PROJECT DETAILS

- **Title**: Evaluation of harvest losses and their causes in canola across western Canada
- **Funders:** Agriculture and Agri-Food Canada, Alberta Canola, Canola Council of Canada, Manitoba Canola Growers and SaskCanola
- **Research program:** Growing Forward
- **Principal investigator:** Robert (Rob) Gulden
- **Collaborators/additional investigators:** Neil Harker, Linda Hall, Steve Shirtliffe, Christian (Chris) Willenborg
- **Year completed:** 2013

Final report

Canola is the major oilseed crop grown in western Canada. Canola, however, also is a crop with high potential for seed shatter and previous research showed that seed losses at harvest can be substantial (Gulden et al. 2003). This survey of 35 fields over two years in the Saskatoon area revealed large variability in the harvest losses and seedbank additions of volunteer canola among fields from different producers (Gulden et al. 2003). On average, producers lost 5.8% of yield (about 3,000 viable seeds m-2); however, harvest losses ranged from about 3 to greater than 10% of final yield. The accompanying survey questionnaire indicated no clear association with any particular management practice. The canola growing region of western Canada covers a broad range of areas with different yield potential and whether harvest losses in the Saskatoon area are representative of the canola growing region as a whole is not known. In addition, producers are increasingly interested in direct harvest of canola. This is common practice in Europe where substantial harvest losses have been documented at times when adverse weather conditions prohibit timely harvest of the crop (Price et al. 1996, Pekrun et al. 1998). In response to the findings by Gulden et al. (2003), a more thorough field survey is warranted that examines yield losses in other canola growing regions. A more extensive on-farm survey was conducted and the following four objectives were addressed:

1) Are harvest losses similar among production areas in western Canada?
2) Have harvest losses in canola changed over the past decade?
3) Are on-farm harvest losses different for straight-cut compared to swathed canola?
4) What factors contribute to harvest losses in canola?

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Methods

From 2010 to 2012, surveys of total canola harvest losses were conducted in producer fields in the three Prairie provinces. Four regions were targeted, based around Winnipeg, MB, Saskatoon, SK, Edmonton, AB and Lacombe, AB. The majority of surveyed fields were located within 150 km of each base, although in some regions some fields were located further away. Within each year and region, the number of sampled fields ranged from 9 (Edmonton 2010) to 48 (Winnipeg 2012), resulting in a total of 310 fields sampled throughout this survey. The canola growers included in the survey were chosen at random. In mid-summer of each sampling season, the producers were asked to provide two or three canola fields during each harvesting season. Due to changes in rotation and weather conditions, not all producers were able to provide fields for the survey each year, however, as many producers as possible were visited repeatedly over the three years to allows for the determination of the impact of year on their canola harvest losses.

Total harvest losses were measured as described by Gulden et al. (2003). In brief, shortly after harvest, canola seed, crop residue and some soil were recovered from three representative transects laid out perpendicular across adjacent swaths or combine passes in direct-harvested systems using a shop vac. Across each transect, 25 cm*25 cm or 30 cm*30 cm subsamples were collected at 1 m intervals and bulked. Each transect represented one replicate. Samples were air dried and dry sieved to remove large residue and soil aggregates and other particles larger and smaller than canola seeds. This was followed by wet sieving to remove soil aggregates of the same size as canola seed. After wet sieving, samples were air dried and exposed to a blower to remove light material and then hand-picked to remove all remaining foreign material. Seed samples were weighed and harvest losses were determined.

For each sampled field, producers were asked to respond to a questionnaire that addressed agronomic information and specifics about how the field that was harvested. The questionnaire requested information in three broad categories including: farm specific information, field specific information and harvest management. In addition, environmental variables for wind incurred between swathing and harvest, for swath harvested fields, and 20 days before harvest for direct-harvested fields, were determined from the nearest publicly available weather station. In 2010 and 2011, regional precipitation during that same time period was also determined, but found to have no influence on harvest losses and therefore was discontinued in 2012.

The variables used to explain total proportional and total absolute harvest losses in canola were the following:

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Farm specific information
Farm size - Total cropped acreage of the farm.
Total canola acres – Total number of acres planted to canola that season.
Proportion of canola – Ratio of total canola acres divided by total farm acreage.

Field specific information
Field size – Size of each surveyed field in acres.
Years since canola – Number of years since the last canola crop was grown in in the field (limited to 6).
Variety – Canola variety that was grown in the field.
Seeding rate – Canola seeding rate (lbs / ac).
N fertility – Amount of fertilizer applied (lbs / ac).
Fungicide application – Fungicide application at flowering (Yes or No).
Canola yield – Farmer reported yield for the field (bu / ac).
Thousand Kernel Weight – Thousand kernel weight of seed recovered after harvest.

