

- Yellow pea development was characterized in Manitoba (Fig. 6). Two key stages of pea that coincide with scouting and management decisions are V4-5 (herbicide) and R2 (fungicide). On average, these stages occurred 29 and 52 days after seeding, respectively.
- Pea aphids arrived between June 12 and July 3 during the study period and the dates varied among the treatments in Carman.
- Significant differences in pea aphid counts among treatments occurred at some dates in each site-year but the nature of the differences varied by site-year. Differences in pea aphid populations among intercrops and compared to pea monocrop may be related to physical and biological attributes of the companion crop such as flowering timing and stature, which can influence movement of pea aphids and natural enemies. Pea growth and development as well as pea density and biomass can be affected by intercropping and may also help explain differences in pea aphid presence and populations.
- These applied intercrop studies provide evidence that further research is needed to better understand the effect of intercropping practices on pea aphid populations and natural enemies.

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Pea Response to Preceding Crop, Residue Management and P Fertilizer

(Carman and Roblin, MB • 2020-2024)

Opportunities for pea production in Manitoba are expanding with initiatives and investments such as Protein Industries Canada, the Protein Highway and the Manitoba Protein Advantage. Several new pea protein facilities have been built in Manitoba to source yellow peas from Manitoba farmers. It is our mission to support these opportunities for farmers by conducting pea agronomy research that will develop of best management practices to improve the productivity and profitability of pea production in Manitoba.

The first experiment we have undertaken will test 3 management practices: crop sequence, residue management and phosphorus (P) fertilizer use and placement. We will compare peas seeded into tilled vs. direct seed wheat and canola stubble, and within each of those residue-tillage combinations, we will compare side band P, seed placed P and no starter P. Currently, those management practices vary widely among farmers and there is no local research informing us on how they affect pea yield, quality and profitability.

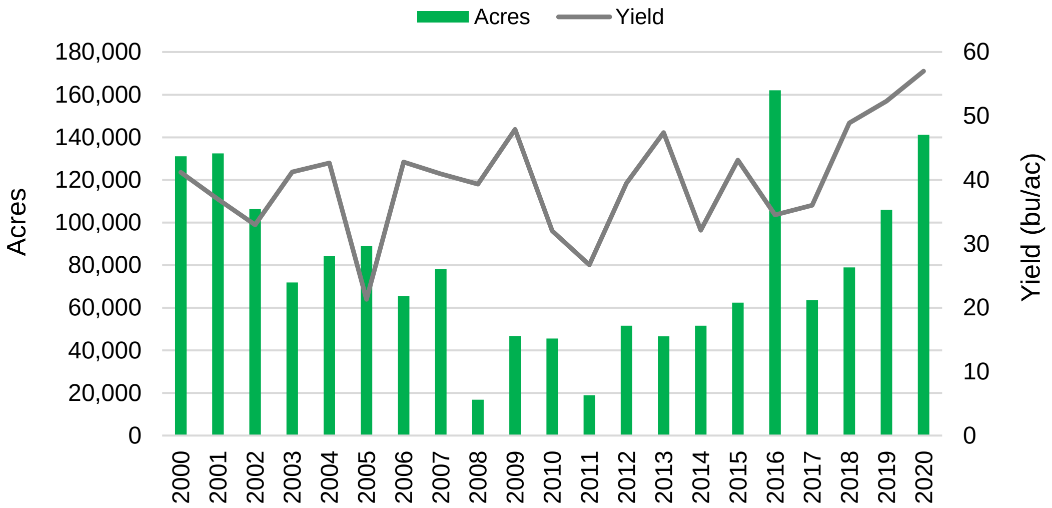

Figure 12. Yellow pea acres and yield in Manitoba from 2000-2020 (source: MASC).

Establishing a Pea Crop Rotation Experiment

(Carman, MB • NEW in 2021)

Root rot is currently the greatest constraint in pea production in western Canada. Several pathogens cause root rot in pea, but it is the recent widespread occurrence of *Aphanomyces* that is particularly problematic. There is currently no genetic resistance to *Aphanomyces* and it is a long-lived structure in the soil that thrives in wet soil conditions. The only effective management tools available that can help reduce root rot are crop rotation, seed treatment and seeding date. If root rot is a problem in pea field, it is recommended to rotate away from peas for a minimum of 6-8 years. To better understand the impact of crop rotation length on soil inoculum, plant infection and pea yield, the establishment of long-term research is a priority. Beginning in 2021, we will be setting up a crop rotation experiment at Carman, Manitoba to compare crop rotation lengths of 3, 5 and 7 years (in other words, peas grown once every 3, 5 and 7 years).

Intercropping with Soybeans and Peas in the Interlake

(Arborg, MB • 2019-continuing)

Intercropping is the practice of seeding, growing and harvesting 2 or more crops together. The concept is to utilize crop combinations that complement one another through mechanisms such as resource use efficiency and potentially result in over-yielding and greater profitability compared to monocropping. Careful consideration needs to be given to how the crops are be seeded, managed, harvested and separated. The most common intercrop grown commercially in Manitoba is pea-canola. Beginning in 2019, we started to test pea-canola, soybean-flax, pea-flax and pea-oat intercrop combinations at Arborg, MB. For each intercrop combination, 2-3 seeding rate ratios were tested and compared to pea, soybean, canola, flax and oat monocrops.

To assess the productivity of intercrops compared to their component crops grown in monoculture, the land equivalent ratio (LER) is used. LER is the combined ratio of the individual crop yields from the intercrop divided by the respective monocrop yield. It is desirable to achieve a LER > 1 which indicates over-yielding (more land would be required to produce the same yield with individual monocrops compared to the intercrop). Gross and marginal revenues are also calculated because seasonal growing conditions and market prices are important variables that affect the productivity, yield and economic return of cropping in a given year.

Pea-canola intercropping has consistently over-yielded and gross revenues have been highest for peas, flax and intercrops containing peas.

Objectives

1. Gain experience in intercropping: observe and evaluate agronomic performance of intercropping compared to monocrops.
2. Evaluate yield, land equivalent ratio (LER) and profitability of intercropping compared to monocrops.
3. Overall, start a knowledge base on if and how intercrops can be utilized in cropping systems in the Interlake and Manitoba.

This report contains the experimental details from 2020 and a synopsis of 2019 and 2020. For experimental details from 2019, please visit: https://mbdiversificationcentres.ca/wp-content/uploads/2020/04/Soybean-Peas-Intercropping-PESAI-2019.pdf

Materials and Methods

The 2020 intercropping trial was seeded into tilled wheat residue on May 21, 2020 at Arborg, MB with a plot seeder on 9” row spacing. All intercrops were seeded in the same, mixed row except soybean-flax where soybean was seeded down the mid-row fertilizer tube to achieve row separation (4.5”). Soil type at the research site is a heavy clay (Fyala series) and background soil test levels were 112 lbs N/ac and 11 ppm P_20_5. Specific agronomic practices used for each intercrop treatment are listed in Tables 14a and 14b. Data analysis for LER and marginal revenue across all individual treatments, grouped crop combinations (e.g. pea-canola vs. soy-flax vs. canola) and by seeding rate among crop combinations (e.g. analysis of seeding rate combinations of pea-canola) was conducted for each year (see page 68 for methodology). Few statistical differences were detected (data not shown).

Project funding provided by Prairies East Sustainable Agriculture Initiative

PESAI

Summary

This was the second successful year of experimenting with intercropping in the Interlake region of Manitoba. Treatments included three seeding rate combinations of pea-canola, soybean-flax, pea-flax and pea-oat compared to pea, canola, flax, soybean and oat monocrops. Results of the experiment including treatment descriptions, agronomic practices, yield, gross and marginal revenues and general observations are listed in Table 14a and 14b and the performance of each intercrop treatment in across both study years is discussed at the end of the report. Both growing seasons at Arborg have been dry receiving only 148 and 190 mm from May through August in 2019 and 2020, respectively (55-70% of normal). In both years of study, flax and pea have produced the highest marginal revenue of the monocrops. Canola was challenged with flea beetles and grasshoppers in 2020. Pea-canola was the only intercrop to consistently over-yield in 2019 and 2020 (Fig. 14a) while marginal revenues were impressive for pea, pea-oat and pea-flax (Fig. 14b). After two years of study in Arborg, we have been able to draw some conclusions on optimum seeding rate ratios, consistency of over-yielding and profitability (see individual intercrop treatment discussions). The pea-oat intercrop was sampled for total dry matter and forage nutrient analysis (Table 14c) which will be helpful for livestock farmers.

