ADF Project Progress Report Format

1. ADF file number, Project title, and reporting period.

ADF File #: 20150338. Title: The Effect of Pre-harvest Glyphosate on Quality of Milling Oats
Reporting Period: Final Report: May 1, 2016 to December 1, 2019

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2. Specify project activities undertaken during this reporting period.

Oat (*Avena sativa* L.) is an important cereal crop in western Canada. From 2015 to 2017, 1 295 700 ha (i.e. 3 201 739 acres) were seeded to oat in Saskatchewan and total production during those years averaged 3.4 tonnes ha^{-1} (Statistics Canada, 2018a). From January 1 to December 31, 2017 Canada exported a total of 1 527 358 tonnes of oat (Statistics Canada, 2018b). Harvest aids and desiccants can be an effective tool to improve crop quality and harvest efficiency by reducing or eliminating the presence of actively growing weeds, and enhancing the dry down of the crop (Griffin et al. 2010; Yenish and Young 2000). Glyphosate is a non-selective systemic herbicide that can be very effective as a desiccant when applied appropriately. In corn (*Zea mays* L.), glyphosate should only be applied as a desiccant when the grain moisture if 35% or less and when the crop is physiologically mature (Griffin et al. 2010). While glyphosate can provide very effective dry-down, if applied too early it can affect seed quality and germination (Yenish and Young 2000). Since glyphosate translocates from sources to sinks within the plant, it is possible that the herbicide will end up in the grain after application in minimal amounts. This detection can cause concern regarding consumption of such products and their use in processing.

a.) **Methodology:** *Include approaches, experimental design, tests, materials, sites, etc. Please note that any significant changes from the original work plan will require written approval from the Ministry.*

Experiment 1: Effect of pre-harvest glyphosate application timing on oat yield and seed physical and functional qualities.

The objective of this research was to examine the effect of glyphosate applied at various seed moisture content on seed quality, and to compare this with swathing treatments conducted at the same timing. This experiment was conducted at two locations in 2016, 2017, and 2018: Kernen Research Farm (clay loam soil) and Goodale Research Farm (loam soil). The experiment consisted of two factors: harvest method (pre-harvest glyphosate @ 900 g ai ha^{-1} and swathing) and timing (60, 50, 40, 30, and 20% seed moisture content (SMC). There was also a direct harvested check that was harvested at 12.5 % SMC. In 2016, 39 mm of rain fell 10 days prior to the first application timing at Kernen resulting in the missing of the 60, 50 and 40% SMC treatments. In all other site years, treatments were applied at the appropriate time. The experimental design was a RCBD with 4 replicates and plot size was 4m wide x 8m long. Oat (*cv.* AC Morgan) was seeded at 350 seeds m^{-2} in May on canola and wheat stubble at the Goodale and Kernen sites, respectively. Specific dates for field operations can be found in Tables 1, 2 and 3. Experimental areas received a pre-seed application of glyphosate @ 675 g ae ha^{-1}. Fertilizer was applied based on soil test recommendations to achieve a target yield of 5900 kg ha^{-1}. Stellar^{TM} (florasulm + fluroxypyr + MCPA ester) and Curtail^{TM} M (clopyralid + MCPA ester) were applied at labelled rates at Kernen and Goodale, respectively to control broadleaf weeds. Priaxor® was applied to control leaf diseases when pressure warranted application. Swath treatments were cut with a 4.2 m swather at the inidciated seed moisture contents. Visual ratings of desiccation progress were made at 3, 7, 14, and 21 days after application (DAA) based on the Canadian Weed Science Society 0 to 100 rating scale. On this scale, 80% represents commercially acceptable weed control, whereas 70 to 80% represents commercially acceptable weed suppression. The visual ratings were used to calculate an area under the desiccant progress curve (AUDPC):

$$AUDPC = \left(\frac{D_1+D_2}{2}\right)(t_2 - t_1) + \left(\frac{D_2+D_3}{2}\right)(t_3 - t_2) + \left(\frac{D_3+D_4}{2}\right)(t_4 - t_3) \quad [1]$$

where D_1, D_2, D_3, and D_4 represent observed desiccation ratings at each evaluation day; t_1, t_2, t_3, and t_4 represent the number of the days after each herbicide application (Jeger and Viljanen-Rollinson 2001; Simko and Piepho 2012). The four desiccation ratings were converted into a single relative value for reporting via the AUDPC equation, which models the progression of desiccation between ratings (McNaughton et al. 2015). Oats were harvested with a small plot combine at maturity. Harvested seeds were dried for one week at room temperature (21 C) to a constant moisture, cleaned, and the weight of the seed was recorded. Seed moisture content was recorded at the time of harvest. The weight of 1000 seeds (TSW) was determined by weighing 250 seeds and multiplying by four. Test weight, % plump and % thin kernels were also determined from seed samples. Seed samples were retained and sent to Dr. Nancy Ames, AAFC, Winnipeg for further testing for functional quality.

Dehulling and Milling Quality

Dehulling of oat samples was performed on a Codema oat dehuller using 70 g whole oats as starting material with 1.5 minutes dehulling time and the percentage of hull was calculated. After dehulling groats were stored at -27 ˚C or colder until the time of analysis. The crude groat portion was collected from the Codema and hand sorted into intact groats, broken groats, whole oats, loose hulls and any contaminating seeds, which were weighed separately and used to calculate groat percentage, percent groat breakage, hulls and whole oats remaining after dehulling and milling yield. Milling yield was calculated as per Doehlert et al., 1999(1) and is defined as the kilograms of whole oats required to yield 100 kg of clean groats, therefore a lower value is desirable. Colour measurement was done on cleaned, intact groats using a Minolta Chromo Meter CR-410 to obtain values for L*, a* and b* colour scales where higher L* values indicate increased lightness, higher positive a* values indicate increased redness and higher b* values indicate increased yellowness.

Groat Composition and Flour Pasting Properties

Oat groats were milled using a Retsch ZM200 Centrifugal Mill to pass through a 0.5mm screen to produce wholemeal flour. Wholemeal was stored at -27 ˚C or colder until the time of analysis. AACC International Approved Methods for moisture content (method 44-15.02(2)), beta-glucan content (method 32-23.01(3)), protein content (%N × 6.25; Flash 2000 Nitrogen/Protein Analyzer; method 46-30.01(4)) and total starch content (method 76-13.01(5)) were performed and are presented on a percent, dry basis (db). The Rapid Visco-Analyser was used to test wholemeal flour for alpha-amylase activity/stirring number (method 22-08(6)) and oat pasting properties (76-22.01 (7)).

Flaking Quality

Samples were processed into rolled oats using laboratory scale heat-moisture treatment to mimic industrial kilning followed by flaking on a 18 x 6 Dual Drive Laboratory Flaking Mill (Ferrell-Ross). Sealed glass jars containing 80 g of cleaned, intact groats previously tempered to 20% moisture content were placed a closed steamer for 40 minutes, whereby reaching a temperature of 95 to 100 ˚C. Hot, steamed groats were immediately fed into the feeder of the flaking mill and flattened using a consistent roll gap for all samples.

Flake samples were collected, spread in an open container no thicker than 1 cm deep and allowed to cool/dry for approximately 16 hours before storing in plastic bags at -27 ˚C or colder until the time of analysis . Flake thickness was measured with a digital micrometer taking an average of 10 flakes. Colour measurement of the flake samples was done as described above for groats. Flake granulation was determined by sifting a 50 g sample over U.S. Standard Test Sieves (No. 6 = 3.35 mm; No. 8 = 2.36 mm; No. 12 = 1.7 mm) on a Ro-Tap shaker. The proportions of flakes remaining on top of each sieve and collected through the smallest sieve into the bottom pan were calculated and expressed as a percentage. Sub-samples of flakes were ground into flour (Retsch ZM200 Centrifugal Mill equipped with a 0.5mm screen) and analyzed for differences in pasting properties using the Rapid Visco-Analyser according to AACC International Approved Method for oat pasting properties (76-22.01 [(7)]).

Residue Analysis
A subset of samples was chosen for glyphosate residue analysis including only the glyphosate treated plots grown at both locations in 2017. Both groat and flake samples were ground (Retsch ZM200 Centrifugal Mill equipped with a 0.5mm screen) and sent to the Grain Research Laboratory, Canadian Grain Commission for analysis, which was performed using FMOC derivatization with LC-HRMS (based on Tittlemier et al. 2017[(8)]) with added cleanup step to separate gelatinous mix.

Statistical analysis
The data was analyzed using SAS statistical software version 9.4 (SAS Institute Inc, Cary, NC). Analysis of Variance (AVOVA) was performed using a generalized Linear Model by following a Proc Glimmix procedure. The means were compared using Dunnet test ($p \leq 0.05$) and direct harvest method was used as a control in the Timing Study.

Table 1. Specific dates for field operations at the Kernen Research Farm and Goodale Research Farm near Saskatoon, SK in 2016.

	Seeding Date	Swath Date	Spray Date	Target Seed Moisture (%)	Application Moisture (%)	Harvest Date
Kernen	May 30	n.a.	n.a.	60	n.a.	Aug 22
		n.a	n.a.	50	n.a.	Aug 22
		Aug 11	Aug 11	40	34	Aug 22
		Aug 15	Aug 15	30	31	Aug 22
		Aug 18	Aug 18	20	17	Aug 22
Goodale	May 25	Aug 11	Aug 11	60	51	Sept 9
		Aug 15	Aug 15	50	44	Sept 9
		Aug 18	Aug 18	40	40	Sept 9
		Aug 23	Aug 23	30	34	Sept 9
		Aug 29	Aug 29	20	23	Sept 9

Table 2. Specific dates for field operations at the Kernen Research Farm and Goodale Research Farm near Saskatoon, SK in 2017.

	Seeding Date	Swath Date	Spray Date	Target Seed Moisture (%)	Application Moisture (%)	Harvest Date
Kernen	May 12	July 26	July 26	60	61	Aug 18
		Aug 3	Aug 3	50	50	Aug 18
		Aug 10	Aug 10	40	41	Aug 22
		Aug 13	Aug 13	30	33	Aug 22
		Aug 18	Aug 18	20	22	Aug 22
Goodale	May 11	July 26	July 26	60	57	Aug 18
		July 29	July 29	50	50	Aug 18
		Aug 2	Aug 2	40	41	Aug 18
		Aug 9	Aug 9	30	30	Aug 24
		Aug 14	Aug 14	20	21	Aug 24

Table 3. Specific dates for field operations at the Kernen Research Farm and Goodale Research Farm near Saskatoon, SK in 2018.						
	Seeding Date	**Swath Date**	**Spray Date**	**Target Seed Moisture (%)**	**Application Moisture (%)**	**Harvest Date**
Kernen	May 24	July 26	July 26	60	59	Aug 30
		Aug 1	Aug 1	50	48	Aug 30
		Aug 10	Aug 10	40	40	Aug 30
		Aug 15	Aug 15	30	28	Aug 30
		Aug 21	Aug 21	20	17	Aug 30
Goodale	May 16	July 24	July 24	60	59	Aug 23
		July 30	July 30	50	49	Aug 23
		Aug 3	Aug 3	40	41	Aug 23
		Aug 10	Aug 10	30	34	Aug 23
		Aug 17	Aug 17	20	18	Aug 23

Experiment 2: Agronomic factors and harvest management impacts on oat yield and seed quality

The objective of this experiment was to assess whether plant densities and varietal maturity interacted with harvest method with regard to oat yield and quality. The hypothesis was low densities of late maturing cultivars would have green tillers at glyphosate application timing, this contributing to potential problems. This experiment was conducted at two locations in 2016, 2017, and 2018: Kernen Research Farm (clay loam soil) and Goodale Research Farm (loam soil). The experiment consisted of three factors: oat cultivar (CDC Dancer – early maturing; Pinnacle – very late maturing), seeding rate (250 and 500 seeds m^{-2}), and harvest method (pre-harvest glyphosate @ 900 g ai ha^{-1}, swathing, and direct harvest). The experimental design was a RCBD with 4 replicates and plot size was 4m wide x 8m long. A summary of dates of field operations from 2016 – 2018 can be found in Tables 4, 5 and 6. Experiments were seeded on canola stubble and wheat stubble at the Goodale and Kernen sites, respectively. Experimental areas received a pre-seed application of glyphosate @ 675 g ae ha^{-1}. Fertilizer was applied based on soil test recommendations to achieve a target yield of 5900 kg ha^{-1}. Stellar^{TM} (florasulm + fluroxypyr + MCPA ester) and Curtail^{TM} M (clopyralid + MCPA ester) were applied at labelled rates at Kernen and Goodale, respectively to control broadleaf weeds. Priaxor

® was applied in July to control leaf diseases when pressure warranted application. Swath treatments were carried out with a 4.2 m swather. Data collection included drydown visual ratings, seed yield, SMC, thousand kernel weight, test weight, % plump and % thin kernels. Seed samples were retained and sent to Dr. Nancy Ames, AAFC, Winnipeg for further testing for functional quality. For seed composition and quality analyses, the same methodologies were followed as in Experiment 1, described above, with the exception on flake water absorption. The water absorption capacity of flakes was measured according a modification to the AACC International Approved Method 56-40.01[9] whereby a sample weight of 25 g of oat flakes was used instead of 50g. Means were compared using the Tukey Honest significant difference method ($p \leq 0.05$) using JMP 14 statistical software (SAS Institute Inc, Cary, NC).