Harvest Method – Swathed or Straight-cut
Swathed only
Crop maturity at swathing – Estimate of % colour change of seeds on main rachis at swathing
Swathing date – Julian date when field was swathed.
Swather width – Width of swather (feet).
Swather speed – Average swather ground speed (MPH).
Time of day of swathing - Morning, afternoon, evening, or any combination of these.

Combine
Harvest date – Julian date when field was harvested.
Days in swath – Number of days between swathing and harvest of the swathed crop.
Combine manufacturer and type – Manufacturer and type (Rotary, Conventional, or Hybrid).
Combine speed – Average combine ground speed (MPH).
Combining time of day – Morning, afternoon, evening, or any combination of these.

Environmental variables
Wind – Maximum daily wind speeds were obtained from the nearest Environment Canada, or provincial weather stations during the harvest season (see above). Initially, average daily maximum wind speed, sum of daily maximum wind speeds, number of days with wind speeds above 30, 40, or 50 km/hr were determined and correlated with harvest losses. Average maximum wind speed best correlated with harvest losses and therefore was used as an explanatory variable.

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Data analysis

Harvest loss data was subjected to analysis of variance using the mixed procedure in SAS. The dataset was subsampled to adequately address the effects of categorical variables on yield losses. This was required to account for the inherent unbalanced nature of the survey dataset. For example, to determine whether there was a difference between harvest losses between swath-harvested or direct-harvested canola, only the subset of data from producers in Saskatchewan which used both methods on their farms was used. Before each analysis, the data were tested to determine whether the residuals conformed to the normal distribution, outliers were removed and harvest loss data were transformed when necessary to meet the assumptions of ANOVA. For each analysis, fixed effects were those that were being investigated, and random effects included all other pertinent variables (e.g. producer, field, location, year) and random variables were nested as required (e.g. field (producer * year)). Heterogeneity of variances among treatments were corrected when required. Means were separated using Fisher's protected LSD test using the pdmix800 macro in SAS. Individual analyses are described in more detail for each objective in that specific section.

Treatment of continuous variables was different. The relationship between continuous variables and harvest losses were examined using correlation within each region and, after standardization within each region, a global correlation analysis was conducted. In addition to correlation with individual continuous explanatory variables, a multiple regression approach was used including continuous variables and categorical variables for which 4 or fewer levels existed. Each level was coded as a dummy variable and the total number of variables used had to be limited to this level to not exceed the number of explanatory variables given the total number of fields in the survey. More detail on these approaches is provided in the individual sections.

Results

1) Are harvest losses similar among production areas in western Canada?

2) Have harvest losses in canola changed over the past decade?

Canola yields and harvest losses were different among regions and were strongly affected by year. Yields in this survey were not measured, but were reported by producers (Table 1). A broad range of average canola yields were reported among the four locations that ranged from 28.5 bu/ac (WPG 2011) to 60.1 bu/ac (EDM 2010). As with canola yield, absolute total canola harvest losses were different among regions and varied among years. Average regional harvest losses ranged from 1.34 to 3.75 bu/ac and with the exception of EDM2010, were closely related to average regional yield. Average regional proportional harvest losses (harvest losses expressed as a percentage of reported yield) ranged from a low of 2.37% (EDM 2010) to a high of 8.45% (SAS 2012). At Edmonton in 2010, absolute and proportional yield losses were lower than expected, particularly given the high canola yields that were reported among the 9 fields sampled that season. We suspect potential problems during seed recovery from the samples may have

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contributed to the otherwise unexplainably low seed recovery at this location. For that reason and the fact that only 9 fields were affected, we excluded these data from the analysis that addressed objective 4. When excluding harvest losses in Edmonton in 2010, the lower limit for proportional harvest losses was 4.01% (LAC 2012). The average number of seeds lost during harvest which have the potential to contribute to future volunteer canola populations ranged from about 2,500 (WPG 2012) to 6,100 seeds m-2 (SAS 2011) when Edmonton 2010 was excluded.

Average proportional total harvest losses in this survey, were similar to those observed in a survey in the Saskatoon area about 10 years ago (Gulden et al. 2003) where harvest losses in canola were about 5.9% averaged over two years. However, generally higher yields of modern cultivars have resulted in a tendency for greater absolute total harvest losses and an increased number of seeds added to the volunteer canola seedbank.

Table 1. Number of sampled fields, canola yield, and yield loss in each region for each year the survey was conducted. Within columns, means followed by different letters indicate significant differences among means using Fisher's protected least significant difference.