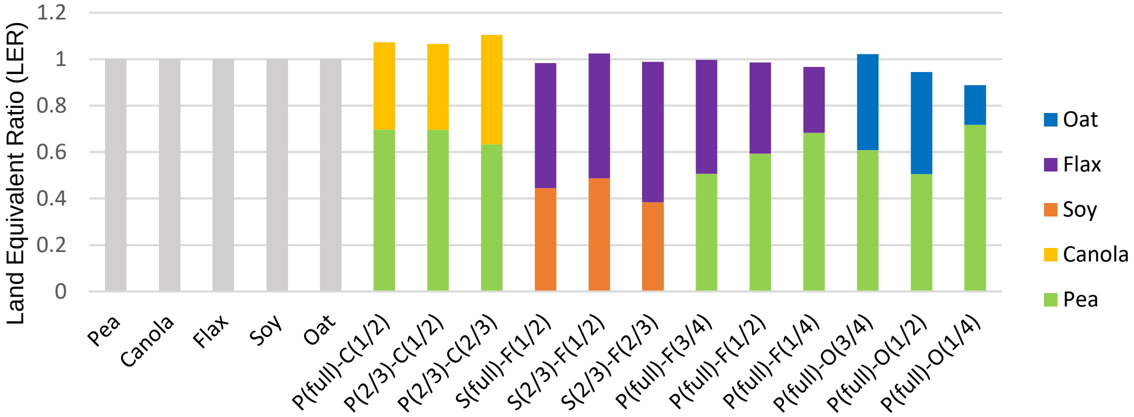

Figure 14a. Average total Land Equivalent Ratio (LER) for each intercrop treatment composed of each partial LER crop component (n=3) at Arborg, MB in 2020.

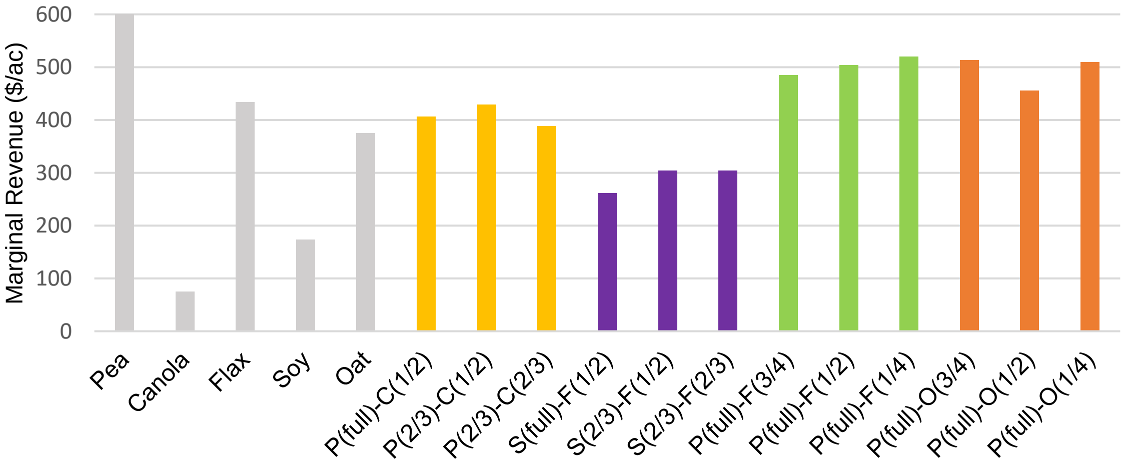

Figure 14b. Average marginal revenue of monocrop and intercrop treatments at Arborg, MB in 2020.

Table 14a. Seeding rates, varieties, seed depth, plant stand, plant height, yield and profit of intercrop treatments in 2020 at Arborg, MB.

No.	**Treatment**	**Crop**	**Seed rate strategy**	**Variety**	**Seeding rate** (seeds/m^2)	**Plant stand*** (plants/m^2)	**Land Equivalent Ratio ¥**	**Height** (cm)	**Yield †** (bu/ac)	**Gross ‡ revenue** ($/ac)	**Marginal revenue ‡** ($/ac)
1	Pea	Pea	Full	CDC Amarillo	100	80	1.0	68	90.4	723	612
2	Canola	Canola	Full	5545 CL	108	52	1.0	83	19.3	217	75
3	Flax	Flax	Full	CDC Glas	700	394	1.0	55	35.7	500	434
4	Soybean	Soybean	Full	NSC Watson	49	47	1.0	55	25.5	290	174
5	Oats	Oats	Full	Souris	355	149	1.0	77	105.2	394	376
6	Pea-canola	Pea	Full	CDC Amarillo	100	86	1.07	60	62.9	585	406
		Canola	1/2	5545 CL	54	25		76	7.3		
7	Pea-canola	Pea	2/3	CDC Amarillo	67	42	1.07	60	62.8	583	430
		Canola	1/2	5545 CL	54	33		79	7.2		
8	Pea-canola	Pea	2/3	CDC Amarillo	67	53	1.10	57	57.3	561	388
		Canola	2/3	5545 CL	72	36		74	9.1		
9	Soy-Flax	Soybean	Full	NSC Watson	49	47	0.98	44	11.3	399	262
		Flax	1/2	CDC Glas	350	223		58	19.2		
10	Soy-Flax	Soybean	2/3	NSC Watson	33	35	1.02	45	12.4	410	304
		Flax	1/2	CDC Glas	350	185		62	19.2		
11	Soy-Flax	Soybean	2/3	NSC Watson	33	35	0.99	46	9.8	414	304
		Flax	2/3	CDC Glas	467	335		61	21.6		
12	Pea-Flax	Pea	Full	CDC Amarillo	100	62	1.0	57	45.8	612	485
		Flax	3/4	CDC Plava	525	273		62	17.5		
13	Pea-Flax	Pea	Full	CDC Amarillo	100	68	0.99	60	53.6	626	504
		Flax	1/2	CDC Plava	350	175		61	14.1		
14	Pea-Flax	Pea	Full	CDC Amarillo	100	76	0.97	67	61.7	636	520
		Flax	1/4	CDC Plava	175	86		55	10.2		
15	Pea-Oat	Pea	Full	CDC Amarillo	100	78	1.02	59	55.0	603	513
		Oat	3/4	Souris	266	100		78	43.6		
16	Pea-Oat	Pea	Full	CDC Amarillo	100	80	0.95	64	45.6	539	456
		Oat	1/2	Souris	178	90		77	46.4		
17	Pea-Oat	Pea	Full	CDC Amarillo	100	79	0.89	62	64.8	586	510
		Oat	1/4	Souris	89	36		71	18.0		

*Optimum plant stands for monocrops: peas (7-8 plants/ft^2 or 70-80 plants/m^2), canola (5-7 plants/ft^2 or 50-70 plants/m^2), flax (37-56 plants/ft^2 or 396-599 plants/m^2), soybean (4 plants/ft^2 or 40 plants/m^2) and oats (18-23 plants/ft^2 or 194-248 plants/m^2).

† Average crop yields in the Bifrost-Riverton municipality: 36.8 bu/ac peas, 30.1 bu/ac canola, 17.8 bu/ac flax and 31.3 bu/ac soybean (MASC, 1993-2019).

‡ Profit margins were calculated as follows: *Gross revenue ($/ac)* = Yield x Market price
Marginal revenue ($/ac) = Gross revenue – Seed – Fertilizer – Pesticide – Separation ($0.25/bu)
(Market prices from Manitoba Agriculture 2021 Costs of Production: $8.00/bu peas, $11.25/bu canola, $14.00/bu flax, $11.40/bu soybean and $3.75/bu oats)

¥ Land equivalent ratio (LER) = $\frac{\text{yield of intercrop species 1}}{\text{yield of monocrop species 1}} + \frac{\text{yield of intercrop species 2}}{\text{yield of monocrop species}}$

Table 14b. Seeding depth, weed control, fertility and general notes/observations of intercrop treatments in 2020 at Arborg, MB.