Table 4. Specific dates for field operations at Kernen Research Farm and Goodale Research Farm near Saskatoon, SK in 2016.

					250 seeds m^{-2}			500 seeds m^{-2}		
		Harvest Method	Seeding Date	Target Moisture (%)	App Date	App moisture	Harvest	App Date	App moisture	Harvest
Kernen	Dancer	Desiccate	May 25	30	Aug 19	33	Aug 30	Aug 19	28	Aug 30
		Swath		30-35	Aug 18	33	Aug 30	Aug 18	28	Aug 30
		Straight		12.5	.	.	Sept 9	.	.	Sept 9
	Pinnacle	Desiccate	May 25	30	Aug 19	35	Aug 30	Aug 19	31	Aug 30
		Swath		30-35	Aug 18	35	Aug 30	Aug 18	31	Aug 30
		Straight		12.5	.	.	Sept 9	.	.	Sept 9
Goodale	Dancer	Desiccate	May 25	30	Aug 23	35	Sept 6	Aug 23	27	Sept 6
		Swath		30-35	Aug 23	35	Sept 6	Aug 23	27	Sept 6
		Straight		12.5	.	.	Sept 6	.	.	Sept 6
	Pinnacle	Desiccate	May 25	30	Aug 29	31	Sept 14	Aug 29	29	Sept 14
		Swath		30-35	Aug 29	31	Sept 14	Aug 29	29	Sept 14
		Straight		12.5	.	.	Sept 14	.	.	Sept 14

Table 5. Specific dates for field operations at Kernen Research Farm and Goodale Research Farm near Saskatoon, SK in 2017.

					250 seeds m^{-2}			500 seeds m^{-2}		
		Harvest Method	Seeding Date	Target Moisture (%)	App Date	App moisture	Harvest	App Date	App moisture	Harvest
Kernen	Dancer	Desiccate	May 12	30	Aug 13	29	Aug 22	Aug 10	32	Aug 22
		Swath		30-35	Aug 13	29	Aug 22	Aug 10	32	Aug 22
		Straight		12.5	.	.	Aug 22	.	.	Aug 22
	Pinnacle	Desiccate	May 12	30	Aug 16	31	Aug 22	Aug 14	29	Aug 22
		Swath		30-35	Aug 16	31	Aug 22	Aug 14	29	Aug 22
		Straight		12.5	.	.	Aug 29	.	.	Aug 29
Goodale	Dancer	Desiccate	May 21	30	Aug 9	31	Aug 24	Aug 9	29	Aug 24
		Swath		30-35	Aug 9	31	Aug 24	Aug 9	29	Aug 24
		Straight		12.5	.	.	Sept 1	.	.	Sept 1
	Pinnacle	Desiccate	May 21	30	Aug 16	30	Aug 24	Aug 14	29	Aug 24
		Swath		30-35	Aug 16	30	Aug 24	Aug 14	29	Aug 24
		Straight		12.5	.	.	Sept 1	.	.	Sept 1

Table 6. Specific dates for field operations at Kernen Research Farm and Goodale Research Farm near Saskatoon, SK in 2018.

					250 seeds m^{-2}			500 seeds m^{-2}		
		Harvest Method	Seeding Date	Target Moisture (%)	App Date	App moisture	Harvest	App Date	App moisture	Harvest
Kernen	Dancer	Desiccate	May 24	30	Aug 20	32	Aug 31	Aug 17	33	Aug 31
		Swath		30-35	Aug 20	32	Aug 31	Aug 17	33	Aug 31
		Straight		12.5	Aug 30	14.8	Aug 31	Aug 30	15.6	Aug 31
	Pinnacle	Desiccate	May 24	30	Aug 20	35	Aug 31	Aug 17	33	Aug 31
		Swath		30-35	Aug 20	35	Aug 31	Aug 17	33	Aug 31
		Straight		12.5	Aug 30	16.8	Aug 31	Aug 30	13.1	Aug 31
Goodale	Dancer	Desiccate	May 28	30	Aug 14	30%	Aug 23	Aug 10	34%	Aug 23
		Swath		30-35	Aug 14	30%	Aug 23	Aug 10	34%	Aug 23
		Straight		12.5	Aug 23	18%	Aug 23	Aug 23	13.5%	Aug 23
	Pinnacle	Desiccate	May 28	30	Aug 17	30%	Aug 23	Aug 14	33%	Aug 23
		Swath		30-35	Aug 17	30%	Aug 23	Aug 14	33%	Aug 23
		Straight		12.5	Aug 23	15.7%	Aug 23	Aug 23	13.4%	Aug 23

Experiment 3: Combining cultural practices and post-emergence herbicides to manage perennial broadleaf weeds in oat

The objective of this study was to determine if we could combine optimal cultural practices with herbicide timing to better manage perennial weeds in oat crops. This experiment was conducted on two parcels of leased land: one 6km east of Saskatoon (2016) and the other was approximately 5 km north east of the Kernen Research Farm (2017). These sites had similar soil textures and an inconsistent infestation of Canada thistle (*Circium arvense* L. Scop.), dandelion (*Taraxacum officinale* F.H. Wigg.), perennial sow-thistle (*Sonchus arvensis* L.), and field horsetail (*Equisetum arvense* L.). The experiment consisted of three factors: seeding rate (250 and 450 seeds m^{-2}), post-emergence herbicide (untreated, bromoxynil-MCPA at 280 + 280 g ai ha^{-1}, and florasulam + clopyralid + MCPA at 5 + 75 + 415 g ai ha^{-1}), and pre-harvest herbicide (untreated, glyphosate at 900 g ai ha^{-1}). The experimental area received a pre-seed glyphosate treatment of 675 g ai ha^{-1}

prior to seeding. AC Morgan was seeded on wheat stubble on May 17 in 2016 and on May 18 in 2017. Fertilizer was applied based on soil test recommendations to achieve a target yield of 5900 kg ha^{-1}. Post-emergence herbicides were applied at the 3-4 leaf stage of oat (June 22, 2016; June 20, 2017). Pre-harvest applications were applied on September 15 in 2016 and August 22 in 2017. Data collection included crop emergence, weed ratings, and crop yield. The most important data was collected in the spring of 2018, when perennial weed counts were conducted. Residual dandelion counts were conducted in the spring of 2017 on the 2016 experiment to determine the effect of the 2016 treatments on perennial weed densities.

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

Objectives	**Progress**
1) To determine the effect of application timing of pre-harvest glyphosate on oat yield, as well as seed physical and functional qualities;	FINISHED: Experiments have been conducted as per protocol at both locations.
2) To investigate the interaction of cultural practices with pre-harvest glyphosate on seed physical and functional quality;	FINISHED: Experiments have been conducted as per protocol at both locations.
3) To investigate alternative cultural / herbicide combinations for managing perennial weeds.	FINISHED: Experiments have been conducted as per protocol at a single site is it was very difficult to find sites with appropriate weed densities.

add additional lines as required

c.) Discussion: *Provide discussion necessary to the full understanding of progress made during this reporting period and the relevance of any findings. Detail any major concerns or project setbacks.*

Environmental Conditions: 2016 – 2018

Table 1. Mean monthly temperature (°C) and precipitation (mm) data at the Kernen Crop Research Farm (Saskatoon, SK) from 2016 – 2018.

Year	May	June	July	August	September	Average/Total
	----------------------------------*Mean Temperature (°C)*------------------------------------					
2016	13.5	17.6	18.4	16.9	12.0	15.7
2017	11.6	16.0	19.5	17.8	13.1	15.6
2018	14.49	17.67	18.88	16.81	6.78	14.9
Long Term Average*	10.4	15.5	18.5	17.3	12.9	14.9
	----------------------------------*Precipitation (mm)* ---					
2016	49.6	46.4	66.6	81.0	27.8	271.4
2017	56.0	43.6	32.4	30.0	46.4	208.4
2018	36.4	20.6	47.0	27.4	42.0	173.4
Long Term Average*	40.3	67.2	62.5	48.0	27.0	245.0

* Historical weather data collected from Kernen Crop Research Farm Weather Station: 2007 - 2017

Experiment 1: Effect of pre-harvest glyphosate application timing on oat yield and seed physical and functional qualities.

Statistical analysis

Due to a protocol error, all data from Kernen 2016 was eliminated from the final analysis. All remaining site years were combined for statistical analysis of the following variables: plant dry-down, seed moisture content at harvest, seed yield, thousand kernel weight, test weight, and percent plump and thin kernels. Data was analyzed using the PROC GLIMMIX procedure of SAS 9.4 (SAS Inst. 2016). The fixed effects in this model were application timing and harvest method, while the random effects were site, replication nested within site, and all site interactions with fixed factors. The COVTEST showed that all data could be combined across site years – however, doing so eliminated any significant treatment effect in the seed quality data. Therefore, all seed quality data is presented by site year.

Plant drydown (AUDPC)

The three visual ratings at 7, 14 and 21 DAA for each treatment were used to determine desiccation progress over time, which is calculated by the area under the desiccation progress curve (AUDPC):

$$AUDPC = (\frac{D_1 + D_2}{2})(t_2 - t_1) + (\frac{D_2 + D_3}{2})(t_3 - t_2)$$

where D1, D2, and D3 represent observed desiccation ratings at each evaluation day; t1, t2, and t3 represent the number of the days after each herbicide application. The AUDPC equation was used to convert the three desiccation ratings into a single relative value for the purpose of reporting; the greater the calculated AUDPC value, the further desiccation had progressed between ratings.

Glyphosate timing consistently had an effect across all site years (Table 2). As has been previously reported, applying glyphosate at 60% SMC resulted in a higher AUDPC value than straight combining at Goodale, and applications ≥ 40% SMC resulted in higher AUDPC than straight combining at Kernen. Overall, when glyphosate is applied at or above 40% SMC resulted in a greater AUDPC value than straight combining alone when sites were combined. To phrase this another way, there appears to be no benefit in terms of oat dry-down when glyphosate is applied ≤30% SMC. Glyphosate applied at earlier stages did not reduce AUDPC (the rate of dry-down).

Table 2. Effect of application timing of glyphosate on AUDPC of oat at Goodale Research Farm (2016-2018) and Kernen Research Farm (2017-2018).

Application Timing (SMC)	Kernen	Goodale	Sites Combined
20	997 c	904 c	941 c
30	180 bc	1297 abc	1210 bc
40	1311 ab	1571 abc	1467 ab
50	1446 a	1837 ab	1681 ab
60	1537 a	2029 a	1833 a
Direct	921 c	1006 bc	972 c
$LSD_{0.05}$	270	869	479

Means followed by the same letter do not differ significantly at P<0.05

Seed moisture content (SMC) at harvest

Harvest method had a significant effect on SMC across all site years (Table 3). Swathing resulted in lower harvest seed moisture content than glyphosate treatments (Table 4). While timing of glyphosate application was shown to be important in terms of oat dry down, it did not have a significant effect on seed moisture content at harvest (P=0.08), although there was a numerical reduction in SMC compared with the direct-harvested treatment.

