Hail Damage Research Report

Soybean and Pulse Agronomy Lab

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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).

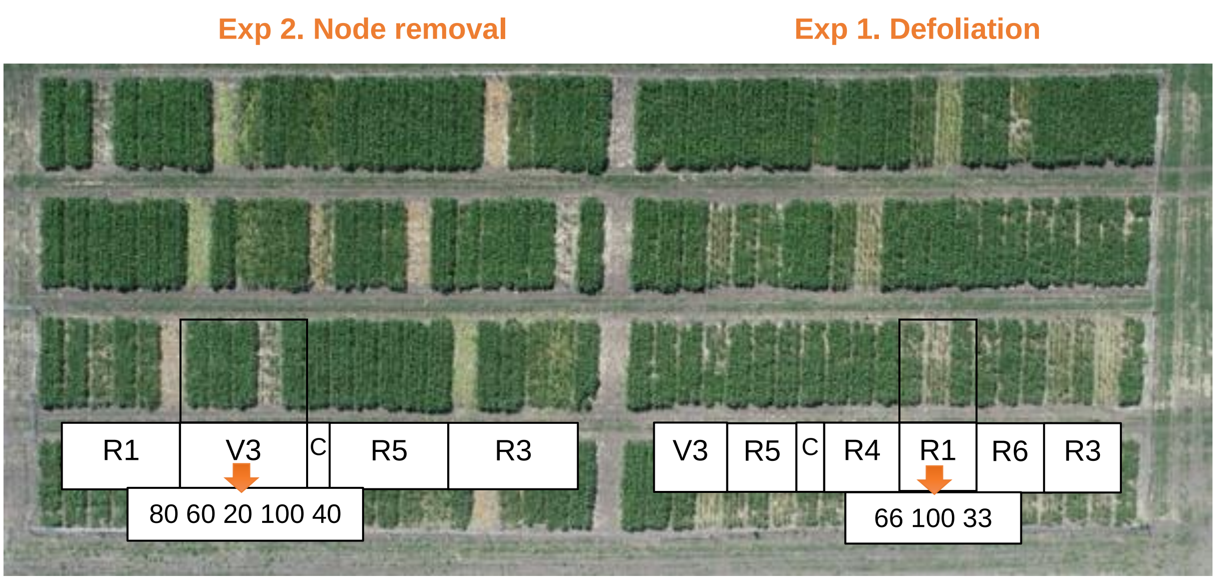

Figure 5a. Soybean node removal (L) and defoliation (R) experiments at Portage 2018. Plot labels given for Replicate 2 (third from the top).

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.