No.	Treatment	Crop	Seed rate	Depth	Herbicides/weed control*	Fertilizer applied†	General notes and observations
1	Pea	Pea	Full	1.5”	Pre-emerge: Authority In-crop: Odyssey	15 lbs/ac P_2O_5	Pea aphids were sprayed July 20. Harvest date Aug 26.
2	Canola	Canola	Full	0.75”	Pre-emerge: None In-crop: Odyssey	38 lbs N/ac; 15 lbs/ac P_2O_5	Sprayed for flea beetles in June and for a flea beetles and grasshoppers in August. Desiccated Sept 2.
3	Flax	Flax	Full	0.75”	Pre-emerge: Authority 480 In-crop: Clethodim	15 lbs/ac P_2O_5	Desiccated Sept 4.
4	Soybean	Soybean	Full	1”	Pre-emerge: Authority 480 In-crop: Glyphosate	15 lbs/ac P_2O_5	Harvest date Sept 15.
5	Oats	Oats	Full	1.5”	Pre-emerge: None In-crop: None	15 lbs/ac P_2O_5	Harvest date Aug 19.
6	Pea-canola	Pea Canola	Full 1/2	0.75”	Pre-emerge: None In-crop: Odyssey	15 lbs/ac P_2O_5	Pea-canola was sprayed for flea beetles in June and for a late season attack of flea beetles and grasshoppers in August. Pea-canola was desiccated Sept 2.
7	Pea-canola	Pea Canola	2/3 1/2	0.75”		None	
8	Pea-canola	Pea Canola	2/3 2/3	0.75”		None	
9	Soy-Flax	Soybean Flax	Full 1/2	0.75”	Pre-emerge: Authority 480 In-crop: Clethodim	15 lbs/ac P_2O_5	To achieve row separation, soybean was seeded down the mid-row resulting in 4.5-inch separation from the flax row. Maturity of both crops aligned well. Harvest date was Sept 15.
10	Soy-Flax	Soybean Flax	2/3 1/2	0.75”		None	
11	Soy-Flax	Soybean Flax	2/3 2/3	0.75”		None	
12	Pea-Flax	Pea Flax	Full 3/4	1”	Pre-emerge: Authority 480 In-crop: Clethodim	None	Pea-flax was desiccated Sept. 4.
13	Pea-Flax	Pea Flax	Full 1/2	1”		15 lbs/ac P_2O_5	
14	Pea-Flax	Pea Flax	Full 1/4	1”		None	
15	Pea-Oat	Pea Oat	Full 3/4	1.5”	Pre-emerge: None In-crop: None Hand weeding for wild oat patches	None	Wild oats were a problem in the trial area. Hand-weeding was done but the weed pressure may be a confounding factor. Harvest date was Aug 26.
16	Pea-Oat	Pea Oat	Full 1/2	1.5”		15 lbs/ac P_2O_5	
17	Pea-Oat	Pea Oat	Full 1/4	1.5”		None	

*There was a wild oat patch running through Replicate 2 that was hand weeded in all treatments. Pea-oat and oat treatments were also hand weeded for wild oats.

†All intercrop treatments were to receive 15 lbs P_20_5/ac but only 1 of each intercrop treatment received the starter P due to human error.

Pea-canola

All pea-canola treatments produced a land equivalent ratio (LER) greater than 1 (Table 14a), indicating that over-yielding occurred. Over-yielding also occurred in all treatments in 2019. Peas yielded very well in the intercrop (57-63 bu/ac) and monocrop treatments (90 bu/ac). Canola yielded poorly in the monocrop (19 bu/ac) and the intercrop treatments (7-9 bu/ac), likely due to early and late season insect damage and above average temperatures through flowering. The mean daily temperature in July 2020 was 20.0°C compared to the long-term average of 18.6°C (page 64). The pea-canola treatment where both crops were seeded at 2/3 of a full rate produced a slightly higher LER than the other two treatments. The pea-canola treatment with peas seeded at 2/3 rate and canola at ½ rate resulted in the highest marginal revenue ($430/ac) which was $24-42/ac higher than the other two treatments but much lower than the monocrop peas ($613/ac). In both years of study, the established plant stands of the pea (2/3 rate)-canola (1/2 rate) treatment were similar - 21 pea plants/m^2 and 17-24 canola plants/m^2 which is 31% establishment for pea and 35% establishment for canola.

Intercropping pea and canola in 2019 and 2020 consistently resulted in over-yielding (LER from 1.07 to 1.20). Seeding peas at 2/3 rate (67 seeds/m^2) and canola at a ½ rate (54 seeds/m^2) resulted in the most economic pea-canola intercrop. Overall, intercrop peas produced 70 to 106% of monocrop pea yield and canola produced 16-37% of monocrop canola yield. In both years, the additional cost of a higher canola rate was not offset by increased yield. In 2020, a third treatment was included that used a full rate of pea and ½ rate of canola, but the additional seed cost of a higher pea rate was not offset by increased yield. Marginal revenues of canola treatments in both 2019 and 2020 were reduced due to insecticide applications. More favorable growing conditions for canola would improve the economics for monocrop canola and may alter the yield ratio between pea and canola in the intercrops.

Pea-canola intercrops have been well studied in Manitoba and has consistently over-yielded compared to pea and canola monocrops. At Carman and Kelburn, MB from 2001-2003[1], Dr. Martin Entz's research team found that pea-canola resulted in over-yielding 100% of the time under conventional management with an average LER of 1.21. Pea-canola intercrops were studied in on-farm trials at Carman, MB in 2015[2] and 2016[3]. Peas and canola were seeded in the same mixed row at ~2/3 of a full rate (110 lbs/ac peas and 3-4 lbs/ac canola; 180 lbs/ac monocrop peas; 5-6 lbs/ac monocrop canola) with three supplemental N rate comparisons. Increasing N rate in the intercrops increased canola yield, reduced pea yield and reduced marginal revenue. In both years of on-farm study at Carman, LERs ranged from 1.04 to 1.16 and marginal revenue was highest with the 0N or low N rate.

[1] Agronomic Benefits of Intercropping Annual Crops in Manitoba. University of Manitoba Department of Plant Science Natural Systems Agriculture. https://www.umanitoba.ca/outreach/naturalagriculture/articles/intercrop.html

[2] Manitoba Pulse & Soybean Growers. 2015. On-Farm Evaluation of Peaola Intercropping. https://manitobapulse.ca/wp-content/uploads/2018/02/On-Farm-Evaluation-of-Peaola-Intercropping-2015.pdf

[3] Manitoba Pulse & Soybean Growers. 2016. On-Farm Evaluation of Peaola Intercropping. Retrieved https://manitobapulse.ca/wp-content/uploads/2018/02/On-Farm-Evaluation-of-Peola-2016.pdf

Soybean-Flax

The soybean-flax treatments produced a land equivalent ratio close to 1 (0.98 to 1.02) indicating that over-yielding did not occur. Flax yielded very well in the monocrop treatment (36 bu/ac) while soybeans were below average (26 bu/ac). In the intercrop treatments, flax yielded 19-22 bu/ac (54-61% of monocrop flax) and soybean yielded 10-12 bu/ac (38-49% of monocrop soybean). Among the intercrop treatments, LERs were similar but marginal revenue was highest where soybean was seeded at 2/3 rate (33 seeds/m^2) and flax at a ½ rate to 2/3 rate (350-395 seeds/m^2). At 36 bu/ac flax, however, the intercrop treatments were not as profitable as monocrop flax in 2020.

From two years of study at Arborg, intercropping soybean and flax has produced LERs from 0.55 to 1.02 and has not been consistently economical compared to monocrop flax. Out of the seeding rate combinations tested, a soy-flax intercrop seeded in separate rows with a 2/3 rate of soybean (33 seeds/m^2) and ½ to 2/3 rate of flax (350-395 seeds/m^2) has provided the highest LER and MR. In 2019, soybean and flax were seeded in the same row which resulted in the flax outcompeting soybean. This has also been observed at Melita (Scott Chalmers, personal communication). Variety choice is an important consideration to ensure that both crops mature at a similar time. With CDC Glas flax, we used S007-Y4 soybean in 2019 which matured later than the flax and in 2020, we used NSC Watson, which matured earlier and closer to flax. The intercrops were not desiccated.