Table 3. ANOVA for harvest SMC at Kernen and Goodale Research Farms: 2016-2018

	F-value	
Harvest Method (H)	7.86	*
Timing (T)	2.53	
H x T	2.43	

*, **, *** indicate significance at 0.05, 0.01, and 0.001 respectively

Table 4. Effect of harvest method on harvest SMC %. Kernen Research Farm (2017-2018) and Goodale Research Farm (2016-2018)

Harvest Method	**SMC (%)**	
Glyphosate	11.7 (±2.6)	a
Swathing	10.3 (±2.4)	b
Direct	13.5 (±2.8)	a

Means followed by different letters are statistically different at P<0.05.
Standard error means are in brackets

Seed yield

Both harvest method and application timing had an effect on oat seed yield (Table 5); however there was no significant interaction between these two variables (P=0.06). Glyphosate and direct harvest treatments yielded 19% and 28% more than swathing treatments, respectively (Table 6). Regarding application timing, applying glyphosate ≥ 40% SMC significantly reduced oat seed yield (Figure 1). There was a 2028.07 kg ha^{-1} difference between the highest yielding (application at 20% SMC) and the lowest yielding (application at 60% SMC) treatments. This represents a potential yield loss of up to 38% if glyphosate is applied when seed moisture is greater than 40%.

Table 5. ANOVA for seed yield at Kernen and Goodale Research Farms: 2016-2018

	F-value	
Harvest Method (H)	12.1	*
Timing (T)	14.2	***
H x T	2.8	

*, **, *** indicate significance at 0.05, 0.01, and 0.001 respectively

Table 6. Effect of harvest method on oat seed yield. Kernen and Goodale Research Farms: 2016-2018

Harvest Method	**SMC (%)**	
Glyphosate	5048.4	a
Swathing	4071.6	b
Direct	5688.5	a
$LSD_{0.05}$	779.4	

Means followed by different letters indicate a significant difference at P<0.05

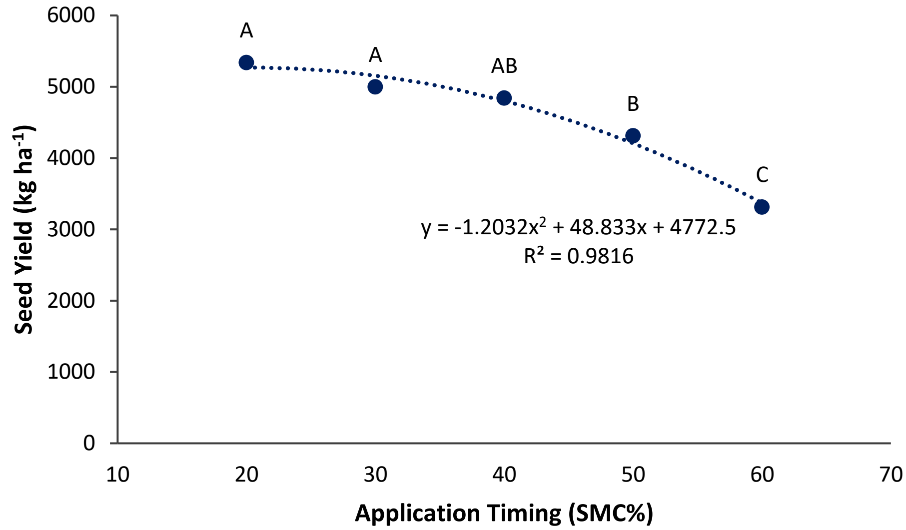

Figure 1. Effect of application timing on oat seed yield. Different letters above points represent a significant difference between means (P<0.05). Kernen Research Farm (2017-2018) and Goodale Research Farm (2016-2018).

Thousand Kernel Weight (TKW)

There was an interaction between harvest method and application timing for oat thousand kernel weight (TKW) (Table 7). Thousand kernel weights declined when either glyphosate or swath timings were applied at 50% SMC or greater. The lowest TKWs were observed when glyphosate or swathing occurred at 60% SMC.

Table 7. Interaction of harvest method on Thousand Seed weight (g) for oat. Goodale Research farm (2016-2018) and Kernen Research Farm (2017-2018).

Application Timing (SMC%)	**Harvest Method**			
	Glyphosate		**Swathing**	
20	37.6	ab	37.5	ab
30	38.4	a	36.7	bc
40	36.8	abc	34.7	bc
50	34.3	c	29.7	d
60	29.4	d	23.7	e
Direct	37.9 a			
$LSD_{0.05}$	2.8			

LSD is for the two-way interaction. Means followed by the same letter do not differ significantly at P<0.05

Test Weight
There was an interaction between application timing and harvest method of test weight across all site years. As was observed for TKW, when glyphosate application or swathing occurred at higher SMCs, test weights significantly dropped (Table 8). However, this effect was more dramatic for swathing treatments than glyphosate treatments. When swathing occurred at 60% SMC, test weights dropped by 73.2 g (29%) in comparison to the direct harvest treatment.

Table 8. Interaction of harvest method on test weight for oat (g). Goodale Research Farm (2016-2018) and Kernen Research Farm (2017-2018)

Application Timing (SMC)	**Harvest Method**			
	Glyphosate		**Swathing**	
20	248.3 (±5.7)	ab	246.1 (±5.7)	ab
30	249.2 (±5.7)	a	251.3 (±5.7)	a
40	249.6 (±5.7)	a	245.7 (±5.7)	ab
50	237.6 (±5.7)	abc	222.7 (±5.6)	bc
60	218.4 (±5.6)	c	175.6 (±5.4)	d
Direct	248.8 (±5.7) a			

Standard errors are in brackets beside means. Means followed by the same letter do not differ significantly at P<0.05

Percent plump and thin kernels
There was a significant interaction between application timing and harvest method for percent thin kernels in oat (Table 9). Both harvest method and application timing had a significant impact on percent plump kernels in oat; however there was no significant interaction between these two factors (P=0.06; Table 10). Across all site years, the percent thin kernels increased as either harvest method was applied at higher SMCs. In general, this increase in the percentage of thin kernels was more dramatic in swathed treatments. By swathing at or above 50%, the amount of thin kernels increased 13-fold on average in comparison to the direct harvest treatment. When glyphosate was applied at 60% SMC, there was 5.5-times as many thin kernels present than was when glyphosate was applied at 20% SMC. Overall when glyphosate was being applied at or below 50% SMC, there was no significant impact on the percentage of thin kernels present. For swathing treatments, there was no significant increase in the amount of thin kernels when swathing occurred at or below 40% SMC.

Table 9. Interaction of harvest method on percent thin kernels for oat. Goodale Research Farm (2016-2018) and Kernen Research Farm (2017-2018)

Application Timing (SMC)	Harvest Method			
	Glyphosate		Swathing	
20	1.7 (±0.7)	d	2.0 (±1.0)	d
30	1.7 (±0.8)	d	2.4 (±1.3)	cd
40	2.0 (±1.0)	d	4.3 (±2.1)	c
50	3.0 (±1.6)	cd	13.3 (±3.7)	b
60	9.5 (±3.2)	b	26.9 (±4.8)	a
Direct	1.5 (±0.6) e			

Standard errors are in brackets. Means followed by the same letter do not differ significantly at P<0.05

The greatest percentage of plump kernels occurred when plots were harvested directly (Table 10). Using glyphosate instead of swathing as a harvest method resulted in 10% more plump kernels. As was observed for the percentage of thin kernels, the amount of plump kernels declined as swathing or glyphosate were applied at higher seed moistures. Applying these harvest methods above 40% SMC resulted in 25% less plump kernels on average. Overall to maximize the amount of plump kernels present, and minimize the percentage of thin kernels, glyphosate applications or swathing should not occur at SMCs above 40%.

Table 10. Effect of harvest method and application timing on plump kernels for oat. Goodale and Kernen Research Farm: 2016-2018.

Harvest Method	Plump Kernels (%)
Direct	94.5 a
Glyphosate	88.3 a
Swathing	78.2 b
LSD $_{0.05}$	8.2
Application Timing (SMC)	
20	94.1 a
30	93.7 a
40	90.9 a
50	78.1 b
60	59.4 c
LSD $_{0.05}$	12.1

LSD is for the two-way interaction. Means followed by the same letter do not differ significantly at P<0.05.

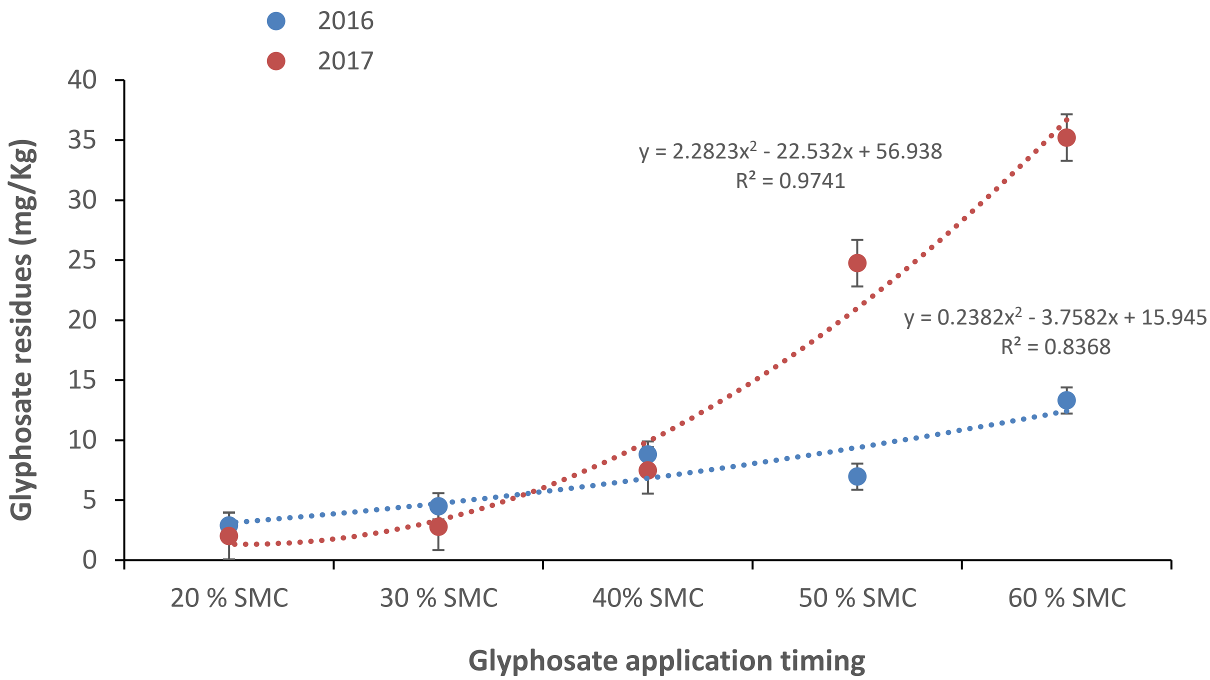

Figure 2. Effect of application timing on glyphosate seed residue. Data were combined across sites. Error bars represent +/- 1 standard error of the mean.

Seed residues:

The analysis for seed residues showed significant differences between years and thus, each was analyzed separately. In both years, glyphosate residue generally increased as treatments were made at progressively more immature growth stages (higher moisture contents) (Fig. 2). For example, glyphosate seed residues in 2017 increased from 2.0 at 20% seed moisture to 35.2 ppm at 60%, which represents an approximate 17-fold increase (Fig. 2). Similar results were observed in 2016 at both sites, although the magnitude of the differences was smaller owing to lower seed residue values at higher seed moisture contents. At both sites, swathing treatments had negligible levels of glyphosate reside, regardless of glyphosate application timing. Swathing treatments generally exhibited similar levels of residue to the direct harvested treatment, to which no glyphosate was applied.

The accumulation of glyphosate residue in lentil seed is crucial for lentil exporters because buyers may reject oat shipments if the glyphosate residue exceeds the MRL (Pratt, 2011). In the current study, average glyphosate residues did not exceed 5 ppm at the 30% application timing, nor did they exceed 10 ppm at 40% application timing (Fig. 4). These values are not above the Canadian MRL of 15 ppm, nor are they above the US MRL of 30 ppm. In fact, average glyphosate residues were only above the Canadian and US MRLs in the 50% and 60% seed moisture treatments, which not only off-label (30% seed moisture content), but are far too high at which to apply a harvest aid like glyphosate. As shown above, the application of glyphosate at these seed moisture contents results in a significant decline in yield. Nevertheless, it is therefore critical that growers do not apply glyphosate as a harvest aid when seed moisture content is above 40%. Our results also show that applications made prior to 40% seed moisture content consistently produced higher glyphosate residues. At early seed developmental stages, seeds are major sucrose sinks and glyphosate will translocate to those developing seeds. As the crop matures, the demand for sucrose from these sinks declines and less glyphosate is translocated to the developing seeds, resulting in reduced glyphosate residues (Zhang et al. 2016). Based on this, and the results shown here, we are confident suggesting that if growers apply glyphosate at the label recommendation of 30% seed moisture, glyphosate residues in the seed would not be expected to exceed MRLs in North America.