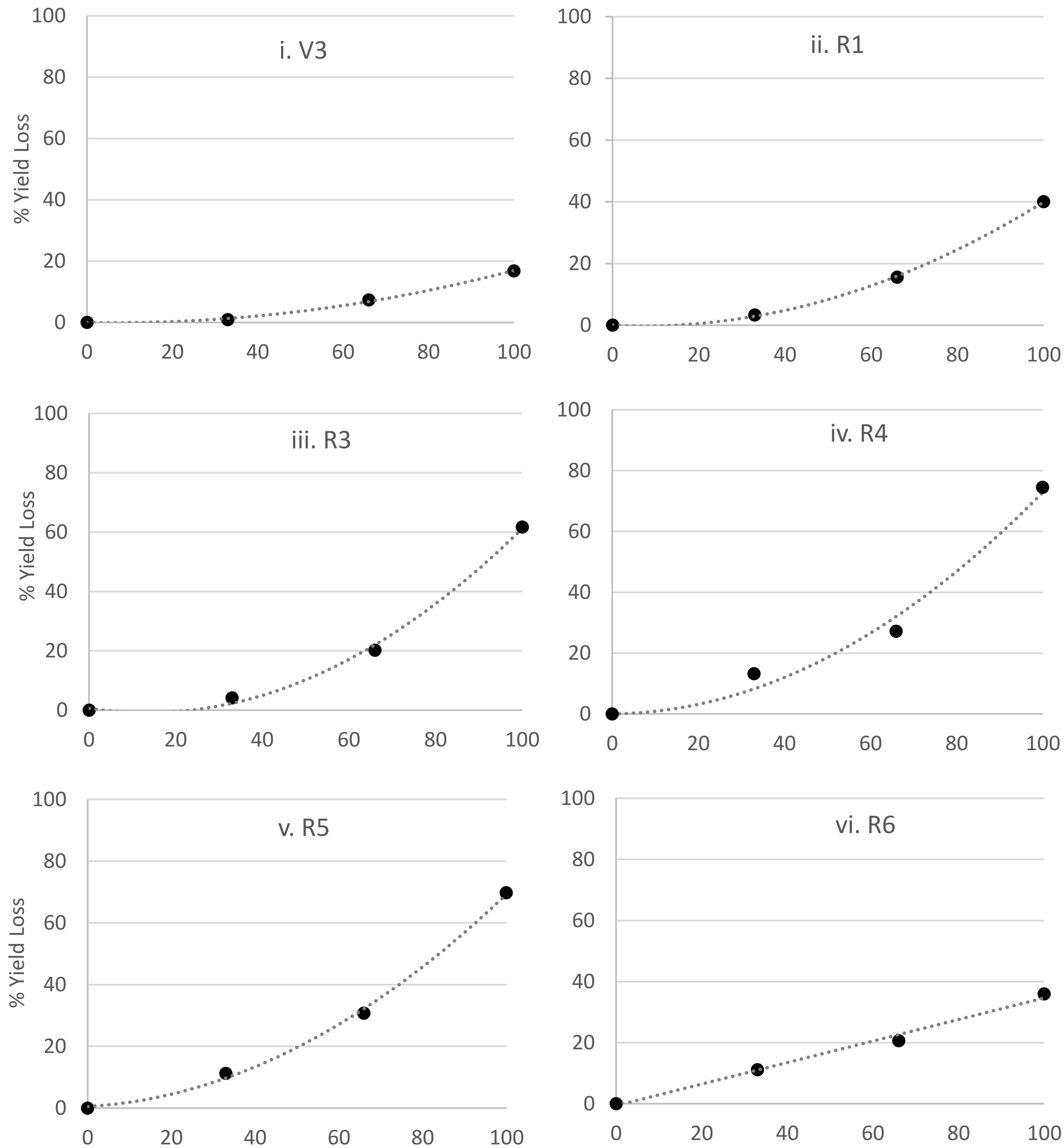

Figure 5bi-vi. Relationship between soybean yield loss and % leaf defoliation at six growth stages in Manitoba averaged across 5 site-years (Minto and Portage la Prairie, MB from 2015-2018).

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.**

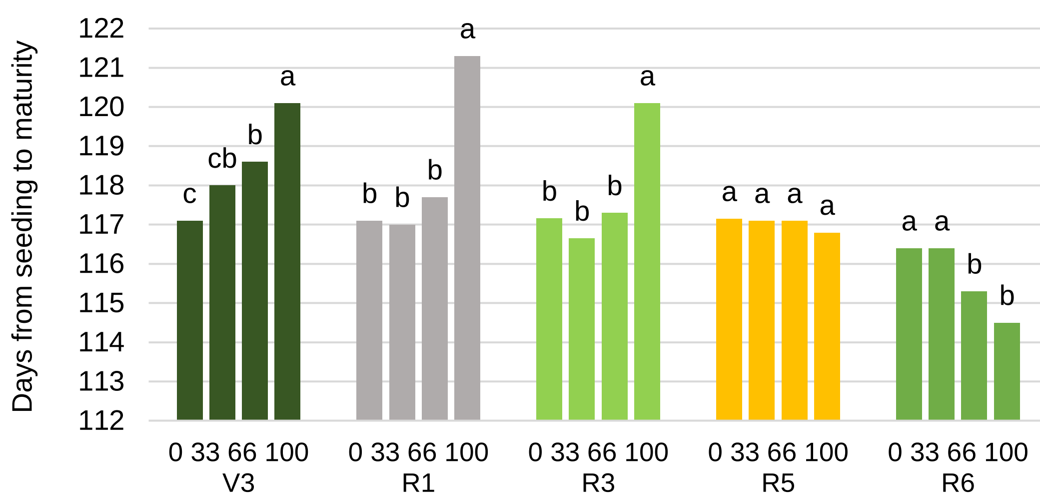

Figure 5c. Effect of leaf defoliation on soybean maturity at each growth stage and defoliation level based on 5 site-years in Manitoba (2015-2018).