Pea-Flax

Pea-flax treatments produced a land equivalent ratio (LER) close to 1 (Table 14a), indicating that over-yielding did not occur. Marginal revenue for all intercrop treatments ($485-520/ac) was higher than monocrop flax ($434/ac) which yielded 36 bu/ac but lower compared to monocrop peas ($613/ac) which produced an exceptional yield of 90 bu/ac. Among the intercrop treatments, the LERs were similar (0.97-1.0), but the marginal revenue was highest with the pea (full rate)-flax (1/4 rate). In 2019, we tested pea (full rate)-flax (1/2 rate) and pea (2/3 rate)-flax (2/3) rate - both the LER and marginal revenue of the two seeding rate combinations were similar. In both years of study, peas matured ahead of flax and a desiccant was applied to facilitate timely harvest. **From two years of study at Arborg, intercropping pea and flax has resulted in LERs from 0.98 to 1.02. Marginal revenue of intercropping pea-flax in 2019 was lower than flax and pea monocrops and in 2020, pea-flax marginal revenue was higher than flax but lower than peas. More work is needed to identify the optimum seed rate ratio for pea-flax intercropping. In 2019, it was also observed that flax chlorosis may be reduced with intercropping.**

Pea-Oat

The pea-oat treatments produced LERs from 0.89 to 1.02 indicating that over-yielding did not occur compared to oat and pea monocrops. Among the intercrop treatments, the pea (full rate)-oat (3/4 rate) produced the highest LER (1.02) and marginal revenue ($513/ac) but marginal revenue was still lower than monocrop peas which yielded 90 bu/ac. In 2019, we could not calculate LER (no oat monocrop in the trial) but the pea (full rate)-oat (1/2 rate) was more economical than both crops seeded at 2/3 rate. **From two years of study at Arborg, the over-yielding benefit and optimum seeding rate ratio for pea-oat intercropping remains somewhat unclear. It is likely that a full pea seeding rate should be maintained and that there is good weed suppression (no in crop herbicide has been required).**

In 2020, we also collected above ground biomass samples at pea flowering and oat heading for forage analysis. Samples were collected from each replicate of the oat monocrop and pea (full)-oat (1/2 rate) intercrop treatments. The overall average values for each treatment are in Table 14c. Pea-oat intercrop dry matter was slightly lower but CP and RFV were higher. It is important to note that grain varieties were used and different results may be expected with forage varieties.

Table 14c. Forage nutrient analysis of oat monocrop and pea-oat intercrop from Arborg 2020. Samples were collected on July 9, 2020 at pea flowering (R2) and oat heading (inflorescence).

	Feed Basis	Oat	Pea-Oat
Moisture (%)	As Fed	3.0	4.2
Dry Matter (%)	As Fed	96.8	95.8
Crude Protein (%)	As Fed	10.0	14.5
Relative Feed Value	Dry Matter	96.0	110.0
Total Dry Matter (lbs/ac)	Dry Matter	10,220	9,002
Calcium (%)	As Fed	0.2	0.7
Phosphorus (%)	As Fed	0.3	0.3
Magnesium (%)	As Fed	0.2	0.4
Potassium (%)	As Fed	2.6	2.7
Sodium (%)	As Fed	0.4	0.3
Acid Detergent Fibre (%)	As Fed	33.6	33.3
Neutral Detergent Fibre (%)	As Fed	58.2	51.1
Non Fibre Carbohydrates (%)	As Fed	18.4	19.9
Total Digestible Nutrients (%)	As Fed	59.7	58.9
Metabolizable Energy (Mcal/kg)	As Fed	2.2	2.2
Net Energy for Lactation (Mcal/kg)	As Fed	1.4	1.3
Digestible Energy (Mcal/kg)	As Fed	2.6	2.6
Net Energy for Maintenance (Mcal/kg)	As Fed	1.3	1.3
Net Energy for Gain (Mcal/kg)	As Fed	0.8	0.0

Relay cropping with winter cereals and grain legumes at Carman

(Carman, MB 2017-continuing)

We have been experimenting with relay and intercropping systems at Carman, MB since 2017 under dry growing season conditions (135-219 mm from May through August = 42-69% normal precipitation). The goal of this experiment has been to gain experience and knowledge of the agronomy and management of relay and intercrop systems (e.g. seeding and harvest operations, pest and fertility management). The experiments have included an array of cropping systems and have sometimes been limited by equipment capabilities, therefore, not all agronomic practices have been optimized. That being said, optimum agronomic practices for relay and intercropping systems have not been developed for our region. Each year we aim to refine our practices. Our intent is to share our experiences and observations and build a knowledge base of relay and intercropping systems in Manitoba. Agronomic details, yield and economic results of each crop combination can be found in Tables 15a-d, and a brief summary of our findings for each crop combination is provided below. The crop combinations that we have tested include:

- Fall rye-soybean relay crop
- Fall rye-dry bean relay crop
- Fall rye-yellow pea relay crop
- Fall rye-winter camelina intercrop
- Winter wheat-soybean relay crop
- Winter wheat-dry bean relay crop
- Winter camelina-soybean relay crop
- Winter wheat- pea relay crop
- Pea-canola intercrop
- Pea-flax intercrop
- Soybean-flax intercrop

Overview of winter cereal and soybean relay crop systems

The relay systems we tested produced good winter cereal yields (24-69 bu/ac) – the challenge is establishing soybean and producing soybean yield, which may not be possible in our relatively short and dry Manitoba environment. Challenges to establishment include dry seedbed, allelopathy, crop competition and shading. We tested some variations of seeding rate and row spacing and gained experience in these systems. Our observations indicate that seeding rates of both the winter cereal and soybean can be reduced in the relay crop system where row spacing of each crop type is increased. The row spacing configuration (Fig. 15f) is a trade-off between the winter cereal and soybean yield whereby winter cereal yield is greatly reduced in twin rows while soybeans gain a moderate advantage. In 2021, we will use a 2/3 rate of the winter cereal and 3 seeding rates of soybean (100, 80 and 60%) on 22.5” twin rows which is intermediate between the single alternating rows and 30” center twin rows we have previously tested (Fig. 15f). Moisture availability has likely been the greatest limiting factor to soybean establishment to the relay crop system in the environments we have tested. This system warrants further testing in Manitoba environments where higher precipitation amounts are received.

Fall rye-Soybean relay crop

Over 3 years of study (2018-2020) under dry conditions, the fall rye and soybean relay crop system has had limited success at Carman. We tested some variations of row spacing and seeding rates. Over-yielding did not occur (LER <1) and marginal revenue was not maximized compared to the monocrops. Fall rye established well and yielded 33-78 bu/ac (78-92% of fall rye monocrop) but soybeans performed poorly. Soybeans were seeded May 14-23 when the fall rye was 12-18” tall and tillering. Establishment and growth of soybean was suppressed in both single and twin rows with soybean yield ranging from 0-6 bu/ac (0-20% of monocrop soybean).

In 2018-19 when a full and half rate of fall rye was compared in single rows, plant establishment and yield was comparable. In 2019-20 when single and twin rows were compared, row spacing appeared to be a trade-off between fall rye and soybean yield but non-optimum soybean seed rate may have been a limitation. For fall rye and soybean in the 2019-20 test years, the same in-row seed spacing was used for all row spacing configurations reducing the overall seed density to ≤60% of a full seed rate when seeded as a monocrop. Despite these lower seeding rates and plant stands, fall rye still produced excellent yield – optimum seed rate for wide row cereals is yet to be established. In 2021, new seed discs will allow us to increase the seeding rate for soybeans in wide rows. Overall, fall rye suppressed weeds well and no herbicide application was required. Testing under higher moisture conditions and optimizing plant spatial arrangement (row spacing and seeding rate) is warranted.

Figure 15a. FR-Soy twin row system prior to and after FR harvest (L); FR-Soy single row system prior to and after FR harvest (R). Pictures taken July 28, 2020 and August 26, 2020.

Fall rye-Winter camelina intercrop

This crop combination was tested in 2019-20 (Fig. 15e). In the fall of 2019, these crops were seeded in single alternating rows at a full seeding rate (Table 15a). Seed metering issues with the very small camelina seed led to an uneven plant stand. Weed pressure was minimal likely due to the fall rye and no in-crop herbicides were applied. Camelina matured earlier than the fall rye so a harvest-aid was used to improve harvestability. Both crops were harvested together in early August with yields of 50 bu/ac and 2 bu/ac for fall rye and camelina, respectively. Over-yielding did not occur (LER = 0.78) but marginal revenue was intermediate between fall rye and winter camelina monocrops. We will continue to test this crop combination in 2020-21.

Winter wheat-Soybean relay crop

Over 3 years of study (2018-2020) under dry conditions, the winter wheat and soybean relay crop system has had limited success at Carman. We tested some variations of row spacing and seeding rates. Over-yielding did not occur and marginal revenue was reduced compared to the monocrops. Winter wheat establishment was more variable than fall rye and yielded 26-64 bu/ac (58-96% of monocrop). Soybean establishment was better in winter wheat than fall rye, but still low, and yield was similarly poor, ranging from 0-4 bu/ac.

In 2019-20, when twin and single rows were compared, the single row system where winter wheat and soybean were in alternating 7.5” rows resulted in a greater LER and marginal revenue (Table 15a). The single row system was more favorable to winter wheat yield compared to twin row. Neither system improved marginal revenue over monocrop winter wheat. A herbicide application was made prior to soybean emergence and use of dicamba tolerant soybeans would allow for broadleaf weed control in crop. With the varieties we used, canopy height clearance of winter wheat over soybean at harvest was minimal compared to fall rye and soybean (greater canopy height difference), and may be a consideration for harvest.