Seed Quality (Table and Figure numbers are specific to this section):

Beta- glucan content varied significantly depending on harvest method, timing and site year (Table 1). Beta-glucan content was similar for direct combining (4.28%), glyphosate applied at 20-40% and swathing at 20-30% (Table 1).

Table 1: ANOVA results showing F-Ratios for effects on groat composition and quality.

	Site Year	Harvest Method	Harvest Method *Site Year Interaction
Beta-Glucan	143***	188***	16***
Protein	320***	14***	5***
Total Starch	120***	20***	5***
Flour RVA Stirring Number	238***	168***	11***
Flour RVA Oat Pasting	72***	142***	5***
Hull %	279***	323***	16***
Groat %	428***	722***	47***
Remaining Hull %	193***	513***	73***
Milling yield	21***	33***	11***
Groat Breakage %	108***	288***	54***
Groat Colour L*	9874***	42***	16***
Groat Colour a*	372***	126***	15***
Gorat Colour b*	622***	68***	10***
DF	4	10	40
P<0.05 = *; P<0.01 = **; P<0.001 = ***			

Table 2. Summary of Dunnett's Test comparing pre-harvest methods against direct harvest control.										
	Glyphosate Applied at Various Seed					Swathed at Various Seed Moisture				
Quality Characteristic	20%	30%	40%	50%	60%	20%	30%	40%	50%	60%
Beta-Glucan	ns	ns	ns	***	***	ns	ns	***	***	***
Protein	ns	ns	ns	*	***	ns	ns	ns	ns	***
Total Starch	ns	ns	ns	ns	***	ns	ns	ns	ns	***
Flour RVA Stirring Number Method	ns	ns	*	***	***	ns	ns	ns	***	***
Flour RVA Oat Pasting Method	ns	ns	ns	***	***	ns	***	***	***	***
Hull %	ns	ns	ns	***	***	ns	ns	***	***	***
Corrected Groat %	ns	ns	ns	***	***	ns	ns	***	***	***
Remaining Hull %	ns	ns	ns	ns	***	ns	ns	ns	***	***
Milling yield	ns	ns	ns	ns	***	ns	ns	ns	ns	***
Groat Breakage	ns	ns	ns	***	***	ns	ns	ns	***	***
Groat Colour L*	ns	ns	ns	***	ns	ns	ns	ns	ns	***
Groat Colour a*	ns	ns	ns	***	***	ns	ns	***	***	***
Gorat Colour b*	ns	ns	ns	ns	**	ns	ns	ns	***	***
Falke Granulation (> 3.35 mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Flake Granulation (< 3.35 and > 2.36 mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Flake Granulation (< 2.36 and > 1.7 mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Flake Granulation (< 1.7 mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Flake Colour L*	ns	ns	ns	ns	ns	ns	ns	ns	*	***
Flake Colour a*	ns	ns	ns	ns	ns	ns	ns	**	*	***
Flake Colour b*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Flake Thickness	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Ground Flake RVA Viscosity	ns	ns	ns	ns	ns	ns	ns	ns	**	***

A significant result indicates that the pre-harvest treatment was different from the control (straight combine at 12.5 % SMC).
ns = not significant; P<0.05 = *; P<0.01 = **; P<0.001 = ***

When treatments were combined across site years (Table 3), the average beta-glucan content ranged from 2.91% to 4.36%. Both harvest method and glyphosate application or swathing timing had an effect on beta glucan content. Beta glucan declined when glyphosate was applied at 50% or greater or if swathing timing was 40% or greater (Table 3). There was a significant interaction between site year and harvest method (Table 1). Significantly lower beta glucan levels were observed at both locations in 2018 and Kernen, 2017 (Table 4).

Table 3. Effect of harvest method and timing on oat groat composition, over all site years.						
Treatment	Beta-Glucan (%, db)		Protein (%, db)		Total Starch (%, db)	
Timing (% SMC)	Glyphosate	Swathing	Glyphosate	Swathing	Glyphosate	Swathing
20	4.36 A	4.32 A	17.08 CDE	17.16 CD	61.65 AB	62.00 AB
30	4.34 A	4.30 A	17.00 CDE	16.91 CDE	61.80 AB	61.96 AB
40	4.23 A	4.00 B	17.14 CDE	16.76 DE	62.08 AB	62.59 A
50	3.80 C	3.10 D	17.36 BC	16.63 E	61.28 B	62.15 AB
60	2.91 E	3.08 DE	17.78 AB	18.07 A	60.11 C	58.68 D
Direct	4.28 A		16.91 CDE		61.73 AB	

Comparison of means using Tukey's test. For each component, means followed by the same letter do not significantly differ at P<0.05.

Table 4. Effect of growing environment on oat groat composition.

Site Year	Beta-Glucan (%, db)	Protein (%, db)	Total Starch (%, db)
Goodale 2016	4.28 A	14.79 C	64.56 A
Goodale 2017	4.18 A	17.32 B	61.47 B
Goodale 2018	3.61 C	17.99 A	59.90 C
Kernen 2017	3.85 B	17.61 B	61.22 B
Kernen 2018	3.51 C	18.11 A	60.14 C

Means within the same column followed by the same letter do not differ significantly at $P<0.05$.

Protein:

Oat protein content was influenced by site year and harvest method and the associated interaction (Table 1). Protein levels were greater than 16% across all site years with the highest levels being observed with swathing or glyphosate application at high % SMC (Table 3). All treatments resulted in protein levels similar to direct combining with the exception of the glyphosate at %0 and 60% and swathing at 60% moisture. When harvest treatments and timing were combined, the year effect was significant (Table 4) with the lowest level (14.8%) in 2016 and the highest (18%) in 2018. The higher protein observed in timing treatments at 60% SMC may be due to the immaturity of the plant and the lack of starch present to dilute the protein. The lower plumps and higher thins with timing treatments at high SMC is also an indication of the lack of starch present in immature seeds.

Starch:

Starch content varied with harvest method and depending on %SMC at application of glyphosate or swathing. However, the differences were small and basically followed the reverse trend of protein as expected (Table 3 and Table 4).

Although statistical differences were identified for oat groat composition depending on the harvest method or the treatment timing (Table 3), the numerical variation was relatively small. If a food processor was just looking at a data sheet based on groat composition, with the exception of treatments with beta glucan content under 4%, these samples would not likely be rejected. However, beta glucan levels under 4% can be problematic for the food processor to meet label claim requirements associated with health benefits.

Flour Properties:

Flour properties were measured using a Rapid Visco-Analyser to assess potential enzyme activity ,such as amylase, associated with sprouting (stirring number) and a flour viscosity test (oat pasting); both can affect processing characteristics. Site year, harvest method and treatment timing had a significant effect on stirring number and oat flour pasting (Table 1 and Table 5). Again, application of glyphosate or swathing at 50 and 60% seed moisture had the greatest effect on the oat flour quality. The glyphosate application and swathing treatment at 60% resulted in reduced viscosity shown by lower stirring numbers of 1240 cP and1415 cP (respectively) compared to the direct combining treatment with 1913cP. The oat pasting results at 60%SMC were even more dramatic where flour viscosity for the swathing treatment was reduced to 624cP compared to 2539cP for the direct combining treatment. Location and year also affected flour properties (Table 6) and while significant differences were observed, the biological significance could be small.

Table 5. Effect of harvest method and timing on oat flour pasting properties, over all site years.

Treatment Timing (% SMC)	Stirring Number Viscosity (cP)		Oat Pasting Viscosity (cP)	
	Glyphosate	Swathing	Glyphosate	Swathing
20	1907 AB	1922 A	2594 A	2326 AB
30	1898 AB	1891 AB	2384 A	2090 BC
40	1835 A	1869 AB	2424 A	1603 D
50	1613 D	1702 C	1866 CD	700 F
60	1240 F	1415 E	1176 E	624 F
Direct	1913 AB		2539 A	

Comparison of means using Tukey's test. For each property, means followed by the same letter do not significantly differ at P<0.05.

Table 6. Effect of growing environment on oat flour viscosity as measured by two Rapid Visco-Analyser (RVA) methods.

Site Year	Stirring Number RVA Viscosity (cP)	Oat Pasting RVA Viscosity (cP)
Goodale 2016	1932 A	2440 A
Goodale 2017	1955 A	1846 B
Goodale 2018	1670 B	1751 BC
Kernen 2017	1624 B	1633 CD
Kernen 2018	1548 C	1569 D

Means within the same column followed by the same letter do not differ significantly at P<0.05.

Milling Quality:

Desirable milling quality characteristics include high % groats, low %hulls, low amount (kg) of oats to produce 100kg of groats (called milling yield) and low groat breakage. Compared to the direct combining control treatment (30%hull and 148kg milling yield); swathing at 40% or greater SMC or glyphosate application at 50% or greater SMC resulted in higher than normal hull percent and undesirably high milling yields (Table 7). The milling yields for the 50% SMC treatments were not significantly different than the lower moisture treatments or the direct combined control, but they could still have an economic impact on a food processor and therefore represent a quality concern. The very high milling yields were similar for both high moisture glyphosate application and swathing (492 and 432 kg oats to produce 100kg groats) (Table 7) . However, the undesirable milling yield increase for the glyphosate treatment at 60% SMC was related to high levels of broken groats present in while the milling yield increase in the swathed material was due to high amounts of hull and undehullled seed remaining (Figure 1). Significant differences in milling quality were observed with growing environment but trends were not evident (Table 8).

Table 7. Effect of harvest method and timing on oat milling quality, over all site years.

Timing (% SMC)	Hull %		Groat %		Milling Yield (kg)	
	Glyphosate	Swathing	Glyphosate	Swathing	Glyphosate	Swathing
20	31.14 D	31.12 D	68.37 A	68.57 A	149 B	149 B
30	30.91 D	31.23 D	68.71 A	68.24 A	148 B	150 B
40	31.74 D	33.78 C	67.89 A	65.19 B	150 B	159 B
50	34.69 C	41.30 B	64.21 B	54.52 C	174 B	212 B
60	41.17 B	52.91 A	53.03 C	35.30 D	492 A	432 A
Direct	30.61 D		69.00 A		148 B	

Comparison of means using Tukey's test. For each qualtiy parameter, means followed by the same letter do not significantly differ at P<0.05.

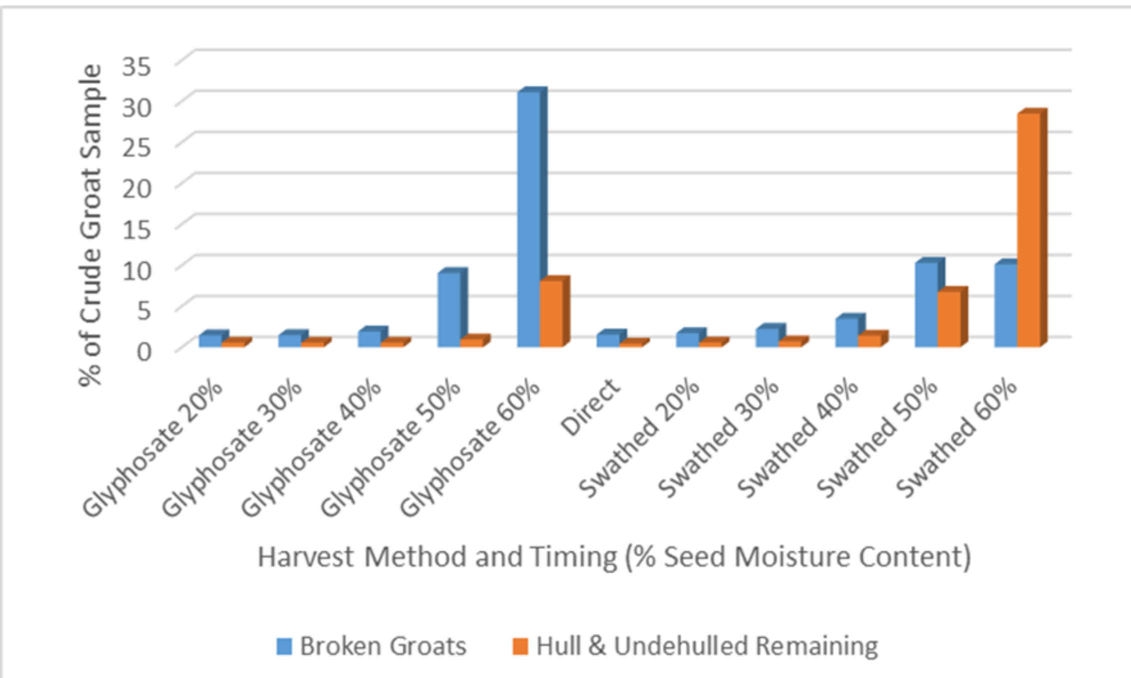

Figure 1. Effect of harvest method and timing on components influencing milling yield.