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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Effect of simulated hail damage on soybean yield and maturity

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

Introduction

Susceptibility of crops to hail damage depends on plant type, growth stage and hail severity but can result in stem breakage, leaf defoliation, stand reduction, stem bruising, direct loss of yield components and/or 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, most 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 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 yield and maturity 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. Unfortunately, 3 site-years were lost due to actual hailstorms (July 16, 2016 in Minto, August 15, 2016 in Portage la Prairie and June 14, 2018 in Minto). Results of Experiment 1 are reported in the 2019-2020 Annual Report.

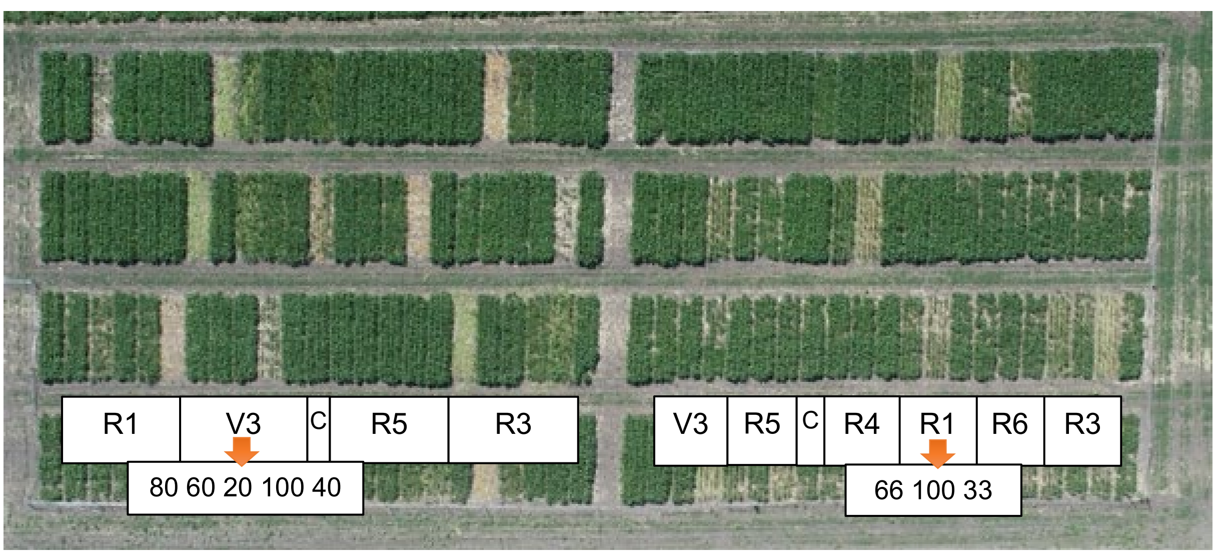

Figure 1. Soybean node removal (L) and defoliation (R) experiments at Portage 2018. Plot labels given for Replicate 2 (third from the top).

Experiment 2: Soybean yield response to node removal (stem breakage) in Manitoba

Objective

To determine the effect of node removal at various growth stage/timings and severity levels on soybean yield and produce region-specific crop insurance data.

> Soybean yield loss when 100% stem breakage occurs during V3 is higher than current data suggests, and this the first report of an 8–14-day delay in maturity.

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 and took place from 2015-2018. 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 included 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, the total number of main stem nodes (excluding the cotyledonary node) was determined by counting nodes on 10 plants/plot. The average number of main stem nodes/plant was then multiplied by 0.20, 0.40, 0.60 and 0.80 to determine the number of main stem nodes that would be removed by manually cutting with garden trimmers. Nodes were counted from the uppermost node on the main stem downwards until the number of nodes to be cut was reached and then a single cut was made to the main stem. For 100% node removal, each plant was clipped above the cotyledonary node.

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 node removal) with 4 replicates was tested at 5 site-years/environments. Node removal took place during 5 growth stages (V3, R1-R2, R3, R4 and R5) and 5 severity levels (20, 40, 60, 80 and 100% of main stem nodes) plus a shared control (0), for a total of 26 treatments (5 timings x 5 severity levels + 1 shared control = 26 treatments). The number of observations for each treatment was unbalanced (Table 1: not all timing x severity combinations were present in each site-year).

Table 1. Number of observations (n) per treatment.