Figure 15b. WW-Soy twin row system prior to and after WW harvest (L); WW-Soy single row system prior to and after WW harvest (R). Pictures taken July 28, 2020 and August 26, 2020.

Fall rye-Yellow pea relay crop

Over 2 years of study (2019-2020) under dry conditions, the performance of the fall rye-pea relay crop system has been inconsistent. In 2019, we used single alternating rows (7.5”) at full seeding rates. Field pea established but growth was suppressed during the early vegetative stage and did not reach flowering (Fig 15c). In the 2019 relay crop, there was no pea yield and fall rye produced 38 bu/ac which was lower than the monocrop fall rye yield of 50 bu/ac. In 2020, we compared single alternating rows (7.5”) and twin rows. In the single alternating rows, fall rye yielded 76 bu/ac (94% of monocrop) and peas produced 5 bu/ac (9% of monocrop) resulting in an LER of 1.04 and good marginal revenue. Pea yield was increased in the twin row system (11 bu/ac) although not significantly enough to offset the reduction in fall rye yield (45 bu/ac). Twin rows are also not ideal for yellow pea relay cropping due to lodging.

We see potential in the fall rye-yellow pea relay crop system with very early seeding, good moisture conditions, single alternating rows and optimized seeding rate. In 2020, the same in-row seed spacing was used for all row spacing configurations reducing the overall seed density to less than ≤60% of a full seed rate of solid seeded monocrops (Table 15a). In 2021, new seed discs will allow us to use up to the full monocrop seeding rate for pea in the relay crop systems. We found that weed control depended on how well the winter cereal established and thus how competitive it was with weeds (for weed control strategies, see Tables 15b and 15d).

Figure 15c. FR-Pea twin row vs. single row and suppression of pea between single FR rows.

Winter wheat-Yellow pea relay crop

In 2020, we tested winter wheat and pea in single alternating 7.5” row and twin rows. With our planter, the same in-row seed spacings was used for all row spacing configurations, reducing the overall seed density to less than 50% of a full seed rate. New seed discs will allow us to overcome this in 2021. Similar to the fall rye-yellow pea relay crop, over-yielding did occur in the single rows. Winter wheat produced 69 bu/ac and peas produced 4 bu/ac resulting in an LER of 1.10 although marginal revenue was below that of both monocrops (Table 15a). Twin rows are not ideal for this system due to severe pea lodging and although the pea yield increased (10 bu/ac), it did not offset the winter wheat yield reduction (39 bu/ac) compared to the single rows.

Figure 15d. WW-pea on single, alternating rows (7.5”) vs. WW-pea in twin rows.

Fall rye-Dry bean relay crop and Winter wheat-Dry bean relay crop

These systems were tested in 2018-19 only. Please see 2018 annual report.

Winter Camelina

From 2018-2020, yields of winter camelina monocrop (cv. Joelle) have ranged from 12-14 bu/ac at Carman. Camelina was seeded in September with a plot drill on 7.5" rows at a seeding rate of 6-8 lbs/ac with seed depth as shallow as possible due to very small seed size. Spring plant density ranged from 3-19 plants/ft^2 which is <20% establishment. Assure II was used for grassy weed control but no broadleaf herbicides are registered in crop so hand weeding was also done. Plant establishment (seed metering, seed depth, winter hardiness), weed control and drought were challenges for this crop.

Figure 15e. WC at flowering, WC at maturity and FR-WC in July (L-R).

Winter camelina-Soybean relay crop

This system was tested for 2 years at Carman (2017-18 and 2018-19) with winter camelina producing 6-9 bu/ac (harvest in late July) and soybeans producing 1-6 bu/ac (harvest in late August). Soybean was seeded at a full seeding rate between the 15" camelina rows in May with 20-52% establishment (40-105,000 plants/ac). With the high cost of soybean seed, this system has not been economical and over-yielding did not occur (LER <1.0).

Winter camelina-Pea relay crop

This crop combination was successfully tested in 2017-18 and is being tested again in 2020-21. Please 2018 annual report.

Pea-Canola intercrop

Pea-canola was tested in 2017-18 and 2018-19 at Carman but has been unsuccessful due to pest infestations and poor establishment. See page 47 for results from the Arborg intercrop experiments. At Carman, peas and canola were seeded in the same mixed 7.5" rows using a full rate of pea (100 seeds/m^2) and a reduced rate of canola (5-7 seeds/ft^2). Seed depth was 1.25" in 2017-18 and canola did not establish well (<1 plant/ft2) which we attributed to deep seeding. We adjusted the seed depth to ¾" in 2018-19 and had better establishment but late season flea beetles and deer grazing reduced yield (Table 15c and 15d).

Soybean-Flax intercrop

This crop combination has been tested for 2 years at Carman (2018 and 2019) and for 2 years at Arborg (2019 and 2020 – see page 47). At Carman 2018, soybean-flax was seeded in alternating 7.5” rows at full seeding rates at a depth of 1.5” with good overall establishment. Both crops were harvested together in late August producing 7 bu/ac soybean and 6 bu/ac flax compared to 25 bu/ac monocrop soybeans. Yield potential was limited by drought and weed competition in 2018. In 2019, we proceeded to test 2 seeding rate ratios – soybean (full)-flax (1/2) vs. soybean (2/3)-flax (2/3) with an improved herbicide strategy (Table 15d). Crops established well and weeds were controlled. Unfortunately, all flax in the intercrops and monocrops died off in late June. The probable cause was residual soil herbicide injury and/or Fusarium wilt. We’ve had good success with testing of pea-flax at Arborg – see page 47 for results and recommendations from the Arborg intercrop experiment.

Pea-Flax intercrop

Pea-flax was tested in Carman 2019 and continues to be tested in Arborg (see page 47). At Carman 2019, we tested two seeding rate combinations in mixed 7.5” rows – pea (full)-flax (full) and pea (2/3)-flax (2/3). Crop establishment was good in both crops and a good weed control strategy is available for this crop combination (Table 15d). Unfortunately, all flax in the intercrops and monocrops died off in late June. There was no harvestable yield in the flax and the peas were lost to deer grazing late in the season. We’ve had good success with testing of pea-flax at Arborg – see page 47 for results and recommendations from the Arborg intercrop experiment.

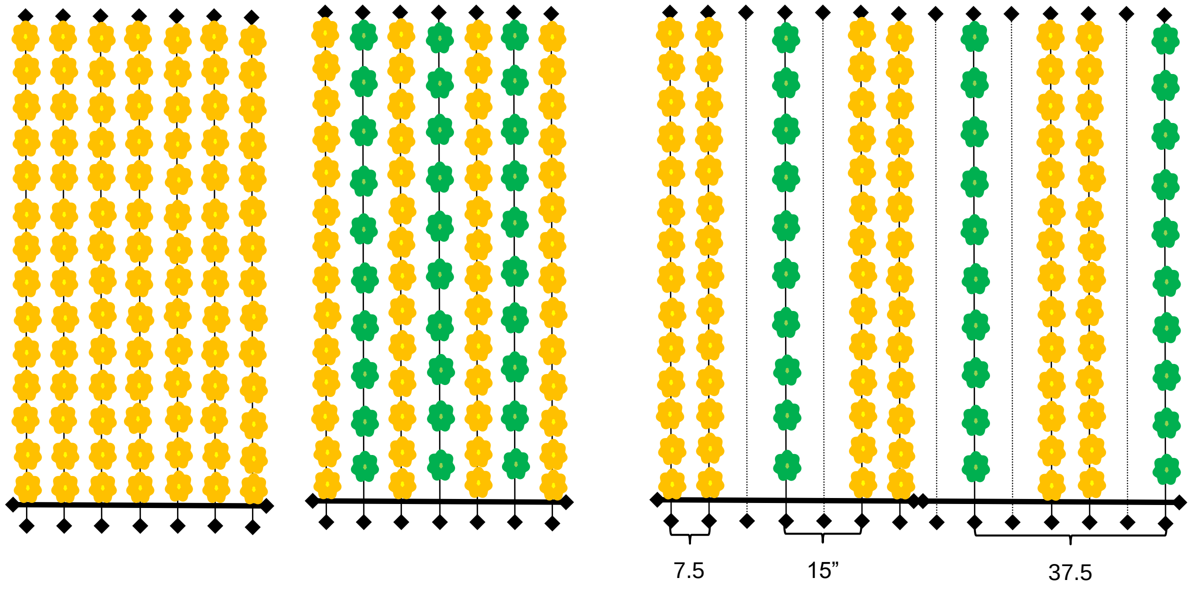

Figure 15f. Row spacing configuration (L-R) for **monocrops**, **“single, alternating”** and **“twin”** rows.