Table 8. Effect of growing environment on oat milling quality.					
Site Year	Hull %	Groat %	Milling Yield (kg)	Hull & Undehulled Remaining (%)	Groat Breakage (%)
Goodale 2016	28.22 D	71.20 A	147 C	0.37 E	4.01 CD
Goodale 2017	38.08 AB	60.69 C	177 C	2.30 D	3.48 D
Goodale 2018	34.72 C	62.72 B	194 BC	3.86 C	8.98 B
Kernen 2017	37.46 B	58.30 D	238 B	9.17 A	5.29 C
Kernen 2018	39.07 A	57.56 D	318 A	6.59 B	12.04 A
Means within the same column followed by the same letter do not differ significantly at P<0.05.					

Groat colour, measured using a Minolta spectrophotometer showed small but significant differences in L*,a* and b* values (lightness or brightness, red and blue respectively) depending on harvest method and %SMC (Table 9). The slightly lower levels of L*, a* and b* in the high moisture swath treatment compared to the direct combined control may reflect weathering in the swath or high proportion or green seeds in immature plant material. The growing environment also had a significant effect on groat colour (Table 10). However, with the exception of L* and b*at Goodale 2016, the L*, a*and b*for the other locations were extremely similar.

Table 9. Effect of harvest method and timing on groat colour measurements, over all site years.						
Treatment Timing	L*		a*		b*	
(% SMC)	Glyphosate	Swathing	Glyphosate	Swathing	Glyphosate	Swathing
20	63.29 CD	63.07 D	4.61 B	4.64 B	19.19 A	19.14 AB
30	63.46 BCD	63.43 BCD	4.61 B	4.64 B	19.25 A	19.08 AB
40	63.58 BC	63.54 BC	4.59 B	4.78 A	19.22 A	19.02 ABC
50	64.14 A	63.46 BCD	4.29 D	4.43 C	19.25 A	18.75 C
60	63.79 AB	61.60 E	3.91 E	3.99 E	18.88 BC	17.61 D
Direct	63.43 BCD		4.56 B		19.20 A	
Comparison of means using Tukey's test. For each colour measurement, means followed by the same letter do not significantly differ at P<0.05.						

Table 10. Effect of growing environment on oat groat colour.			
Site Year	L*	a*	b*
Goodale 2016	75.06 A	4.64 B	20.67 A
Goodale 2017	59.81 D	4.71 A	18.79 B
Goodale 2018	61.54 B	4.15 C	18.27 C
Kernen 2017	59.41 E	4.72 A	18.68 B
Kernen 2018	60.91 C	4.07 D	18.42 C
Means within the same column followed by the same letter do not differ significantly at P<0.05.			

Flake Quality:
Oat groats were processed into oat flakes and tested for various quality characteristics. In general only swathing at 60% SMC reduced flaking quality (Figures 2 and 3; Tables 2, 11 and 12). Flake quality, as measured as flake thickness, flake colour, granulation and flake viscosity, was significantly different for the various site years (Table 13).

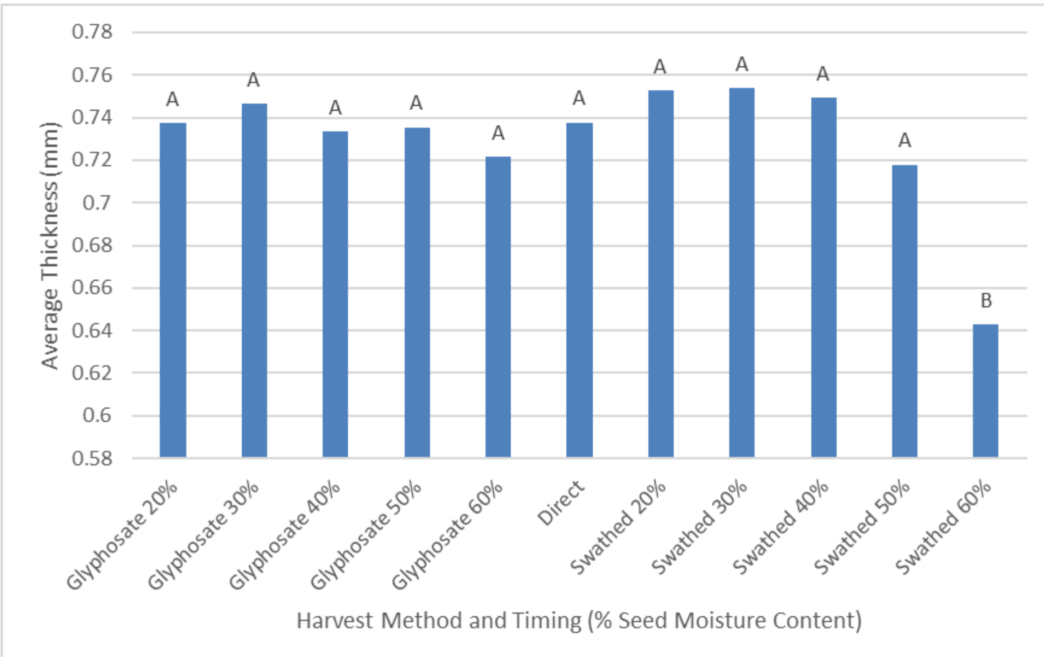

Figure 2. Effect of harvest method and timing on average flake thickness.
Note: Comparison of means using Tukey's test. Bars indicated with the same letter are not significantly different at P<0.05.

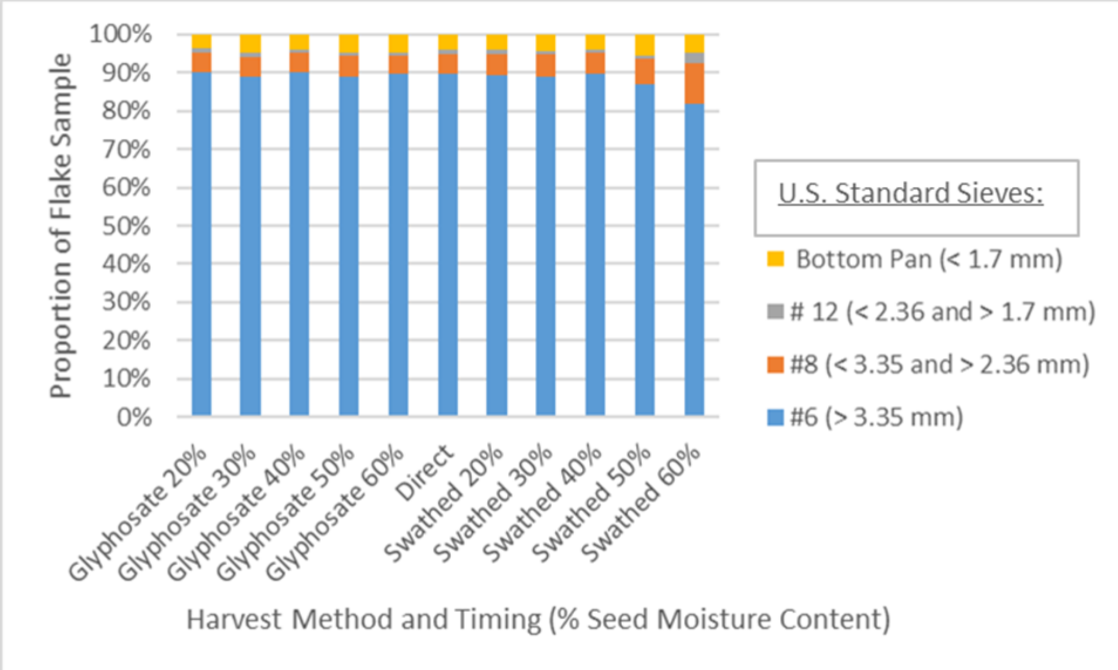

Figure 3. Effect of harvest method and timing on oat flake granulation.
Note: Significant differences were only found with the Swathed 60% SMC treatment.

Table 12. Effect of harvest method and timing on ground flake pasting properties, over all site years.

Treatment Timing (% SMC)	RVA Viscosity (cP)	
	Glyphosate	Swathing
20	3421 A	3590 A
30	3705 A	3418 A
40	3287 AB	3163 AB
50	3139 AB	1977 BC
60	3202 AB	1560 C
Direct	3601 A	

Comparison of means using Tukey's test. For each property, means followed by the same letter do not significantly differ at P<0.05.

Table 13. Effect of growing environment on oat flake quality.

Site Year	Flake Thickness (mm)	Flake Colour L*	a*	b*	Flake Granulation (% on top U.S. Standard Sieve) No. 6 (> 3.35 mm)	No. 8 (< 3.35, > 2.36 mm)	No. 12 (< 2.36, > 1.7 mm)	Bottom Pan (< 1.7 mm)	Ground Flake RVA Viscosity (cP)
Goodale 2016	0.72 B	74.68 B	2.41 B	18.24 A	86.94 B	7.24 A	1.30 B	4.77 A	3895 A
Goodale 2017	0.76 A	74.15 B	2.54 A	18.55 A	93.48 A	3.51 B	0.60 C	2.68 B	3155 B
Kernen 2017	0.71 B	75.54 A	2.18 C	16.79 B	86.05 B	6.79 A	1.55 A	5.88 A	2028 C

Means within the same column followed by the same letter do not differ significantly at P<0.05.

Groat (dehulled oat) Residue Analysis:

When oats were sprayed with glyphosate at 40% seed moisture or lower, the residue levels in the groats were below maximum residue limits (MRL) set for oats in Canada (15 ppm) (Table 14). Similar trends were observed at both locations. Processing groats into flakes did not result in any significant reduction in residue levels except for in the samples with the highest levels (glyphosate applied at 60% seed moisture content) (Figure 4).

Table 14. Effect of glyphosate application timing on groat residue levels at two locations.

Glyphosate Application Timing (% SMC)	Mean Residue Levels (ppm) Goodale	Kernen
20	0.11 C	0.47 D
30	0.38 C	1.06 CD
40	3.34 C	5.02 C
50	14.89 B	19.49 B
60	24.87 A	29.87 A

Comparison of means using Tukey's test. Treatments within the same column/location followed by the same letter do not significantly differ at P<0.05.