Location	Year	Fields	Yield		Harvest Losses					
		#	bu / ac		bu / ac		% of Yield		seeds / m^2	
Edmonton	2010	9	60.1	A	*1.46	EFG	*2.37	G	*2191	F
	2011	21	44.4	BC	2.53	BC	5.50	BCDE	4409	BCD
	2012	14	38.6	DEF	1.87	CDE	4.72	DEF	2790	EF
Lacombe	2010	25	37.7	EF	2.47	BC	6.16	ABCD	4277	CD
	2011	23	49.1	B	3.75	A	7.13	AB	6009	AB
	2012	25	40.9	CDE	3.03	AB	4.01	F	5004	ABC
Saskatoon	2010	26	38.2	EF	2.23	CD	5.65	BCDE	4366	C
	2011	40	44.6	BCD	3.17	AB	6.63	ABC	6129	A
	2012	18	33.7	FGH	3.14	AB	8.45	A	6052	AB
Winnipeg	2010	34	40.6	CDE	1.86	DF	4.50	EF	3374	DE
	2011	46	28.5	H	1.48	EG	5.27	CDE	2857	EF
	2012	48	32.1	G	1.34	G	4.16	F	2510	F

* This location year has been excluded from the remaining analyses due to the exceptionally low harvest losses measured relative to yield, suggesting issues with seed recovery from field samples.

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Producer Effect

Differences in proportional total harvest losses were examined among producers. Due to the unbalanced nature of this effect, the analyses were conducted within region. Differences in proportional total harvest losses were observed among producers in Lacombe and Saskatoon regions, but not in the Edmonton and Winnipeg regions (Table 2). Differences among producers were observed in regions where the range of average harvest losses among producers was highest over the three year survey (7.1 % Lacombe and 7.4 % Saskatoon). These results suggest that management decisions at the producer level contribute to harvest losses in canola and that some producers can consistently achieve lower harvest losses than others. This also means that producers exert a significant amount of control over the losses incurred during canola harvest and that some reduction in proportional total harvest losses in canola is possible through improved management.

While the ranges in average proportional harvest losses among producers in Edmonton and Winnipeg were lower (5.1 and 4.4 %, respectively) and not statistically significant, the ranges in harvest losses among producers still were of biological importance in these regions and is it feasible that similar conclusions could be drawn in these regions. Some producers consistently achieved very low harvest losses indicating that there is considerable room for improvement and reductions in the total proportional canola harvest losses on some farms across western Canada. Within each region, no differences in total absolute canola harvest losses were observed among producers. Variation in yield among years likely contributed to these results.

Table 2. Minimum and maximum average proportional total harvest losses among producers in each region. P-values for differences among producers and the number of producers contributing to the analysis for each region are indicated and significant p-values are indicated in bold.

		Average Producer Harvest Losses (% of Yield)		
Region	# Producers	Min	Max	p-value
EDM	10	3.0	8.1	0.1529
LAC	17	2.3	9.4	**0.0101**
SAS	15	3.8	11.2	**0.0159**
WPG	21	2.2	6.6	0.3066

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3) Are on-farm harvest losses different for direct-harvested compared to swath-harvested canola?
Comparison of direct-harvested versus swath-harvested canola was done in Saskatchewan only where there were producers that used both methods of harvesting canola in the same year allowing for a direct comparison between these harvest methods. Lacombe was the other region where a few producers used the direct-harvesting system, however, a direct on-farm comparison was not possible at Lacombe. Over the three years of the study, no producers in the Winnipeg or Edmonton regions were found who direct-harvested their canola crops.

In the direct comparison between the harvest methods in Saskatchewan, absolute total harvest losses were higher in 2011 than in 2010 (Table 3) and a similar trend was observed in proportional total harvest losses. Lack of a difference in the total proportional harvest losses between the years was due to the combination of high variability in both harvest losses and total yield.

Table 3. Total yield, total harvest losses (absolute and proportional) and seedbank addition of canola as influenced by year.

	Yield	Harvest Losses		Seedbank addition
	kg / ha	kg / ha	% of Yield	Viable seeds m^{-2}
Year				
2010	2289 (130)	135 (22)	6.0 (0.9)	4404 (742)
2011	2671 (110)	221 (18)	8.3 (0.8)	6859 (610)
	*	**	NS	*
Mean	2509 (92)	184 (17)	7.3 (0.6)	5821 (534)

[a] Standard errors are indicated in parentheses
*, **, denote significance at the 0.05 and 0.01 probability levels, respectively.
NS - denotes not significant.