Table 15a. Yield and economic analysis of soybean and pulse relay crop treatments at Carman 2019-20.

Treatment (row configuration)	**Crop**	**Row Config.**	**Variety**	**Seeding rate** (seeds/ft^2)	**Plant stand*** (plants/ft^2)	**Land Equivalent Ratio ¥**	**Height** (cm)	**Yield †** (bu/ac)	**Gross ‡ revenue** ($/ac)	**Marginal revenue ‡** ($/ac)
Fall Rye	Fall Rye		AC Hazlet	24	11.7	1.00	82.5	80.7	444	396
Winter Wheat	Winter Wheat		AC Emerson	26	15.6	1.00	70.3	67.0	385	322
Soybean	Soybean		S007-Y4	5	3.9	1.00	62.9	30.5	320	178
W. Camelina	W. Camelina		Joelle	8 lbs./ac	4.1	1.00	73.6	14.0	154	90
Field Pea	Field Pea		CDC Amarillo	7	4.3	1.00	73.2	50.9	356	301
Fall Rye-Soybean (single)	Fall Rye	Single, alternate	AC Hazlet	14**	5.5	0.77	76.7	60.5	340	212
	Soybean		S007-Y4	2	1.5		42.5	0.7		
Fall Rye-Soybean (twin)	Fall Rye	Twin	AC Hazlet	11**	5.1	0.71	78.2	41.6	289	190
	Soybean		S007-Y4	1	0.7		55.8	5.8		
Winter Wheat-Soybean (single)	Winter Wheat	Single, alternate	AC Emerson	14**	7.2	0.97	73.7	64.4	342	207
	Soybean		S007-Y4	2	1.9		43.3	0.4		
Winter Wheat-Soybean (twin)	Winter Wheat	Twin	AC Emerson	11**	5.7	0.73	70.2	39.2	253	149
	Soybean		S007-Y4	1	0.7		53.1	4.5		
Fall Rye-Field Pea (single)	Fall Rye	Single, alternate	AC Hazlet	14**	5.0	1.04	78.0	76.2	453	363
	Field Pea		CDC Amarillo	4	2.5		52.7	4.8		
Fall Rye-Field Pea (twin)	Fall Rye	Twin	AC Hazlet	11**	4.3	0.78	76.0	44.5	324	237
	Field Pea		CDC Amarillo	1	0.8		68.7	11.4		
Winter Wheat-Field Pea (single)	Winter Wheat	Single, alternate	AC Emerson	14**	6.3	1.10	72.3	68.8	389	295
	Field Pea		CDC Amarillo	4	2.0		49.6	3.9		
Winter Wheat-Field Pea (twin)	Winter Wheat	Twin	AC Emerson	11**	5.5	0.77	65.8	38.7	272	182
	Field Pea		CDC Amarillo	1	0.7		59.8	9.9		
Fall Rye-W. Camelina (single)	Fall Rye	Single, alternate	AC Hazlet	24	7.2	0.78	81.4	49.9	299	217
	W. Camelina		Joelle	8 lbs./ac	2.0		67.7	2.2		

*Optimum plant stands for monocrops: fall rye (24 plants/ft^2 or 260 plants/m^2), winter wheat (20-30 plants/ft^2 or 215-325 plants/m^2), camelina (20 plants/ft^2 or 215 plants/m^2), soybean (4 plants/ft^2 or 40 plants/m^2) and peas (7-8 plants/ft^2 or 70-80 plants/m^2)

**Winter cereal seeding rates limited by seed spacing capacity of the planter/seed discs (minimum seed spacing is 1.8 cm within row)

† Average crop yields in the Dufferin municipality: 61.0 bu/ac fall rye, 69.8 bu/ac winter wheat, 36.7 bu/ac soybean, 30 bu/ac peas (MASC, 2011-2020).

‡ Profit margins were calculated as follows: *Gross revenue ($/ac)* = Yield x Market price
Marginal revenue ($/ac) = Gross revenue – Seed – Fertilizer – Pesticide – Separation ($0.25/bu)
(Market prices from Manitoba Agriculture 2021 Costs of Production: $5.25/bu fall rye, $5.75/bu winter wheat, $11.40/bu soybean, $8.00/bu peas)
(Market prices from Smart Earth Camelina: $11.00/bu camelina)

¥ Land equivalent ratio (LER) = $\frac{\text{yield of relay crop species 1}}{\text{yield of monocrop species 1}} + \frac{\text{yield of relay crop species 2}}{\text{yield of monocrop species}}$

Table 15b. Agronomic summary table for pulse and soybean relay crops at Carman 2019-20.

Crop	Row Config.	Seed Rate (seeds/ft^2)	Seed Depth (in)	Pesticide summary	Fertilizer applied	General notes and observations
Fall Rye		24	1.25	In-crop: Thumper, hand-weed	60-30-0-0	
W. Wheat		26	1.25	In-crop: Thumper, hand-weed	60-30-0-0	
Soybean		5	1.25	In-crop: Odyssey Ultra, RoundUp WeatherMax and hand-weeding	0-15-0-0	
W. Camelina		8 lb./ac	0.25	In-crop: Assure II and hand-weeding	60-30-0-0	Plant population was low throughout due to poor seed metering (camelina seed is smaller than canola). A full plant stand would improve weed control as there are few herbicide options.
Field Pea		7	1.5	In-crop: Odyssey Ultra and hand-weeding Desiccant: Heat LQ	0-15-0-0	
Fall Rye-Soybean	Single alternate	14 2	1.25 1.25	In-crop/pre-emerge: Thumper In-crop: Hand-weed	60-30-0-0 0-15-0-0	No in-crop herbicide option so a pre-seed or pre-emerge (likely more effective) is a very important weed control method, otherwise strong plant stands are necessary. Crop competition between soybean and cereal significantly reduced soybean growth compared to twin row configuration. Harvest was not problematic.
Fall Rye-Solybean	Twin	11 1	1.25 1.25	In-crop/pre-emerge: Thumper In-crop: Roundup WeatherMax and hand-weeding	60-30-0-0 0-15-0-0	A herbicide pass onto the soybean rows is an option with specialized equipment but weeds are suppressed well with the fall rye. Fall rye was hand harvested since harvesting with a plot combine would damage the soybeans (tires). To facilitate harvest of relay crop soybeans with winter cereals, farmers have made modifications by adding specialized row guards.
W. Wheat-Soybean	Single, alternate	14 2	1.25 1.25	In-crop/pre-emerge: Thumper In-crop: Hand-weed	60-30-0-0 0-15-0-0	No in-crop herbicide option so a pre-seed or pre-emerge is an important weed control method, otherwise strong plant stands are necessary. Crop competition between soybean and cereal significantly reduced soybean growth compared to twin row. Harvest was not problematic.
W. Wheat-Soybean	Twin	11 1	1.25 1.25	In-crop/pre-emerge: Thumper In-crop: Roundup WeatherMax and hand-weeding	60-30-0-0 0-15-0-0	Winter wheat was hand harvested since harvesting with a plot combine would damage the soybeans (tires). To facilitate harvest of relay crop soybeans with winter cereals, farmers have made modifications to existing combines by adding specialized row guards. Compared to the fall rye twin, the soybeans appeared to be more stressed (likely moisture) throughout most of the year, appearing smaller and more chlorotic and having lower yield.
Fall Rye-Field pea	Single, alternate	14 4	1.25 1.5	In-crop/pre-emerge: Thumper In-crop: Hand-weed Desiccant: Heat LQ	60-30-0-0 0-15-0-0	Good plant stands required to control grassy weed populations since there are no in-crop herbicide options. Pea growth reduced relative to twin or monocrop system due to higher crop competition from cereal. Harvest-aid/dessicant recommended for greater harvest uniformity.
Fall Rye-Field pea	Twin	11 1	1.25 1.5	In-crop/pre-emerge: Thumper In-crop: Odyssey Ultra and hand-weeding	60-30-0-0 0-15-0-0	Singular pea rows on essentially 15" row spacing (between pea and adjacent cereal row) resulted in severe pea lodging. Dessicant/harvest-aid should be considered.
W. Wheat-Pea	Single, alternate	14 4	1.25 1.5	In-crop/pre-emerge: Thumper In-crop: Hand-weed Desiccant: Heat LQ	60-30-0-0 0-15-0-0	Used Thumper as a pre-emerge on the peas. Good plant stands essential for limiting grassy weed competition. Pea growth reduced compared to twin or mono due to higher crop competition from cereal. Harvest-aid/dessicant recommended for greater harvest uniformity.
W. Wheat-Pea	Twin	11 1	1.25 1.5	In-crop/pre-emerge: Thumper In-crop: Odyssey Ultra and hand-weeding	60-30-0-0 0-15-0-0	Singular pea rows on essentially 15" row spacing (between pea and adjacent cereal row) resulted in severe pea lodging. Dessicant/harvest-aid should be considered.
Fall Rye- W. Camelina	Single, alternate	24 8 lb./ac	1.25 0.25	In-crop: Hand-weed Desiccant: Heat LQ	60-0-0-0 60-30-0-0	Camelina plant population was very low. Aside from poor germination/emergence as a potential cause, applications of 60 lb/ac N and 30 lb/ac P both seed-placed may have been toxic to very small seeds especially at the shallow seeding depth. Harvest-aid is recommended to align harvest dates between crops as well as to improve uniformity of camelina and improve its harvestablilty - green, ropey stems.