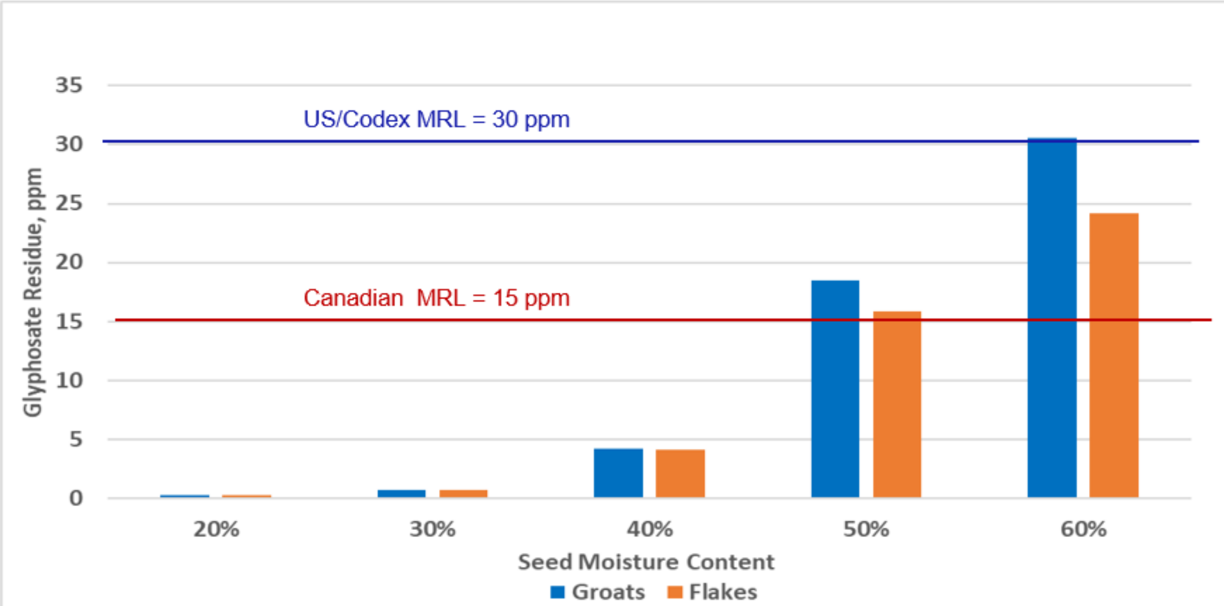

Figure 4. Effect of flaking on glyphosate residue levels. MRL = maximum residue limit mg/kg (or ppm)

Experiment 2: Agronomic and harvest management impacts on oat yield and seed quality

Statistical analysis

Data was analyzed using the GLIMMIX procedure of SAS 9.4 with an LSD test to compare LSMEANS for those factors that had a significant effect or interaction (SAS Inst. 2016). Based on the normality of the residual data, data were then analyzed using a normal or log normal distribution in PROC GLIMMIX (Bowley, 2015; SAS Inst. 2016). Harvest moisture, yield, TKW, test weight, percent thin kernels, percent plump kernels, beta-glucan, protein, groat, flake water absorption, and milling yield were all analyzed using PROC GLIMMIX with a Gaussian distributed because the residuals were normally distributed. Groat breakage was analyzed using PROC GLIMMIX with a LOGNORMAL distribution and then back-transformed using an ODS OUTPUT statement to give the mean and standard errors of the significant effects (Bowley, 2015). Fixed effects in the model were harvest method, cultivar, and seeding rate, while the random effects were site, replication nested within site, and all site interactions with fixed factors. The random effects were examined using a COVTEST to determine if site years could be combined. The COVTEST revealed that we were able to combine all site years of data for statistical analysis (Table 12). There was a significant site-year x seeding rate x harvest method x cultivar interaction for Beta-glucan content (Z-value = -2.65, P<0.01). Because this Z-value was negative, this indicates a minimal contribution to the variation of the random effect (Kiernan et al. 2012). Therefore, all data was pooled for the analysis of Beta-glucan. An ANOVA is presented for all measured variables in Table 13. No factor or combination of factors had a significant effect on the dry-down (AUDPC), yield, test weight, or milling yield of oat across all site years (Table 13).

Table 12. Random effects and their interaction with cultivar, seeding rate, and harvest method were assessed using the Wald Z test (COVTEST). Data was combined across all site years. The Z-values are presented based on the Wald Z Test for AUDPC, harvest moisture, yield, TKW, % thin, % plump, test weight, beta-glucan, protein, groat, groat breakage, milling yield, and flake water absorption.

	AUDPC	Harvest Moisture (%)	Yield (kg ha^{-1})	TKW (g)	Thin (%)	Plump (%)	Test Weight (g)	Beta Glucan (%)	Protein (%)	Groat (%)	Groat Breakage (%)	Milling Yield	FWA
							Z-value						
Site	1.14	1.16	0.58	1.35	0.96	1.48	1.34	1.06	1.22	0.82	1.08	-0.03	1.15
Rep(Site)	1.48	1.29	2.04*	1.22	0.96	0.94	1.31	2.07*	1.93	1.29	0.75	1.81	1.85
Site*C	1.14	-0.02	1.21	1.39	1.30	1.40	1.42	0.56	1.40	1.20	1.20	1.21	1.13
Site*SR	1.05	1.26	1.4	1.38	0.38	1.10	0.00	-1.13	1.70	0.97	0.15	1.10	1.15
Site*C*SR	0.92	-0.82	-0.53	-1.10	0.97	0.92	0.65	1.09	-1.69	0.13	0.86	-0.41	0.56
Site*HM	0.04	0.81	1.93	-0.41	0.54	-1.02	1.34	-1.15	0.41	0.70	0.62	1.24	0.38
Site*C*HM	0.01	1.27	-0.32	0.62	0.19	0.52	0.42	1.46	-0.72	0.95	0.90	1.24	0.49
Site*SR*HM	0.11	-0.64	0.18	-0.47	1.82	1.53	0.92	1.09	-1.24	1.35	-0.68	1.29	-1.12
Site*C*SR*HM	0.53	1.06	0.51	1.00	0.30	0.48	0.20	-2.65 **	0.88	-1.46	-1.90	-1.61	-0.14
Residual	7.25 ***	9.91 ***	9.95 ***	9.95 ***	9.95***	9.95***	9.95 ***	8.12 ***	8.12 ***	8.12 ***	8.12 ***	8.12 ***	8.11 ***

Abbreviations: C: cultivar; SR: Seeding rate; HM: Harvest Method; TKW: Thousand kernel weight; FWA: Flake water absorption
*,**,*** indicates significance at P<0.05, 0.01, and 0.001 respectively

Table 13. ANOVA of the effect of cultivar, seeding rate, and harvest method on AUDPC, harvest moisture, yield, TKW, % thin, % plump, test weight, beta-glucan, protein, groat, groat breakage, milling yield, and flake water absorption. Kernen and Goodale Research Farms. 2016-2018.

	AUDPC	Harvest Moisture (%)	Yield (kg ha^{-1})	TKW (g)	Thin (%)	Plump (%)	Test Weigh t (g)	Beta Glucan (%)	Protein (%)	Groat (%)	Groat Breakage (%)	Milling Yield	FWA
							F-value						
Cultivar (C)	0.00	0.01	4.63	5.07	7.85 *	5.01	0.66	0.01	2.04	9.10	0.42	4.18	10.1
Seeding Rate (SR)	3.12	13.24 *	0.16	7.81 *	0.28	0.63	1.06	7.29	2.22	0.10	11.08 *	1.17	0.38
C x SR	3.90	1.21	0.43	0.72	0.68	1.79	0.62	1.13	0.11	0.22	0.02	0.40	1.45
Harvest Method (HM)	2.92	9.94 **	1.04	17.49 ***	19.25 ***	34.38 ***	0.22	7.47 *	5.19 *	4.90 *	18.63 **	4.28	0.82
C x HM	2.51	2.60	2.77	0.38	15.51 ***	8.09 **	1.74	0.72	0.78	0.98	0.98	0.85	0.38
SR x HM	0.99	4.42 *	0.81	0.36	0.49	0.01	1.30	3.33	0.68	0.70	2.91	1.15	3.39
C x SR x HM	0.02	0.40	0.69	0.18	0.13	0.17	1.12	0.84	0.90	0.73	0.59	1.34	0.02

Abbreviations: TKW: Thousand kernel weight; FWA: Flake water absorption
*,**,*** indicates significance at P<0.05, 0.01, and 0.001 respectively

Seed Moisture Content at Harvest

There was a significant interaction between harvest method and seeding rate for oat seed moisture content (Table 14). Seed moisture content was on average 1.3 percentage points lower when treatments were seeded at 500 seeds m^{-2} regardless of harvest method. The highest SMC (14.2%) was observed when plots were seeded at 250 seeds m^{-2} and harvested directly. Swathing treatments had the lowest SMC regardless of seeding rate.

Table 14. The interaction between harvest method and seeding rate on oat seed moisture content (%). Kernen Research Farm and Goodale Research Farm. 2016-2018.

	Seeding Rate (seeds m^{-2})			
Harvest Method	**250**		**500**	
Direct	14.2	A	12.1	BC
Glyphosate	12.6	B	11.3	CD
Swathing	10.6	CD	10.0	D
$LSD_{0.05}$	**2.5**			

Different letters indicate a significant difference between two means (P<0.05)

Thousand kernel weight (TKW)

Harvest method and seeding rate each had a significant effect on TKW, however there was no interaction between these two factors (Table 15). Increasing seeding rates from 250 to 500 seeds m^{-2} reduced TKW by 0.7 g (i.e. 2%). The greatest TKW was observed when treatments were harvested directly. Using swathing as the harvest method reduced TKW by 1.0 g (3%) in comparison to the direct harvested treatment. Glyphosate had no impact on the TKW of oat in comparison to the direct harvest treatments.

Table 15. The effect of seeding rate and harvest method on oat thousand kernel weight (g). Kernen and Goodale Research Farms. 2016-2018.

Seeding Rate (seeds m^{-2})	**Thousand Kernel Weight (g)**	
250	36.1	A
500	35.4	B
$LSD_{0.05}$	**0.65**	
Harvest Method		
Direct	36.2	A
Glyphosate	35.9	A
Swathing	35.2	B
$LSD_{0.05}$	**0.40**	

Different letters indicate a significant difference between two means (P<0.05)

<u>*Percent plump and thin kernels*</u>

There was an interaction between oat cultivar and harvest method that impacted both the percent of plump and thin kernels in this experiment (Table 16). The lowest percentage of thin kernels (<0.89%) and the greatest number of plump kernels (>97.5%) was observed when Pinnacle was either directly harvested or glyphosate was used as the harvest method. On average, swathing oat resulted in 1.9- fold increased the amount of thin kernels, regardless of cultivar. In regards to percent plump kernels, Pinnacle was not as responsive to changes in harvest method as CDC Dancer was. Again, swathing oats resulted in 2% less plump kernels on average in comparison to direct harvest and glyphosate treatments. Overall, Pinnacle had a lower percentage of thin kernels than CDC Dancer, and either harvesting plots directly or desiccating with glyphosate had a positive impact on the amount of plump and thin kernels measured, although this effect was not always statistically significant.

Table 16. The interaction between harvest method and cultivar on percent thin kernels. The interaction between cultivar and harvest method on percent plump kernels. Kernen Research Farm and Goodale Research Farm. 2016-2018.

	Cultivar			
	Dancer		**Pinnacle**	
Harvest Method	**Thins (%)**			
Direct	1.16	BC	0.82	C
Glyphosate	1.25	BC	0.89	C
Swathing	2.39	A	1.45	B
$LSD_{0.05}$	**0.47**			
	Plump (%)			
Direct	96.8	A	97.7	A
Glyphosate	96.7	A	97.5	A
Swathing	95.0	B	96.9	A
$LSD_{0.05}$	**0.92**			

Different letters indicate a significant difference between two means (P<0.05)

<u>Seed Quality (Separate Table and Figure Numbers for this section)</u>

Significant year, location and cultivar effects were observed for most of the quality variables (Table 15 and Table 16). Analysis of variance for experiment 2 (Table 15) suggest that harvest method, but not seeding rate or cultivar, had an effect on beta glucan content. A closer look at the data (Appendix Tables 1a and 1b) shows that for the cultivar Pinnacle, beta glucan in the swathed treatment was 4.58% compared to 4.7% in the glyphosate treatment. Similar results were seen for swath vs glyphosate at the lower seeding rate (4.54 vs 4.66 % beta glucan). Such differences would not be considered biologically significant regardless of the statistical outcome. For protein and starch composition, seeding rate and cultivar effects were statistically significant but not harvest method (Table 15). However, protein content and starch content varied only slightly (Appendix Tables 2a, 2b, 3a and 3b).

Seeding rate had a significant as well as meaningful effect on % groat, milling yield and breakage. Milling yield was poorest (146kg) for the low seeding rate combined with swathing and highest (140kg) with the higher seeding rate and direct combined or treated with glyphosate (Appendix Table 9b).
Notable cultivar effects were observed for % groat and flake quality (absorption and granulation). The lowest groat percent (70%) was observed with Pinnacle combined with the swathing treatment and the highest

(74%) with CDC Dancer using either direct combining or glyphosate application (Appendix Table 7a). For flake quality characteristics, significantly higher flake absorption was observed for Pinnacle across harvest treatments (Appendix Table 14a). The cultivar CDC Dancer had a larger proportion of large flakes (Appendix Table 15) and a lower amount of very small (broken) flakes compared to Pinnacle (Appendix Table 18).
Flour quality, as measured by RVA pasting, and several milling characteristics (hull, groat, milling yield and breakage) showed significant seeding rate X year interactions. Only flour pasting and groat colour (a*) showed harvest method X cultivar interactions.

No significant interactions between seeding rate and harvest method were observed for any of the quality parameters.

Table 15: ANOVA results showing F-Ratios for effects on groat composition and quality.