There was no difference in absolute or proportional total harvest losses, or seedbank additions between the swath-harvested and direct-harvested canola (Table 4) in Saskatchewan in 2010 and 2011. This agrees with observation by Price et al. (1996) in the UK who also reported no difference in seed loss between swath-harvest and direct-harvest methods in spring-planted canola under ideal weather conditions. Lack of a difference between the harvest methods is an

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encouraging result as it suggests no penalty for the direct-harvest method and the potential for a more efficient harvesting process that eliminates the swathing operation. Interestingly, no difference in canola yield was found between the harvest methods in this comparison. There have been anecdotal suggestions that the increased time for seed filling / maturation in direct-harvested canola may increase yield, however, this was not observed in this study.

There was however, a difference in Thousand kernel weight (TKW) between the two harvest methods. Lost seeds of the direct-harvested canola were about 7% larger in size than the seeds recovered from the windrowed canola. Whether this was a result of prolonged maturation and seed filling in the less mature, upper pods of the standing plants, or preferential losses of large seeds from lower pods is not known. Proportional total harvest losses in this comparison were relatively high. At what stage during the harvest process these relatively high harvest losses occurred in the swath-harvested treatments is not known, but this may contributed to the observed results.

In the present study, seed loss was compared between 15 windrowed and 12 direct harvested canola fields which were obtained from five producers who used both harvest methods. Therefore, further research is required on more fields and in more regions to better understand harvest losses between the two harvest methods.

Table 4. Total yield, total harvest losses (absolute and proportional), TKW and seedbank addition of canola as influenced by harvest method.

	Yield	Harvest Losses		TKW	Seedbank addition
Harvest Method	kg / ha	kg / ha	% of Yield	g	Viable seeds m^{-2}
Swath-harvested	2631 (169)	251 (49)	9.5 (1.7)	2.9 (0.1)	8210 (1628)
Direct-harvested	2629 (176)	257 (51)	10.4 (1.8)	3.1 (0.1)	7905 (1680)
$LSD_{0.05}$	NS	NS	NS	**	NS

[a] Standard errors are indicated in parentheses.
** denotes significance at the 0.01 probability level.
NS denotes not significant.

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4) What factors contribute to harvest losses in canola?

Combine Manufacturer and Type
The effect of individual combine type (rotary, conventional or hybrid) and manufacturer on harvest losses in canola where entire fields were harvested with one type of machine and for which a reasonable number of fields were available were subjected to statistical analysis. The hybrid combine type category was excluded due to insufficient replication.

Neither combine type, nor combine manufacturer had a significant effect on proportional or absolute total harvest losses in canola (Table 5). This analysis did not investigate the nuances of combine type and manufacturer in isolation and although there may have been differences in the contribution of these to the total harvest losses, combine type and manufacturer did not play an exclusive role in the on-farm harvest losses that were observed during this survey. For example, one might expect that rotary combines result in lower harvest losses than conventional combines and the multiple regression analysis below suggests that combine type indeed contributed to proportional total harvest losses. This specific analysis, however, indicated that other factors were more important in determining proportional and absolute total harvest losses in canola in a given season than the type and manufacturer of the combine that was used to harvest the crop.

Table 5. Proportional and absolute total harvest losses in canola as affected by combine manufacturer (JD = John Deere, NH = New Holland, IH = International Harvester) and type (Conventional vs. Rotary). The number of fields for each type and manufacturer as well as the p-values of the main effects and interactions are indicated.

Combine			Harvest Losses	
Type	Manufacturer	Field #	% of Yield	kg / ha
Conventional				
	JD	43	5.15	124.4
	NH	10	4.80	101.5
Rotary				
	IH	62	5.30	124.4
	JD	37	4.91	117.9
	NH	23	4.68	120.1
			p-value	
Manufacturer			0.7790	0.3838
Type			0.6428	0.6096
Interaction			0.9214	0.6376

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Fungicide Application at Flowering

Throughout this survey, about 42% of the fields were treated with a fungicide at flowering to prevent *sclerotinia*. An ANOVA was conducted to determine the effect of fungicide use on on-farm harvest losses in canola. Among the four regions, there were substantial differences in the proportion of fields to which fungicides were applied (Table 6) and this was taken into account in the ANOVA.

Overall, the application of a fungicide at the time of flowering resulted in an overall reduction in the proportional total harvest losses in canola of about 1.4%. Fungicide application at flowering did not affect absolute total harvest losses in canola which suggests that either the reduction in proportional total harvest losses was primarily the result of increased yield of the canola crop to which fungicides were applied, or more likely that fungicides were applied preferentially only to canola crops with high yield potential. Correlations in each region showed that fungicide applications were positively (Pearson R = 0.36 to 0.48) and significantly (p-values 0.0001 to 0.0031) correlated with crop yield, supporting these possibilities although they are difficult to separate in this survey. Moreover, higher yielding crops were associated with proportionally lower harvest losses, irrespective of fungicide use which further confounds this observation. In infested fields, use of fungicides may have influenced harvest operations by resulting in more even maturation of those crops in which fungicide use was warranted which may also have been a contributing factor. Based on these results, the 1.4% reduction in harvests losses alone that were attributable to the use of a fungicide at flowering was not sufficient to pay for the use and application of that fungicide. This however, does not include any potential yield benefits attributable to fungicide the application.