Table 15c. Yield and economic analysis of soybean and pulse relay crops at Carman 2018-19.

Treatment (seed rate)	**Crop**	**Variety**	**Seed rate** (seeds/ft^2)	**Plant stand*** (plants/ft^2)	**Land Equivalent Ratio ¥**	**Height** (cm)	**Yield †** (bu/ac)	**Gross ‡ revenue** ($/ac)	**Marginal revenue ‡** ($/ac)
Fall Rye	Fall Rye	AC Hazlet	32	16.3	1.00	99.1	50.4	277	237
Winter Wheat	W. Wheat	AC Emerson	35	20.8	1.00	72.1	44.7	234	185
Winter Camelina	W. Camelina	Joelle	8 lb/ac	19.2	1.00	64.2	13.0	142	85
Soybean	Soybean	S007-Y4	5	2.1	1.00	n/a	8.9	93	-21
Dry Bean	Navy Bean	T9905	3	0.9	0	n/a	0.0	0	-122
Field Pea	Field Pea	CDC Amarillo	9	5.3	1.00	52.1	5.0	35	-13
Canola	Canola	5545 CL	11	13.4	1.00	97.6	6.7	70	-81
Flax	Flax	CDC Glas	55	14.8	0	n/a	0.0	0	-77
Fall Rye-Soybean (full)	Fall Rye	AC Hazlet	32	11.7	0.83	96.0	41.6	229	83
	Soybean	S007-Y4	3	0.2		n/a	0.0		
Fall Rye-Soybean (half)	Fall Rye	AC Hazlet	16	13.3	0.77	99.6	38.6	212	73
	Soybean	S007-Y4	3	0.2		n/a	0.0		
Winter Wheat-Soybean (full)	W. Wheat	AC Emerson	35	17.1	0.68	71.3	30.3	159	7
	Soybean	S007-Y4	3	1.2		n/a	0.0		
Winter Wheat-Soybean (half)	W. Wheat	AC Emerson	18	10.7	0.58	73.8	25.8	135	-6
	Soybean	S007-Y4	3	0.5		n/a	0.0		
Fall Rye-Dry Bean (full)	Fall Rye	AC Hazlet	32	15.9	0.76	90.0	38.5	212	92
	Navy Bean	T9905	3	1.6		n/a	0.0		
Fall Rye-Dry Bean (half)	Fall Rye	AC Hazlet	32	13.5	0.83	90.8	42.0	231	145
	Navy Bean	T9905	1	1.5		n/a	0.0		
Winter Wheat-Dry Bean (full)	W. Wheat	AC Emerson	35	16.7	0.53	69.6	23.5	123	-2
	Navy Bean	T9905	3	0.0		n/a	0.0		
Winter Wheat-Dry Bean (half)	W. Wheat	AC Emerson	18	18.4	0.61	70.8	27.4	144	27
	Navy Bean	T9905	3	2.2		n/a	0.0		
W. Camelina-Soybean	W. Camelina	Joelle	68	6.3	0.57	58.5	6.1	76	-49
	Soybean	S007-Y4	5	1.0		n/a	0.8		
Fall Rye-Field Pea	Fall Rye	AC Hazlet	32	14.1	0.74	94.2	37.5	206	122
	Field Pea	CDC Amarillo	9	2.5		n/a	0.0		
Fall Rye-Winter Camelina	Fall Rye	AC Hazlet	32	17.4	0.00	83.7	0.0	0	-68
	W. Camelina	Joelle	8 lb/ac	6.7		65.7	0.0		
Field Pea-Canola	Field Pea	CDC Amarillo	9	5.2	1.51	51.3	4.7	74	-40
	Canola	5545 CL	5	1.6		98.8	3.9		
Soybean-Flax (half)	Soybean	S007-Y4	5	2.1	0.80	n/a	7.1	74	-71
	Flax	CDC Glas	27	6.1		n/a	0.0		
Soybean-Flax (2/3)	Soybean	S007-Y4	3	2.6	0	n/a	0.0	0	-116
	Flax	CDC Glas	37	7.1		n/a	0.0		
Field Pea-Flax (full)	Field Pea	CDC Amarillo	9	4.8	0.76	50.7	3.9	39	-60
	Flax	CDC Glas	28	9.7		36.3	1.0		
Field Pea-Flax (2/3)	Field Pea	CDC Amarillo	6	4.4	0	51.9	0.0	0	-90
	Flax	CDC Glas	36	12.7		37.3	0.0		

*Optimum plant stands for monocrops: fall rye (24 plants/ft^2), winter wheat (20-30 plants/ft^2), camelina (20 plants/ft^2), soybean (4 plants/ft^2), navy bean (>300 plants/ft^2), peas (7-8 plants/ft^2), canola (5-7 plants/ft^2) and flax (37-56 plants/ft^2)

† Average crop yields in the Dufferin municipality: 61.0 bu/ac fall rye, 69.8 bu/ac winter wheat, 36.7 bu/ac soybean, 30.8 bu/ac (1850 lb/ac) navy bean, 30 bu/ac peas, 43.3 bu/ac canola, 15.9 bu/ac flax (MASC, 2011-2020).

‡ Profit margins were calculated as follows: *Gross revenue ($/ac)* = Yield x Market price
Marginal revenue ($/ac) = Gross revenue – Seed – Fertilizer – Pesticide – Separation ($0.25/bu)

(Market prices from Manitoba Agriculture 2020 Costs of Production: $5.50/bu fall rye, $5.25/bu winter wheat, $10.50/bu soybean, $18.00/bu navy bean, $7.00/bu peas, $10.50/bu canola, $12.00/bu flax)
(Market prices from Smart Earth Camelina: $11.00/bu camelina)

¥ Land equivalent ratio (LER) =

$$\frac{\text{yield of relay crop species 1}}{\text{yield of monocrop species 1}} + \frac{\text{yield of relay crop species 2}}{\text{yield of monocrop species}}$$

Table 15b. Agronomic summary table for pulse and soybean relay crops at Carman 2019-20.