	Year	Location (L)	Cultivar (C)	Harvest Method (HM)	Seeding Rate (SR)	SR*Year	HM*C	SR*HM
DF	2	1	1	2	1	2	2	2
BG%	185.5***	10.4**	1.5	5.1*	1.5	2.4	1.6	0.9
Protein %	2190.0***	68.7***	5.0*	3	11.1**	2.1	0.2	0.14
Starch %	390.2***	17.5***	144.8***	0.6	4.2*	0.2	0.7	0.4
Flour RVA Stirring	345.4***	89.9***	158.7***	9.0**	0.8	6.0*	0.4	0.1
Flour RVA Pasting	32.0***	0.8	172.2***	74.8***	2.8	10.1***	14.0***	0.2
Hull %	342.8***	48.2***	429.7***	16.6***	3.6	11.6***	0.9	0.2
Groat %	254.7***	59.3***	489.0***	28.4***	6.4*	14.2***	1.6	0.2
Milling Yield	171.3***	72.1***	267.4***	54.8***	21.2***	24.4***	0.9	0.3
Groat Breakage	817.1***	31.3***	2.3	40.6***	24.6***	23.1***	0.2	0.4
Groat Colour L*	440.6***	220.9***	1951.3***	2.4	0.3	3	2.6	0.2
Groat Colour a*	1192.8***	16.1***	1388.3***	15.9*	0	4.0*	3.7*	1.2
Groat Colour b*	272.8***	33.6***	1010.1***	10.6***	14.2**	1.7	0.3	0.6

* , **, *** indicates significant at p < 0.05, 0.001, 0.0001

Table 16: ANOVA results showing F-Ratios for effects on flake quality.

	Year	Location (L)	Cultivar (C)	Harvest Method (HM)	Seeding Rate (SR)	SR*Year	HM*C	SR*HM
DF	1	1	1	2	1	1	2	2
Water Absorption	690.2 ***	1.3894	99.9***	0.8	0.8	1.2	0.2	1.1
Thickness	107.7***	1.0967	2.7513	0.9	0.2	0.5	0.6	0.7
Flake Granulation:								
Percentage > 3.35 mm	522.2***	58.4***	170.6***	0.2	0.1	0.5	0.0	0.7
Percentage < 3.35 and > 2.36 mm	473.7***	37.5***	172.3***	0.3	0.8	0.6	0.1	0.8
Percentage < 2.36 and > 1.7 mm	241.9***	91.8***	179.9***	0.5	0.5	0.6	0.8	1.2
Percentage < 1.7 mm	304.9***	66.8***	97.0***	0.3	0.1	0.3	0.0	0.6
Flake Colour L*	19.1***	28.7***	102.3***	1.2	0.1	1.1	1.2	1.9
Flake Colour a*	140.1***	28.1***	120.5***	2.6	0.3	2.5	0.6	1.1
Flake Colour b*	98.4***	29.8***	179.2***	0.7	0.2	0.2	0.2	2.5

* , **, *** indicates significant at p < 0.05, 0.001, 0.0001

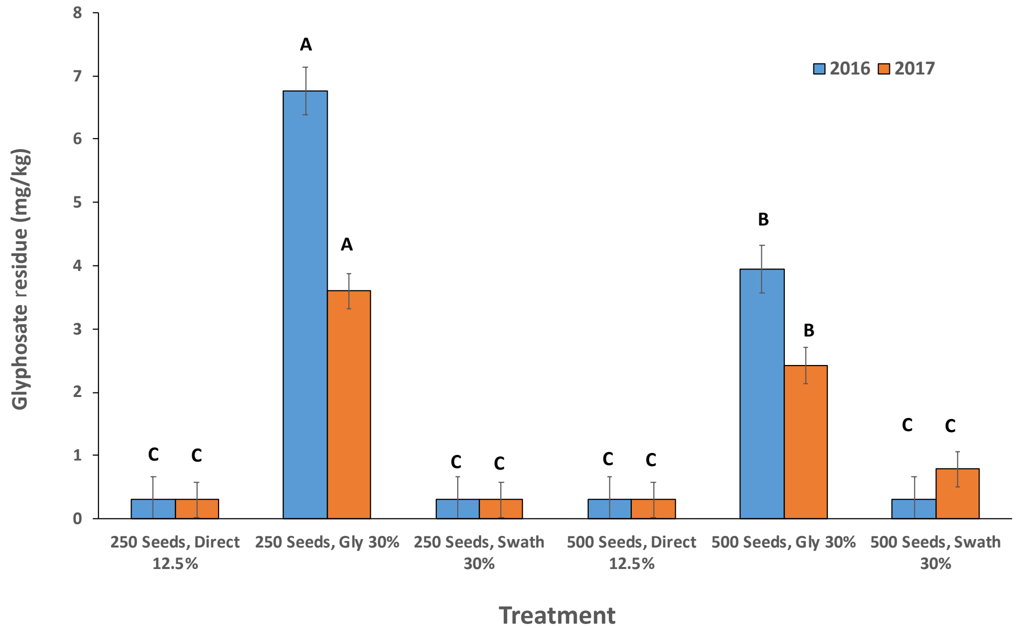

Figure 3. The interaction between seeding rate and harvest treatment on glyphosate seed residue. Different letters above bars indicate a significant difference between two means (P<0.05) within each year. Data were combined across sites but are presented within each year.

Seed residues:

The analysis for seed residues showed significant differences between years and thus, each year was analyzed separately. In both years, cultivar had no impact on glyphosate seed residues. However, there as a significant interaction between planting rate and harvest method. Not surprisingly, glyphosate seed residues were significantly greater where glyphosate was applied compared to treatments where it was not (Fig. 3). Treatments planted to the lower seeding rate of 250 seeds m^{-2} exhibited substantially higher (48 - 72%) glyphosate residues (P< 0.01) than the higher seeding rate of 500 seeds m^{-2}. This trend was consistent across both years and sites. No other differences between treatments were observed.

The accumulation of glyphosate residue in oat grain is crucial for oat processors and end users. In the current study, average glyphosate residues did not exceed 7 ppm at the 30% application timing and thus, they did not exceed the Canadian MRL of 15 ppm. It is important to note that this includes the lowest seeding density of 250 plants m-2, a density lower than most oat growers would typically employ. This density was included in the study based on its ability to delay maturity of the crop based on the production of more tillers. Given the higher residues observed in this treatment, it is likely that this did in fact happen, and did result in significantly higher glyphosate residues. Interestingly, cultivar had no impact on glyphosate seed residues. Given that we selected an early and late maturing cultivar, our results suggest that maturity differences between current oat cultivars are unlikely to contribute to differences in glyphosate residues. What is more important is that growers avoid low plant stands, which increased glyphosate residues in this study. Based on this, and the results shown here, we are confident suggesting that if growers apply glyphosate at the label recommendation of 30% seed moisture and avoid low plant stands, glyphosate residues in the seed would not be expected to exceed MRLs in North America. Nevertheless, treatments without glyphosate did avoid having substantial glyphosate residues and therefore do represent viable options.

Experiment 3: Combining cultural practices and post-emergence herbicides to manage perennial broadleaf weeds in oat

The results of the ANOVA analysis are presented in Table 18. Perennial weeds that were present at the site were Canada thistle, dandelion, perennial sow-thistle, and field horsetail.
Seeding rate was the only factor that had an effect on plant density (Table 18). Mean plant densities for the 250 and 450 seeds m^{-2} seeding rate were 112 and 171 plants m^{-2}, respectively, translating to respective emergence percentages of 45 and 38%. The sites chosen for these studies are very weedy; thus, soil moisture levels are generally lower than normal due to high water use by early emerging weeds. None of the factors affected oat yield (Table 18). The post-emergence herbicide had an effect on dockage percentage (Table 18) with a similar trend for weed seed yield (p=0.070). Dockage percentages and weed seed yields were 1.01, 0.79, and 0.52%, and 36.4, 29.5, and 21.4 kg ha^{-1}, for the untreated check, bromoxynil + MCPA, and florasulam + clopyralid + MCPA, respectively (data not shown). None of the factors had an effect on perennial weed densities or annual weed densities conducted just prior to in-crop spraying. Florasulam + clopyralid + MCPA provided effective in-crop control of field horsetail (personal observation). The important data were collected the following spring when perennial weed counts were taken.

Table 18. ANOVA of combining seeding rate, pre-harvest glyphosate, and post-emergence herbicides on managing perennial weeds in oat. Saskatoon. 2017.

Source	Plant Density (plants m^{-2})	Seed Yield (kg ha^{-1})	Dockage (%)	Weed Seed Yield (kg ha^{-1})	Perennial Weed Density (plants m^{-2})	Annual Weed Density (plants m^{-2})
Seed Rate (SR)	**<.0001**	0.216	0.084	0.106	0.763	0.912
Pre-harvest (PH)	0.052	0.700	0.136	0.065	0.397	0.417
SR*PH	0.494	0.099	0.614	0.808	0.129	0.159
Post-herbicide (POST)	0.786	0.248	**0.014**	0.070	0.609	0.714
SR*POST	0.064	0.702	0.771	0.397	0.866	0.930
PH*POST	0.297	0.704	0.127	0.296	0.789	0.657
SR*PH*POST	0.331	0.881	0.504	0.656	0.519	0.469

Effect of 2016 treatments on spring perennial weed densities

Dandelion was the predominant perennial weed at this site. Dandelion counts taken in the spring of 2017 indicted that the only factor applied in 2016 that had an effect on dandelion density was pre-harvest glyphosate (Table 19). Dandelion densities were 48 and 12 plants m^{-2} for the pre-harvest glyphosate and check treatments. This indicates that under the conditions experienced at this site in 2016 and the spring of 2017, practices other than pre-harvest glyphosate were unable to manage perennial weeds.

Table 19. ANOVA of combining seeding rate, pre-harvest glyphosate, and post-emergence herbicides on dandelion densities the following spring. Saskatoon. 2017.

Source	Dandelion Plant Density (# m^{-2})
Seed Rate (SR)	0.327
PRE-harvest (PH)	**<.0001**
SR*PH	0.088
Post-herbicide (POST)	0.585
SR*POST	0.984
PH*POST	0.997
SR*PH*POST	0.982

Effect of 2017 treatments on spring perennial weed densities

Dandelion counts taken in the spring of 2018 indicate that both pre-harvest glyphosate and post-emergence herbicides can have an impact on dandelion density (Table 20).

Table 20. ANOVA of combining seeding rate, pre-harvest glyphosate, and post-emergence herbicides on dandelion densities the following spring. Saskatoon. 2018.

	Plant Density (# m^{-2})	
Source	**Dandelion (Seedling)**	**Dandelion (Mature)**
Seed Rate (SR)	0.175	0.211
PRE-harvest (PH)	**<.0001**	**0.002**
SR*PH	0.077	0.800
Post-herbicide (POST)	**0.007**	**0.001**
SR*POST	0.213	0.860
PH*POST	**0.001**	**0.002**
SR*PH*POST	0.254	0.439

Treatments that had no POST-emergence herbicide or PRE-harvest glyphosate on average had 3 dandelion seedlings and 5 mature dandelion plants per m^{-2} (Fig. 4). By combining a POST emergence herbicide with PRE harvest glyphosate, dandelion populations were reduced to <1 plant m^{-2} on average. While there was a significant interaction between these two factors, it is plausible that PRE-harvest glyphosate may have a greater impact on subsequent dandelion populations than in-season herbicides used or seeding rates.

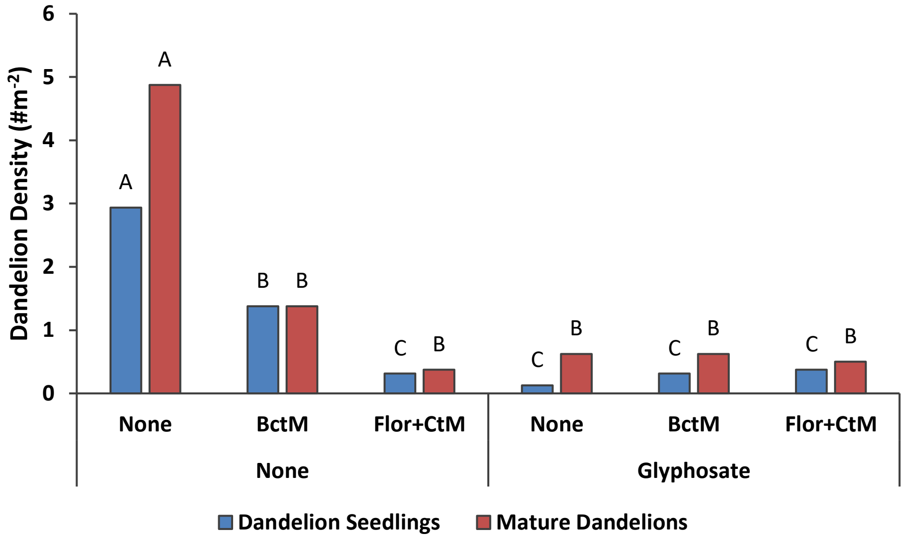

Figure 4. The interaction between POST-emergence herbicides and PRE-harvest Glyphosate. Different letters above bars indicate a significant difference between two means (P<0.05). Abbreviations: BctM = Bromoxynil + MCPA. Flor+CtM = Florasulam + clopyralid. Kernen 2018.

d.) List and briefly discuss any interim conclusions.