	% Node removal/stem breakage					
Timing	**0**	**20**	**40**	**60**	**80**	**100**
V3		20	20	20	20	20
R1-R2		20	20	20	20	20
R3	20	16	16	16	16	16
R4		8	8	8	8	8
R5		12	12	12	12	12

Statistical analysis

Analysis of variance (ANOVA) on the full model was performed using Proc GLIMMIX, 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. Putative outliers were reviewed and removed if necessary. Due to several significant effects, the percent sums of squares (%SS) was obtained through Proc Mixed method=type 3 to assess the contribution to variance of each factor. Because the objective of the research was to obtain soybean yield loss and maturity data by node removal severity for multiple growth stages relevant to Manitoba and western Canada, data from each site-year were pooled and separate analyses were conducted for each node removal timing (growth stage). For these analyses, severity and site-year were treated as fixed effects and block(site-year) as a random effect. Residuals were assessed for normality, outliers and homogeneity of variance. Putative outliers were reviewed and removed if necessary.

To predict yield loss across all severity levels for each node removal timing (growth stage), the % severity factor was partitioned into linear, quadratic and lack of fit components and tested for significance. Since non-linear responses were detected, Proc IML was used to obtain the appropriate coefficients for a polynomial and an exponential model. Efron's Pseudo R2 were estimated to select the best fit non-linear equation. Plots were created for predicted values of the regression equation and LS means (+/- SE) from the study were then overlaid.

Results and Discussion

Overall soybean yield in the control treatments ranged from 47-71 bu/ac among site-years, which is above the provincial average yield of 36 bu/ac. 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 2. In the full model analysis of yield, all main effects and interactions were significant. To account for differences in overall yield among site-years, yield was converted to yield loss [(% yield loss = yield of treatment / yield of control) x 100)], and because relative differences between treatments were 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 and site-year interactions accounted for little variation overall.

Table 2. Summary of three-way analysis of variance for soybean yield, yield loss and maturity (5 site-years in Minto and Portage la Prairie, MB from 2015-2018).

	Yield		**Yield loss**		**Maturity**	
	Pr > F	% SS	Pr > F	% SS	Pr > F	% SS
Site-year	<.0001	7.7	0.7080	0.4	<.0001	66.1
Timing	<.0001	6.1	<.0001	6.3	<.0001	3.2
Site-year x Timing	0.0452	0.8	0.0044	1.0	<.0001	6.8
Severity	<.0001	67.5	<.0001	72.2	<.0001	7.9
Site-year x Severity	<.0001	2.1	<.0001	1.3	<.0001	6.8
Timing x Severity	<.0001	5.5	<.0001	6.0	0.0018	0.7
Site-year x Timing x Severity	<.0001	2.9	<.0001	3.1	0.0005	1.5

Yield loss and yield loss equations

Severity (% main stem node removal) accounted for most of the variation in soybean yield loss (72%), followed by the timing of node removal (6%) and the interaction between severity and timing (6%). All other factors explained ≤ 3% of the variation in yield loss (Table 2). It is well known in crop hail research that the effect of hail damage varies by growth stage. Therefore, to further elicit the effect of timing (crop growth stage) and produce data for crop insurance purposes, data were handled separately for each timing and agrees with separating severity and growth stage for a range of crops reported (Muro et al. 2001; Conley et al. 2009; Bueckert et al 2011; Owen et al. 2013). This also allows investigation of the high-level 3-way interaction, whereby the severity x site-year interaction can be evaluated for each timing.

Table 3. 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-R2**	**R3**	**R4**	**R5**
			Pr > F		
Severity	<.0001	<.0001	<.0001	<.0001	<.0001
Site-year	0.3891	0.9849	0.1957	0.3169	0.3631
Severity x Site-year	<.0001	0.0056	0.1308	0.3310	0.3334

The following discussion focuses on soybean yield response by growth stage that node removal occurred (Table 3 and Fig. 2.). The effect of node removal on yield loss was consistent among environments at R3, R4 and R5 (no interaction between severity and site-year). At V3 and R1-R2, however, there was variability in the observed yield loss response among site-years (data not shown). This variability is attributed to the range in yield loss observed at 100% node removal during V3 (Fig. 1, 29-86% yield loss) and 80% node removal during R1 (19-51% yield loss). Crop recovery may be difficult to estimate during those growth stages for those specific severity levels and is likely dependent on environmental conditions following crop damage.

Figure 2. Variability in soybean re-growth between site-years following 100% node removal during V3 on August 10, 2017 (left) compared to August 8, 2018 (right) at Portage la Prairie.