Treatment	Crop	Seed Rate (seeds/ft^2)	Seed Depth (in)	Pesticide summary	Fertilizer applied	General notes and observations
Fall Rye	Fall Rye	32	1.25	None	60-30-0-0	
Winter Wheat	Winter Wheat	35	1.25	None	60-30-0-0	
Winter Camelina	W. Camelina	8 lb/ac	0.5	Hand weeded	60-30-0-0	
Soybean	Soybean	5	1.25	Roundup WeatherMax	3-15-0-0	Poor establishment and lack of moisture reduced yield.
Dry Bean	Navy Bean	3	1.25-1.5	Basagran Forte w/ Viper ADV & UAN 28%	45-15-0-0	Low plant est. and deer browsing in August resulted in no yield.
Field Pea	Field Pea	9	1.25-1.5	Heat LQ & Merge	3-15-0-0	Deer browsing in late July and August resulted in no yield.
Canola	Canola	11	0.75	Decis, Odyssey NXT, hand weeded	115-15-0-0	High flea beetle pressure in mid-August caused damage to canola pods in all reps. Pests were sprayed with Decis which had poor control.
Flax	Flax	55	0.75	Centurion & Basagran, Assure II w/ Basagran Forte & Merge	35-15-0-0	In late June, flax plants became necrotic due to Fusarium wilt or herbicide injury and did not reach maturity.
Fall Rye-Soybean (full)	Fall Rye Soybean	32 3	1.25 1.25-1.5	None	60-30-0-0 0-0-0-0	Poor soybean establishment between fall rye rows and lack of moisture resulted in no harvestable yield
Fall Rye-Soybean (half)	Fall Rye Soybean	16 3	1.25 1.25-1.5	None	60-30-0-0 0-0-0-0	Poor soybean establishment between fall rye rows and lack of moisture resulted in no harvestable yield.
Winter Wheat-Soybean (full)	Winter Wheat Soybean	35 3	1.25 1.25-1.5	None	60-30-0-0 0-0-0-0	Poor soybean establishment between winter wheat rows and lack of moisture resulted in low soybean yield.
Winter Wheat-Soybean (half)	Winter Wheat Soybean	18 3	1.25 1.25-1.5	None	60-30-0-0 0-0-0-0	Poor soybean establishment between winter wheat rows and lack of moisture resulted in low soybean yield.
Fall Rye-Dry Bean (full)	Fall Rye Navy Bean	32 3	1.25 1.25-1.5	None	60-30-0-0 3-15-0-0	Poor est., drought and late season deer grazing resulted in no harvestable bean yield.
Fall Rye-Dry Bean (half)	Fall Rye Navy Bean	32 1	1.25 1.25-1.5	None	60-30-0-0 3-15-0-0	Poor est., drought and late season deer grazing resulted in no harvestable bean yield.
Winter Wheat-Dry Bean (full)	Winter Wheat Navy Bean	35 3	1.25 1.25-1.5	None	60-30-0-0 3-15-0-0	Poor est., drought and late season deer grazing resulted in no harvestable bean yield.
Winter Wheat-Dry Bean (half)	Winter Wheat Navy Bean	18 3	1.25 1.25-1.5	None	60-30-0-0 3-15-0-0	Poor est., drought and late season deer grazing resulted in no harvestable bean yield.
Winter Camelina-Soybean	W. Camelina Soybean	68 5	0.5 1.25-1.5	Hand weeded	6-30-0-0 0-0-0-0	Soybean seed quality was low. Poor establishment and lack of moisture reduced yield.
Fall Rye-Field Pea	Fall Rye Field Pea	32 9	1.25 1.25-1.5	None	60-30-0-0 3-15-0-0	Deer browsed peas once pods began developing in late July and early August
Fall Rye-Winter Camelina	Fall Rye W. Camelina	32 8 lb/ac	1.25 0.5	None	60-30-0-0 6-30-0-0	Winter camelina matured earlier than fall rye. To avoid camelina from shelling out, the fall rye was harvested at a high moisture and dried down
Field Pea-Canola	Field Pea Canola	9 5	0.75 0.75	Decis (flea beetles), Odyssey NXT & Merge, Heat LQ & Merge	3-15-0-0 3-15-0-0	High flea beetle pressure in mid-August caused damage to canola pods in all reps. Pests were sprayed with Decis which had good control.
Soybean-Flax (half)	Soybean Flax	5 27	1.25 0.5-0.75	Centrurion & Basagran, Assure II w/ Basagran Forte & Merge, Hand weeded	3-15-0-0	Flax plant stand established but in late June and early July, at flowering, disease overcame stands which became necrotic and did not yield.
Soybean-Flax (2/3)	Soybean Flax	3 37	1.25 0.5-0.75	Centrurion & Basagran, Assure II w/ Basagran Forte & Merge, Hand weeded	3-15-0-0	Flax plant stand established but in late June and early July, at flowering, disease overcame stands which became necrotic and did not yield.
Field Pea-Flax (full)	Field Pea Flax	9 28	0.75-1	Assure II w/ Basagran Forte & Merge, Centurion w/ Basagran, Heat LQ &	3-15-0-0	In late June, flax became necrotic due to Fusarium wilt or herbicide injury and did not yield.
Field Pea-Flax (2/3)	Field Pea Flax	6 36	0.75-1	Assure II w/ Basagran Forte & Merge, Centurion w/ Basagran, Heat LQ &	3-15-0-0	In late June, flax became necrotic due to Fusarium wilt or herbicide injury and did not yield. Late season deer browsing resulted in low pea yield.

Growing Season Weather Summary

Table 16. Growing season (May through August) mean daily temperature and monthly precipitation in comparison to long term averages for each study site reported from 2015 to 2020.

	Mean daily temperature (°C)						**Precipitation, mm**					
Site	**May**	**June**	**July**	**Aug**	**M-A**		**May**	**June**	**July**	**Aug**	**M-A**	
Arborg17	10.1	16.2	18.9	16.9	15.5		23	54	76	56	209	↓
Arborg18	13.3	18.4	19.8	17.9	17.4	↑	34	37	58	61	190	↓
Arborg19	8.7	16.3	19.6	17.2	15.5		24	32	67	26	148	↓
Arborg20	9.3	17.2	20.0	18.5	16.2		12	84	61	34	190	↓
LTA-Arborg	10.0	15.8	18.6	17.5	15.5		55	81	70	69	276	
Carman17	12.1	17.1	19.4	17.7	16.6		25	64	23	23	135	↓
Carman18	14.7	18.8	19.9	19.1	18.1	↑	48	97	43	31	219	↓
Carman19	9.6	17.3	19.6	18.1	16.2		37	38	57	62	194	↓
Carman20	10.7	18.3	20.2	18.7	17.1		27	71	54	24	175	↓
LTA-Carman	11.6	17.2	19.4	18.5	16.7		70	96	79	75	319	
Dauphin18	13.6	18.8	19.1	17.3	17.2	↑	38	104	91	3	236	↓
Dauphin19	8.6	16.2	19.1	16.8	15.2		11	60	66	46	183	↓
LTA-Dauphin	10.5	15.7	18.7	17.7	15.7		55	82	73	61	271	
Melita17	12.2	16.8	21.6	18.7	17.4		6	64	45	39	154	↓
Melita18	15.3	19.1	19.4	18.8	18.1	↑	11	98	54	23	187	↓
Melita19	9.7	16.9	19.5	17.6	15.9		16	85	74	101	275	
Melita20	11.2	18.2	20.2	19.0	17.1		20	63	63	35	181	↓
LTA-Melita	11.2	16.5	19.2	18.5	16.3		65	87	62	47	260	
Minto15	12.0	18.0	21.0	20.0	17.8	↑	39	26	41	21	127	↓
Minto17	12.0	16.0	20.0	19.0	16.8	↑	18	61	28	20	128	↓
LTA-Minto	12.0	16.6	12.2	11.1	13.0		61	86	82	67	296	
Portage15	11.3	18.1	20.8	18.8	17.4	↑	76	53	178	64	177	↓
Portage17	11.7	17.2	20.3	18.4	17.0		24	63	15	15	115	↓
Portage18	14.9	19.5	20.6	19.5	18.6	↑	22	93	37	20	172	↓
Portage19	9.8	17.4	20.4	18.1	16.4		33	35	68	37	172	↓
Portage20	11.0	18.4	21.1	19.4	17.4	↑	21	50	60	46	177	↓
LTA-Portage	10.6	16.1	18.9	17.9	15.9		62	86	70	63	280	

LTA = long term average (1991-2020 for Melita,1981-2010 for all other sites)
↑↓ = +/- 10% of long term average
Data sources: Manitoba Agriculture and Environment Canada

Statistical Analysis Methods

Soybean fungicide

Experimental design was a randomized complete block (RCB) with 4 replicates. Data was subjected to ANOVA using Proc Mixed in SAS 9.4 with fungicide treatment and environment/site-year as fixed effects and block as a random effect. Residuals were evaluated for assumptions of ANOVA prior to final analysis. Tukey's HSD was used for LS Means separation for significant effects (P = 0.05).

Intercropping with soybeans and peas in the Interlake

Individual treatment analysis in R
For all treatments in Arborg (2019 and 2020), land equivalent ratios were analyzed with the Kruskal-Wallis rank sum test and marginal revenue values were analysed with a one-way ANOVA followed by Tukey HSD as a post-hoc test.

Combined treatment analysis in R
After combining the same crop combinations (2019 and 2020), the Brown-Forsythe Test was used to analyze land equivalent ratios and marginal revenue values followed by the Dunn test as a post-hoc test. The Shapiro-Wilk normality test, Levene's Test for Homogeneity of Variance and Q-Q plots were used to confirm the assumptions of ANOVA.

Separate analysis by same crop combinations with different seeding rate ratios in R
For Arborg 2019, a two sample t-test was used to find the difference between means of land equivalent ratio and marginal revenue for same crop combinations with different seeding rates. Further, an F test was used to compared the two variances of same crop combinations with different rates. For Arborg 2020, land equivalent ratio and marginal revenue for same crop combinations (pea-canola, pea-flax, pea-oat, and soy-flax treatments) with different seeding rates were analyzed with the one-way ANOVA followed Tukey HSD test as a post-hoc test. Shapiro-Wilk normality test and Levene's Test for Homogeneity of Variance used to confirm assumptions that both groups were sampled from normal distributions with equal variances for land equivalent ratio and Marginal revenue.

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Soybean fungicide

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