Table 6. Effect of fungicide application at flowering on proportional and absolute total on-farm harvest losses in canola averaged over 4 locations and three years. The number of treated and untreated fields are indicted for each region. Within columns, means followed by different letters are significantly different based on Fisher's protected least significant difference.

	Field # by Location				Harvest Losses		
Fungicide	EDM	LAC	SAS	WPG	% of Yield		Kg / ha
Yes	3	18	13	91	6.22	A	135.9
No	41	49	56	26	4.86	B	131.0

Canola Variety

The importance of canola variety to on-farm harvest losses was examined. A total of 32 different canola varieties were recorded throughout this survey, however, only the top four varieties were sufficiently abundant and evenly distributed among years and regions to include in

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a meaningful statistical analysis (Table 7). These four varieties stemmed from the same manufacturer and were grown on more than half (177 fields) of all sampled fields. When combined over years, no significant differences in proportional (5.2 to 6.3 %) or absolute (115 to 149 kg / ha) total harvest losses were observed among these four varieties.

The inherent potential for harvest losses due to pod drop or seed shatter among these four varieties is not known and these results do not prove that there are no inherent differences among these four varieties. Differences in seed shatter and pod drop among varieties is common and easily detected under more controlled conditions such as small plot studies (e.g. project 3.4.2, Wang et al. 2007), however, on producer's farms, many other management and environmental variables contribute to harvest losses in canola meaning subtle inherent differences in pod drop and seed shatter among varieties may be lost.

The range in harvest losses among the remaining 6 of the 10 most commonly grown varieties was similar, but slightly greater than among the top four varieties in proportional (4.5 to 6.6%) and absolute (90 to 180 kg/ha) values (Table 7). Although choice of variety may play a role in canola harvest losses, results from this survey suggest that this is not a dominant role and that other factors may be equally, or more important in contributing to total harvest losses in canola.

Table 7. Total fields in each region and total proportional and total absolute on-farm harvest losses by variety for the 10 most commonly grown varieties in this survey. Statistical analysis was conducted within the four most commonly grown varieties only and p-values for F-tests are indicated.

	Field # by Location				Harvest Losses			
Variety	EDM	LAC	SAS	WPG	% of Yield		kg / ha	
					Mean	SEM	Mean	SEM
IV5440	9	21	25	25	6.3	0.3	149.2	8.3
L150	2	4	10	26	5.3	0.4	114.9	10.3
L130	5	14	2	7	5.2	0.6	160.9	17.5
IV5770	0	0	6	21	6.1	0.5	119.7	10.8
p-value					0.6043		0.4599	
45H29	5	0	0	4	4.5	0.7	89.6	15.4
IV5030	0	0	2	7	5.9	0.8	144.9	27.1
7345RR	4	2	1	0	6.6	0.8	165.8	17.3
IV5020	3	3	0	0	5.5	1.7	140.4	42.0
IV8440	1	4	3	1	6.3	1.3	180.2	35.2
VT500	4	0	1	0	5.2	0.9	144.3	24.9

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Time of Swathing and Time of Combining
Producers were asked to indicate during what part of the day the harvest operations (swathing and combining) occurred. In many cases, however, harvest operations in any one field were not confined to only one part of the day. To test the hypotheses of whether time of day of swathing, or combining influenced proportional or absolute total harvest losses in canola, only the subset of fields in which swathing or combining occurred either only in the morning, or only in the afternoon, or only in the evening were used for this analysis.

For testing the time of day of swathing, a total of 119 fields were identified (Table 8). About one half of these were swathed in the afternoon and the rest were split, almost evenly, between morning and evening. No differences in the proportional or absolute total harvest losses were attributable to the time of day of swathing. It is generally accepted that shatter losses are reduced when the crop is swathed in the morning, however, examination of this factor alone did not reveal a significant effect on total harvest losses.

For testing the time of day of combining hypothesis, 123 fields were identified (Table 8). Only one of these fields was harvested in the morning and as a result, this field and time of combining was excluded from the analysis. About 80% of the fields were harvested in the afternoon and the remainder in the evening. Similarly, time of day of combining alone, could not be identified as a significant factor contributing to total harvest losses.

Table 8. Effect of time of day of swathing and time of day of combining on proportional and absolute total harvest losses in canola. The number of fields for each category and p-values for the F-tests are indicated.