Experiment 1: Effect of pre-harvest glyphosate application timing on oat yield and seed physical and functional qualities.

The results of this study thus far have shown that there is a threshold as to when oats can be sprayed with glyphosate or swathed and not suffer any seed yield or seed quality penalties. Generally it is good practice to spray or swath when oats are between 30-40% SMC. Doing so does not have any substantially negative effects on crop yield or quality characteristics. Applying glyphosate or swathing at or above 50% SMC can reduce the TKW of oat by as much as 14 grams. This in turn has negative effects on seed quality and therefore end use capabilities. When treatments were swathed at or above 60%, there is a risk that beta-glucan levels can drop below 3%, the percentage groat will decline, which ultimately impacts milling yield and increases the amount of wastage during the milling process.

When oat growth is arrested by application of glyphosate or by swathing at high %SMC, preventing normal maturation of the seed, a negative impact on quality is observed. The effects can be similar to oat quality expected with early frost. The impact of glyphosate and swathing on oat quality was influenced by growing location and year. Compared to direct combining without glyphosate, there appears to be no effect on oat quality when glyphosate is applied ≤40% SMC.

Experiment 2: Agronomic and harvest management impacts on oat yield and seed quality

Across all site years, oat cultivar did not have as much of an impact as the other two factors (i.e. seeding rate and harvest method) did. Increasing seeding rates resulted in a reduction in SMC at harvest, lower TKWs, and softer groats. Overall Pinnacle was less effected by changes in harvest method in regards to percent plump and thin kernels. Whereas CDC Dancer had an increase in thin kernels and a decrease in plump kernels when plots were swathed. The results of this study show that using glyphosate as a harvest method has no more of a negative impact than swathing on oat yield or seed quality, regardless of seeding rate or cultivar used.

Experiment 3: Combining cultural practices and post-emergence herbicides to manage perennial broadleaf weeds in oat

In 2017, florasulam + clopyralid + MCPA treatments resulted in lower weed dockage and weed seed yield than the other herbicide treatments. The effect of the treatment factors from the 2016 experiment indicated that pre-harvest glyphosate was the only treatment that was effective in reducing dandelion densities in the spring of 2017. Both pre-harvest glyphosate and post-emergence herbicides applied in 2017 had an impact on dandelion populations in 2018. However, it is plausible that pre-harvest glyphosate had a greater impact on perennial weed control than in-season herbicides used. Dandelion populations were generally higher when a post-emergent herbicide was used alone. However, when it was combined with pre-harvest glyphosate, dandelion populations fell below 1 plant m^{-2}.

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

1) Willenborg C.J., E.N. Johnson, and N.P. Ames. 2017. Will pre-harvest glyphosate affect your oat crop? CropSphere 2017. Saskatoon, SK. January 10, 2017.
2) Featured in Grainews Magazine (March, 2017) – "Oats not affected by pre-harvest glyphosate". Volume 43, pages 12-13.
3) Featured in Top Crop Manager Magazine (Oct. 2017) – "The effect of pre-harvest glyphosate on quality of milling oats". Volume 43, pages 24-26.
4) Willenborg C.J., E.N. Johnson, and N.P. Ames. 2019. Under Pressure: Pre-harvest glyphosate and its impacts on crop yield and quality. Annual Meeting of the Canadian Weed Science Society. Kelowna, BC. Nov. 18-21, 2019. *Invited Presentation*
5) Ames, N., Willenborg, C.J., Malunga, L., and S. Tittlemier. A scientific investigation into the impact of pre-harvest glyphosate application on oat milling quality. Annual meeting of the American Association of Cereal Chemists. Denver, CO. Nov. 3-5, 2019.

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

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

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APPENDIX

DATA SUMMARY TABLES FOR EXPERIMENT 2

Note: Data presented as means across 3 years (2016, 2017, and 2018) and all locations (Kernen and Goodale).

Table 1: Beta glucan content (%)

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	4.66ab	4.65ab
GLYPHOSATE	4.70a	4.61ab
SWATH	4.58b	4.57b

b) Seeding rate vs Harvest

	250	500
DIRECT	4.64ab	4.66a
GLYPHOSATE	4.66a	4.65ab
SWATH	4.54b	4.61b

Table 2: Protein Content (%)

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	16.26ab	16.16ab
GLYPHOSATE	16.35a	16.20ab
SWATH	16.17ab	16.11b

b) Seeding rate vs Harvest

	250	500
DIRECT	16.15ab	16.27ab
GLYPHOSATE	16.18ab	16.37a
SWATH	16.06ab	16.22ab

Table 3: Starch content (%)

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER

DIRECT	61.22b	62.57a
GLYPHOSATE	61.12b	62.73a
SWATH	61.40b	62.69a

b) Seeding rate vs Harvest

	250	500
DIRECT	61.95a	61.85a
GLYPHOSATE	62.05a	61.79a
SWATH	62.23a	61.87a

Table 4: Stirring number

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	1772.7bc	1849.0a
GLYPHOSATE	1778.7b	1843.0a
SWATH	1749.8c	1821.4a

b) Seeding rate vs Harvest

	250	500
DIRECT	1807.4ab	1814.0a
GLYPHOSATE	1810.3ab	1811.4a
SWATH	1782.2b	1789.0ab

Table 5: Flour Pasting viscosity

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	2686.8c	3190.6a

GLYPHOSATE	2638.1c	2972.4b
SWATH	2462.1d	2647.8c

b) Seeding rate vs Harvest

	250	500
DIRECT	2910.3ab	2967.1a
GLYPHOSATE	2777.5c	2833.1bc
SWATH	2546.4d	2563.4d

Table 6: Hull percent

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	27.63b	25.37d
GLYPHOSATE	28.02ab	25.41d
SWATH	28.48a	26.11c

b) Seeding rate vs Harvest

	250	500
DIRECT	26.56b	26.44b
GLYPHOSATE	26.86ab	26.57b
SWATH	27.42a	27.16a

Table 7: Groats percent

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	72.03c	74.52a
GLYPHOSATE	71.45d	74.43a

SWATH	70.88d	73.4d

b) ***Seeding rate vs Harvest***

	250	500
DIRECT	73.42ab	73.14a
GLYPHOSATE	72.79bc	73.09ab
SWATH	72.01d	72.35cd

Table 8: Remaining hull percent

a) ***Harvest vs Cultivar***

	PINNACLE	CDC DANCER
DIRECT	0.162b	0.05c
GLYPHOSATE	0.15b	0.05c
SWATH	0.28a	0.08c

b) ***Seeding rate vs Harvest***

	250	500
DIRECT	0.11b	0.09b
GLYPHOSATE	0.10b	0.09b
SWATH	0.19a	0.17a

Table 9: Milling Yield percent

a) ***Harvest vs Cultivar***

	PINNACLE	CDC DANCER
DIRECT	143.41bc	138.10d
GLYPHOSATE	144.84b	138.39d
SWATH	148.07a	142.16c

b) Seeding rate vs Harvest

	250	500
DIRECT	141.39cd	140.74d
GLYPHOSATE	142.49bc	140.12d
SWATH	146.09a	144.14b

Table 10: Breakage percent

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	2.97b	2.74b
GLYPHOSATE	3.14b	2.83b
SWATH	4.23a	4.14a

b) Seeding rate vs Harvest

	250	500
DIRECT	3.11cd	2.60d
GLYPHOSATE	3.35bc	2.62d
SWATH	4.56a	3.81a

Table 11: Groats colour L

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	58.71b	60.61a
GLYPHOSATE	58.88b	60.58a
SWATH	58.75b	60.49a

b) Seeding rate vs Harvest

	250	500
DIRECT	59.66a	59.66a
GLYPHOSATE	59.73a	59.72a
SWATH	59.65a	59.59a

Table 12: Groats Colour a

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	4.48a	4.17c
GLYPHOSATE	4.44b	4.16c
SWATH	4.52a	4.19c

b) Seeding rate vs Harvest

	250	500
DIRECT	4.32abc	4.34ab
GLYPHOSATE	4.29c	4.30bc
SWATH	4.36a	4.35a

Table 13: Groats Colour

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	18.11c	18.96a
GLYPHOSATE	17.98d	18.82b
SWATH	17.97d	18.85ab

b) Seeding rate vs Harvest

	250	500
DIRECT	18.49ab	18.58a
GLYPHOSATE	18.33c	18.47ab
SWATH	18.37bc	18.45abc

Table 14: Flake absorption

a) ***Harvest vs Cultivar***

	PINNACLE	CDC DANCER
DIRECT	29.24a	27.57b
GLYPHOSATE	29.01a	27.26b
SWATH	29.15a	27.21b

b) ***Seeding rate vs Harvest***

	250	500
DIRECT	28.35a	28.45a
GLYPHOSATE	28.17a	28.11a
SWATH	28.44a	27.92a

Table 15: Flake granulation #6

a) ***Harvest vs Cultivar***

	PINNACLE	**CDC DANCER**
DIRECT	81.79b	88.85a
GLYPHOSATE	81.55b	88.60a
SWATH	81.26b	88.57a

b) ***Seeding rate vs Harvest***

	250	500
DIRECT	84.90a	85.74a
GLYPHOSATE	85.27a	84.59a
SWATH	84.95a	85.17a

Table 16: Flake granulation #8

a) ***Harvest vs Cultivar***

	PINNACLE	CDC DANCER
DIRECT	9.25a	6.43b
GLYPHOSATE	9.37a	6.45b
SWATH	9.56a	6.55b

b) ***Seeding rate vs Harvest***

	250	500
DIRECT	7.98a	7.73a
GLYPHOSATE	7.80a	7.99a
SWATH	8.32a	7.80a

Table 17: Flake granulation #12

a) ***Harvest vs Cultivar***

	PINNACLE	CDC DANCER
DIRECT	3.01a	1.55b
GLYPHOSATE	3.10a	1.53b
SWATH	2.81a	1.52b

b) ***Seeding rate vs Harvest***

	250	500
DIRECT	2.34a	2.19a
GLYPHOSATE	2.20a	2.43a
SWATH	2.10a	2.26a

Table 18: Flake granulation bottom pan

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	6.70a	3.94b
GLYPHOSATE	7.02a	4.18b
SWATH	6.80a	4.14b

b) Seeding rate vs Harvest

	250	500
DIRECT	5.50a	5.14a
GLYPHOSATE	5.43a	5.76a
SWATH	5.34a	5.60a

Table 19: Flake colour L

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	73.91b	75.22a
GLYPHOSATE	74.04b	75.1a
SWATH	73.95b	74.85a

b) Seeding rate vs Harvest

	250	500
DIRECT	74.67a	74.45a
GLYPHOSATE	74.46a	74.73a
SWATH	74.47a	74.33a

Table 20: Flake colour a

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	2.37a	2.05b
GLYPHOSATE	2.34a	2.05b
SWATH	2.39a	2.17b

b) Seeding rate vs Harvest

	250	500
DIRECT	2.18a	2.23a
GLYPHOSATE	2.21a	2.17a
SWATH	2.25a	2.28a

Table 21: Flake colour b

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	17.35b	18.76a
GLYPHOSATE	17.29b	18.53a
SWATH	17.30b	18.65a

b) Seeding rate vs Harvest

	250	500
DIRECT	17.92a	18.20a
GLYPHOSATE	18.03a	17.78a
SWATH	17.92a	18.03a

Table 22: Flake thickness

a) Harvest vs Cultivar

	PINNACLE	CDC DANCER
DIRECT	0.74a	0.74a
GLYPHOSATE	0.73a	0.74a
SWATH	0.73a	0.75a

b) Seeding rate vs Harvest

	250	500
DIRECT	0.74a	0.74a
GLYPHOSATE	0.73a	0.73a
SWATH	0.75a	0.74a