The best fit regression models for soybean yield loss at each growth stage are presented in Fig. 2 and explain 71-96% of the variation in yield loss. Four out of the five growth stage timings resulted in an exponential yield response to node removal severity, whereby as severity increases, yield loss increases more sharply.

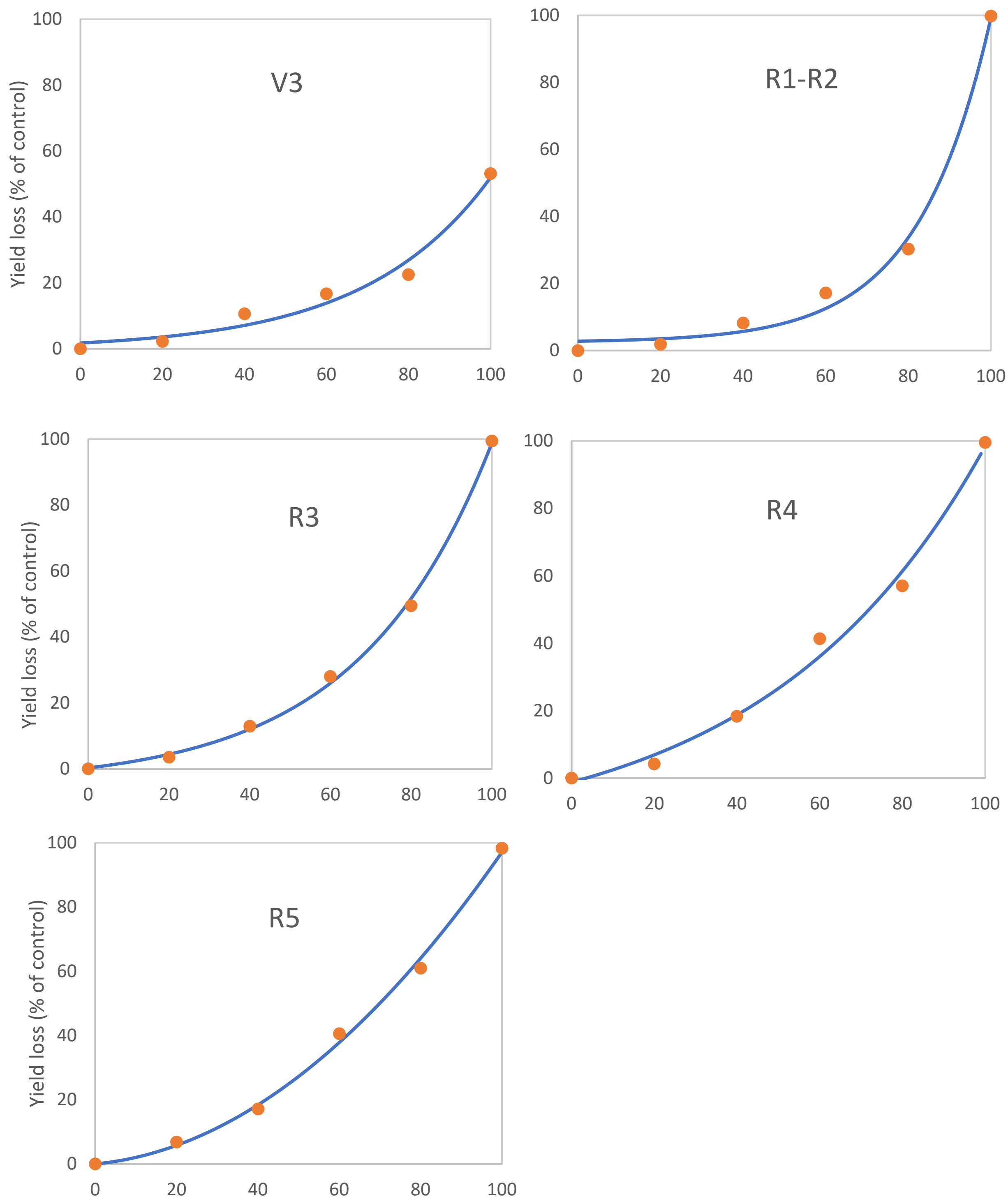

Figure 2. The relationship between soybean yield loss and % node removal at five growth stages in Manitoba averaged across 5 site-years (2015-2018).