	Field #	Harvest Losses	
Operation / Time		% of Yield	kg / ha
Swathing			
Morning	36	6.9	155.0
Afternoon	50	5.4	148.8
Evening	33	5.6	133.9
p-value		0.0704	0.2748
Combining			
Morning	1	n/a	n/a
Afternoon	103	5.6	132.1
Evening	19	5.9	178.4
p-value		0.8048	0.3545

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Continuous variables that affected harvest losses

The remaining 17 variables that were measured and related to harvest losses in this study were comprised of continuous data. To determine their individual contributions to harvest losses in canola and illustrate any regional differences, correlations between each of these variables and proportional or absolute total harvest losses were conducted within each location. A combined analysis including all locations was also conducted. Before the correlations, influential outliers were removed and variables were log or square root transformed to approach normality when necessary. For the combined analysis, response and explanatory variables were standardized to unit standard deviations within locations to minimize the potential of regional bias in the explanatory and response variables. Only correlations with proportional total harvest losses were presented (Table 9). Correlations with absolute total harvest losses were similar although the sign was reversed for the yield explanatory variable.

A number of the explanatory variables were correlated with proportional total harvest losses, however, the total number of explanatory variables (3 to 5) and the specific variables that were associated with harvest losses were not always the same among the regions (Table 9). This illustrated regional differences in the importance of individual variables and their contributions to total harvest losses in canola. In the combined analysis among all regions, three explanatory variables correlated with yield loss. These included two harvest management variables (Julian date of swathing and combine speed) and canola yield which is affected by other management and environmental variables. This is an encouraging result as these variables are all under the control of the producer to some extent.

In three of four regions and overall, increased canola yield was associated with decreased proportional total harvest losses, making it the most consistent in direction and the most strongly correlated variable with on-farm harvest losses in canola (Table 9). This correlation was also the strongest with absolute total harvest losses, but was positive (Pearson $R = 0.28$) indicating an increase in absolute total harvest losses with increasing canola yield (data not shown). Canola yield is influenced by many factors. Increased yield may have contributed to more even and rapid maturation in crops where insufficient stand density (e.g. Saskatchewan region) may have been a yield limiting factor. It is important to emphasize that these results clearly indicate that harvest management and harvest losses begin as early as the time of planting a canola crop.

The second most consistent explanatory variable that was correlated with canola harvest losses was the Julian day of swathing, although the relationship was not in the same direction in all regions (Table 9). In two of four regions and overall, an earlier swathing date was associated with reduced proportional total harvest losses in canola. Earlier swathing suggests an earlier planted and/or earlier maturing crop and possibly a crop that matured more evenly. This would facilitate easier selection of the appropriate time to swath a canola crop. Interestingly, in Saskatchewan, the correlation between swathing date and proportional harvest losses was negative. It is not

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clear why swathing at a later time would be associated with decreased proportional harvest losses in canola in this region over three years. Julian date of swathing and farm size were the only explanatory variables that showed inconsistent significant relationships to harvest losses among regions. Reasons for the inconsistent relationship between farm size and harvest losses also are not clear.

Other explanatory variables that affected proportional total harvest losses either regionally or overall included farm specific variables (farm size and total canola acres), harvest management variables (harvest date and combine speed) and the environmental variable, average maximum wind speed. Increased combine speed was related to increased harvest losses and while only significant overall and in the Winnipeg regions, trended in the same direction in all regions. The particularly long, dry summers and harvest seasons in Manitoba in 2011 and 2012 may have contributed to the ability to operate the combine at higher speeds. Increased combine ground speed is likely associated with increased harvest losses at the front of the combine, but may also contribute to higher losses at the back of the combine. Yield monitors and other tools are available to measure harvest losses at the back of the combine and producers tend to be concerned about and check for harvest losses at the back of the combine. Harvest losses at the pickup, however, are much more difficult to detect and are likely directly related to travel speed. Combine ground speed has been shown to influence harvest losses and seed quality in soybean (Mequita et al. 2006). Similar data for canola does not appear to be available in the literature.

Average maximum wind speed, the only environmental factor tested in this survey was negatively correlated with proportional total harvest losses. Overall, this correlation was as strong as many others, but, was significant only in the Lacombe region. Lacombe and Edmonton were regions where the duration between swathing and harvest was greatest on average, however, the impact of wind was only significant at Lacombe. Moreover, average regional wind speeds were greatest in the Winnipeg region (48 km / hr vs. 35-39 km / hr) indicating that although wind may contribute to increased harvest losses, the role of wind relative to other factors is not entirely clear. Unfortunately, wind data was regional and not available for each specific field which may have contributed to the observed results. Other measures of wind were also correlated to harvest losses including cumulative wind speed (sum of daily max wind speeds) and the number of days with maximum wind speeds above 30, above 40, and above 50 km/hr, however, it was found that all these measures were highly correlated and that average maximum wind speed correlated best with total proportional harvest losses in canola.

Maturity of the canola crop at the time of swathing did not correlate significantly with harvest losses. This was a bit surprising because previous research has indicated increased pre-swathing harvest losses when the crop is swathed at a lower seed moisture content (Bowren and Pittman 1975). It is likely that producer's ratings of the degree of crop maturity are more subjective than

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objective and this would contribute to decreasing or even negating the significance of any association between crop maturity and harvest losses.

Interestingly, total canola acreage was correlated negatively with proportional total harvest losses in canola in the Lacombe and Winnipeg regions. One would hypothesize that optimizing the time sensitive canola harvest operations to minimize harvest losses on farms with greater canola acreage would be difficult to achieve and harvest losses might increase, however, in these regions, the data indicate exactly the opposite. Correlations with other explanatory variables did not reveal any specific reasons for this observation and these results may be related to farmer experience and intuition with harvesting canola.

Table 9. Correlations between explanatory variables and proportional (percent yield loss) harvest losses among each region and overall.

Location	EDM		LAC		SAS		WPG		ALL[a]	
Number of fields	44		67		69		118		286	
	Pearson R									
Farm specific										
Farm Size	**0.40**	**	**-0.28**	*	0.03		-0.08		-0.02	
Total Canola Acres	0.34		**-0.31**	*	0.08		**-0.21**	*	-0.06	
Proportion Canola	-0.11		0.19		-0.17		0.00		0.00	
Field specific										
Field Size	0.13		-0.02		-0.09		-0.05		-0.04	
Years since canola	0.26		0.25		0.13		-0.05		0.09	
Seeding Rate	0.10		-0.18		-0.21		-0.04		-0.09	
Stubble density	-0.06		0.13		**-0.43**	*	0.11		-0.02	
Nitrogen fertility	0.14		-0.08		-0.14		-0.14		-0.10	
Canola Yield	**-0.37**	**	-0.03		**-0.25**	*	**-0.19**	*	**-0.19**	**
Harvest management										
Maturity at Swathing	0.09		0.17		0.09		0.06		0.09	
Swathing Date	**0.45**	**	0.04		**-0.28**	*	**0.24**	*	**0.13**	*
Swather Width	0.01		-0.16		0.00		0.06		0.00	
Swather Speed	0.14		-0.05		-0.10		-0.08		-0.05	
Harvest Date	0.28		0.00		-0.17		**0.25**	**	0.10	
Days in Swath	-0.17		0.13		0.01		0.05		-0.00	
Combine Speed	0.32		0.11		0.08		**0.23**	*	**0.18**	**
Environment										
Avg. Max Wind Speed	-0.33		**-0.29**	*	0.21		-0.09		-0.08	

[a] correlations using standardized coefficients
* p < 0.05 to <0.01; ** p <0.001 to 0.01; ***p<0.001

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Most significant variables affecting harvest losses in canola

To determine which explanatory variables were most influential on proportional and absolute total harvest losses in canola across western Canada, a multiple regression approach was used. TO determine the relative importance of explanatory variables, the standardized coefficients were used for the continuous variables (see previous section) and all discrete variables with fewer than 4 levels [location (EDM, WPG, LAC, SAS), year (2010, 2011, 2012), combine type (Conventional, Rotary), time of swathing operation (Morning, Afternoon, Evening), time of harvest (Morning, Afternoon, Evening)] were included in the initial multiple regression model. The large number of explanatory variables (32) precluded this analysis within region as about 10 observations per explanatory variable are necessary to meet the requirements of the analysis. The best fitting model, selected via the lowest AIC, BIC and SBC criteria, was chosen after removal of influential collinear (highly correlated) variables which were defined using the tolerance and variance inflation criteria. The standardized coefficients of the explanatory variables which indicate the relative influence of each of these and through the sign, the direction in which they influenced harvest losses of the models with the lowest AIC / BIC / SBC are presented below.

Only three or four explanatory variables contributed significantly to the best fitting model and the best fitting models explained only a relatively small portion of the total variation (13% of the proportional total harvest losses and 20% of the absolute total harvest losses). For both measures of harvest losses, the year 2011, combine ground speed and canola yield were the main explanatory variables with a reversal in sign for the effect of yield on proportional vs. absolute harvest losses. Proportional canola harvest losses also were explained, in part, by the use of rotary combine separators, which contributed to lower (negative coefficient) harvest losses. Additional explanatory variables that were not significant, but contributed to the low AIC included proportion of canola, seeding rate and average maximum wind speed for proportional harvest losses and proportion of canola, swather speed and combining in the evening for absolute harvest losses.