At growth stage V3, soybean was the most tolerant to high levels of node removal and was the only growth stage timing to recover from 100% node removal. The average yield loss when 80% of main stem nodes above the cotyledon were removed was 23% and is similar to values currently reported in Iowa (Licht et al. 2016). However, the average yield loss when 100% of main stem nodes are removed was 53% which is greater than values currently reported (38%). Generally, soybeans compensate well for leaf loss during vegetative growth and early flower due to rapid leaf re-growth (Board and Kahlon 2011) and new growth from axillary buds, but our data demonstrates that crop recovery is region specific.

At R1-R2 (flowering), soybean is no longer able to recover following 100% node removal. Yield loss observed for all other severity levels is consistent with observations from other regions.

At R3 (early pod), soybean yield loss observed in our study from 60 and 80% node removal is 20-30% lower than values currently reported for Iowa (Licht et al. 2016) and Nebraska (Klein and Shapiro 2011) and represents the greatest deviation between yield loss values among regions. This may be due to the distribution of yield components (pods and seeds) among main stem nodes, whereby, more pod and seed development occurs on the lower portion of the stem in short-season cultivars or environments.

During R4 (full pod) and R5 (early seed), soybean was most sensitive to node removal with 41-61% yield loss occurring when 60-80% of main stem nodes are removed. To our knowledge, this is the first study to report a yield loss relationship for R4 and R5 since node removal/stem breakage from growth stage R4 onward is considered direct loss. At this point in soybean reproductive development, pods and seeds are formed sufficiently to allow quantitative evaluation of yield loss. During R4 and R5, the effect of node removal severity was consistent among site-years and the yield loss models were similar across severity levels. Thus, suggesting that these crop loss models may be combined and used by crop hail adjustors in place of direct loss measurements which offers two immediate benefits – time efficiency and accuracy, since pods are often detached from the stem and found loose on the ground following a hailstorm.

Table 4. Mean soybean yield loss (%) by node removal severity for each growth stage averaged across 5 Manitoba site-years.

Node removal severity	V3	R1-R2	R3	R4	R5
	% Yield loss				
0%	0e	0e	0e	0e	0e
20%	2.2e	1.9e	3.5e	4.2e	6.8e
40%	10.6d	8.2d	12.9d	18.4d	17.1d
60%	16.7c	17.1c	28.0c	41.3c	40.5c
80%	22.5b	30.3b	49.5b	57.0b	60.9b
100%	53.1a	99.9a	99.4a	99.6a	98.3a

Days to full maturity (R8)

All main effects and interactions influenced soybean days to R8 full maturity (Table 2). The most important factor was site-year, accounting for 66% of the variation in soybean maturity. In the separate analyses by growth stage/timing, the effect of severity on crop maturity varied by site-year (data not shown).

During V3, all levels of node loss significantly delayed soybean maturity compared to the control (Fig. 3). Soybean maturity was delayed by 6-8 days at 40-80% severity and 14 days, on average, when 100% of nodes were removed (Fig. 4). In Manitoba, soybeans progress from physiological maturity to full maturity in about 7 days (range 4-12) therefore a maturity delay of 7 days or greater would be expected to pose a significant agronomic risk to soybeans in Manitoba. The magnitude of maturity delay was 7 days or greater at 4 out of 5 site-years.

During R1, soybean maturity was delayed by 2-6 days on average across severity levels from 20-80%. The magnitude of maturity delay varied from 0 to 11 days among site-years with 2 out of 5 site-years resulting in an agronomically significant delay of 7 days or greater at the highest severity level (80%).

From R3 through R5, the interaction between the effect of severity and site-year becomes clearer and differentiated by site (data not shown). There were no differences in soybean maturity among node loss treatments during the study years at Portage. At Minto, however, soybean maturity was delayed by 5-12 days when 60-60% of nodes were removed. Thus, the risk of hail-damaged soybeans not reaching maturity before fall frost is greater in shorter season regions of Manitoba.