The low R^2 and the fact that in both regressions the year 2011 played one of the most important roles to increasing (positive standardized coefficient) proportional and absolute total harvest losses suggests that environmental parameters not captured by average maximum wind speed may have been a significant determinant of harvest losses in canola. Of course, environment also affects yield and the timing of harvest processes which further reinforces the notion that harvest losses in canola are a complex phenomenon that is difficult to explain even with a large number of explanatory variables. The correlation analysis showed that many explanatory variables were correlated with each other to varying degrees and that their effects on harvest losses were not independent (data not shown). For example, harvest and swathing dates would be influenced by environmental conditions and canola yield, which is also affected by environment, also dictates the ground speed at which swathers and combines can be operated. A number of other examples of correlations among explanatory variables were observed.

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Despite the importance of environment and its possible interaction with other explanatory variables, key management variables also contributed significantly to explaining harvest losses in canola. For proportional total harvest losses, combine ground speed and a rotary combine separator were of similar importance to predicting harvest losses as was canola yield. The remaining explanatory variables (proportion of canola, seeding rate and average maximum wind speed) were of similar, but lower importance and were contributing, but not significant predictors of harvest losses.

Similar results were observed when predicting absolute total harvest losses with the exception that combine type was no longer a contributing variable and the non-significant variables seeding rate and average maximum wind speed were replaced by non-significant contributors swathing speed and combining in the evening; both were negatively related to absolute total harvest losses. Reduced harvest losses when combining in the evening were likely related to reduced shattering as there was no correlation between combine ground speed and combining in the evening (R = -0.045, p-value 0.4676).

Similar to the correlation analysis, the multiple regression approach pointed at key management techniques that are under the control of the producer and likely contributed to the differences in harvest losses observed among producers. These management variables could be altered to reduce harvest losses in canola. Similar to the correlation analysis, these variables included crop yield and factors that affect crop yield as well as harvest management, principally combine ground speed and separator type.

Table 10. Model parameters of farm specific, field specific, harvest specific and environmental explanatory variables as well as model R2 and observations used for the best model describing total proportional and total absolute harvest losses in canola. Standardized parameter estimates and p-values for each parameter estimate are included. Significant parameters are indicated in bold and contributing parameters are not bolded.

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	Harvest losses			
	% of Yield		kg / ha	
Adjusted R-square	0.13		0.20	
Observations used	232		222	
	Std. Est.	p-value	Std. Est.	p-value
Farm specific				
Proportion Canola	-0.090	0.1587	-0.071	0.2599
Field specific				
Seeding Rate	-0.093	0.1396		
Canola Yield	**-0.200**	**0.0017**	**0.380**	**0.0001**
Harvest management				
Swather Speed			-0.099	0.1202
Combine evening			-0.087	0.1640
Combine Speed	**0.204**	**0.0024**	**0.231**	**0.0003**
Rotary Combine	**-0.222**	**0.0038**		
Environment				
Avg. Max Wind Speed	-0.118	0.0581		
2011	**0.273**	**0.0003**	**0.217**	**0.0005**

Conclusions

This study confirmed results from a small, regional study, but more importantly also expanded our understanding of on-farm harvest losses in canola and the factors that contribute to these. Overall, total on-farm harvest losses in canola are a complex phenomenon with many interacting variables that are difficult to separate. Nevertheless, this study clearly indicated that management of harvest losses begins at the time of planting canola.

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Harvest management also was found to be an important contributor to harvest losses in canola and combine speed and combine separator type contributed significantly to harvest losses, although combine separator type could not be identified as a contributing factor in the individual factor analysis. Alternatively, fungicide use at flowering was identified as an individual factor to reduce proportional harvest losses, but was not identified as a contributing variable in the multiple regression analysis. Concentrated regional use of fungicides may have contributed to this. It is likely that these canola crop and harvest management variables were among the leading factors that contributed to the consistent differences in total harvest losses that were observed among producers and clearly indicate that producers have some level of control over the amount of canola seed that is left behind in the field after harvest.

Interestingly, no differences in total harvest losses between direct-harvested and swath-harvested canola were identified. These results were very encouraging but it must be noted that they were based on a regional subset of data collected over two years of this study. To more clearly answer this question, a more intensive on-farm examination of direct-harvesting in comparison to swath-harvesting canola may be warranted if and when direct-harvesting becomes more prominent.

Environmental factors (the significance of year) also played an important role in harvest losses in canola, but these were not exclusively related to wind speeds as indicated by the correlation and multiple regression approaches. A more thorough understanding of the role of environmental variables and how they influence and relate to harvest processes in canola is necessary to improve our understanding of and ability to predict harvest losses in canola.

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