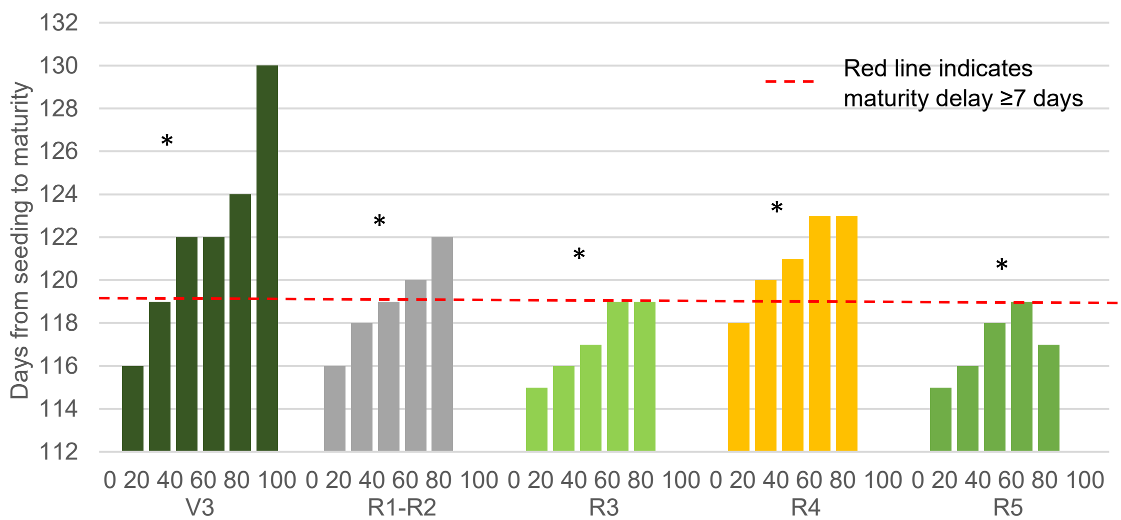

Figure 3. The effect of main stem node removal on soybean maturity at each growth stage and severity level based on 5 site-years in Manitoba (2015-2018).

Conclusions

This study provides the first comprehensive dataset quantifying the impact of node removal/stem breakage on soybean yield and maturity in Manitoba and western Canada. Results indicate that the response of short-season soybean in western Canada to node removal is different compared to southern growing regions (Table 5). Current data appears to be overestimating yield loss in some instances during R3 while the greatest discrepancy occurs during V3 when 80-100% of main stem nodes are removed. The economic loss in yield (23-53%) is substantially higher than current data suggests, and we are the first to document the maturity risk, which equates to an 8 to 14 day delay in reaching R8. Equations for the soybean yield responses in Fig. 2, will be made available to farmers, agronomists and crop insurance adjusters.

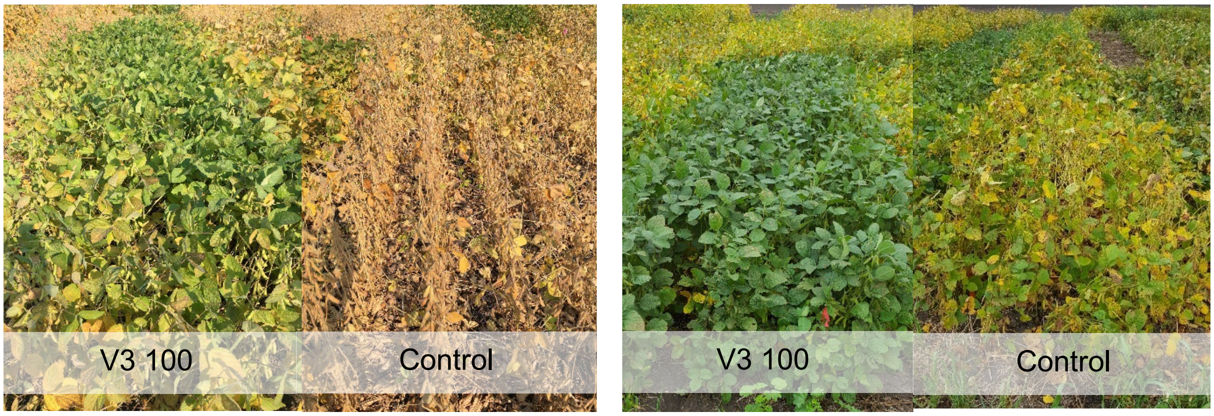

Figure 4. Soybean maturity following 100% node removal during V3 compared to the control at Portage on Sept. 12, 2017 (left) vs. Minto on Sept.10, 2015 (right).

Table 5. Difference between new soybean yield loss data and current data used by crop insurance providers for each growth stage and defoliation level in Manitoba.

	V3	R1	R3	R4	R5	
20	-3.8	-5.3	-5.1			
40	-4.5	-9.7	-9.4			<5%
60	-1.8	-7.8	-12.6	Data not previously reported.		5-10%
80	3.7	-1.8	-12.1			>10%
100	13.8	4.6	-1.1			

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