Government of Saskatchewan
Ministry of Agriculture

ADF Project Progress Report Format

1. **Project title, ADF file number and reporting period.**
   ADF File Number: 20190130. Title: New tools to improve wild oat and weed management in tame oat. Reporting Period: Jan. 1, 2022 to Dec. 31, 2022.

2. **Name of the Principal Investigator and contact information.**

   Christian Willenborg, PhD
   Associate Professor
   Department of Plant Sciences
   College of Agriculture and Bioresources
   University of Saskatchewan
   51 Campus Drive, Saskatoon SK
   Tel: (306) 966-8354
   Fax: (306) 966-5015
   chris.willenborg@usask.ca

3. **Name of the collaborators and contact information**

   William May
   Research Scientist
   Agriculture and Agri-food Canada
   Box 156
   Indian Head, SK, S0G 2K0
   william.may@AGR.GC.CA

   Aaron Beattie, PhD
   Associate Professor
   Department of Plant Sciences
   College of Agriculture and Bioresources
   University of Saskatchewan
   51 Campus Drive, Saskatoon SK
   Aaron.beattie@usask.ca

   Brianne McInnes
   Northeast Agriculture Research Foundation (NARF)
   Melfort, SK
   neag.agro@gmail.com

   Dr. Dilshan Beneragama
   Research Assistant
   Department of Plant Sciences
   51 Campus Drive
   University of Saskatchewan
   Saskatoon, SK, Canada S7N 5A8
   dilshan.benragama.usask.ca

4. Abstract

Every year, growers in Canada spend more money on wild oat control ($500 million) than on any other weed. Wild oat (*Avena fatua* L.) is a competitive weed (Willenborg et al., 2005a,b) that is a significant problem in many crops. Wild oat management is perhaps most challenging in oat crops because the genetic similarity between the two species precludes selective control with herbicides. However, it may be possible to utilize new technology with current herbicides to better manage wild in oat crops. In this grant, we sought to assess the competitive ability of modern oat cultivars. Second, we aimed test whether combining inter-row spraying with weed wicking could improve wild oat control. Two field studies were carried out across three sites (Saskatoon, Goodale, and Indian Head or Melfort) in Saskatchewan in 2022. Data from all locations was inconsistent. Differences seem to exist between varieties with respect to competitive ability. Varieties such as CDC Haymaker and Baler exhibit few changes in yield when weeds are present. Other varieties such as Ruffian tended to decline substantially in the presence of weeds, although location had a major impact on results. Multiple inter-row and wicking applications of herbicides at the 4- and 6-leaf crop stages provided the best combination of wild oat control and plump kernels. By employing inter-row spraying with modern competitive oat cultivars, growers should improve wild oat management in tame oat production.

5. Introduction:

Every year, growers in Canada spend more money on wild oat control ($500 million) than on any other weed. Wild oat (*Avena fatua* L.) is a competitive weed (Willenborg et al., 2005a,b) that is a significant problem in many crops. According to the Prairie weed survey, wild oat was ranked the 2nd most abundant weed species in western Canadian crops and was found in 17% of crops surveyed, even after an in-crop herbicide application (Leeson et al., 2005). Wild oat causes severe reductions in oat yield and quality (Willenborg et al., 2005 a,b). Wild oat contamination in the oat grain sample can lead to down-grading of the sample or redirection of the oat crop to the feed market. Such losses are economically damaging for growers and cost them millions of dollars per year in lost revenue. Consequently, various methods to improve oat competitive ability with wild oat have been examined over the years. Willenborg et al. (2005a) showed that time of emergence and density of wild oat were critical to oat-wild oat competition, and that controlling early emerging wild oat was key to minimizing yield loss. Reductions in oat physical grain quality were also observed, but were small relative to yield loss (Willenborg et al., 2005b). Building on this work, May et al. (2009) reported that early seeding of oat crops at densities above 350 seeds m-2 increased the probability of producing a high yielding, high quality oat crop in the presence of wild oat. More recent work has shown that coupling high seeding rates with side-banded phosphorus application further improved wild oat management in oat crops (May, 2018). Seed size was shown to increase the competitive ability of tame oat with wild oat under greenhouse conditions, with large seeds producing 17% more biomass and 15% more panicles than small seeds (Willenborg et al., 2005c). While all of these studies have improved oat production, wild oat is still a significant problem for oat growers and more research is needed.

Wild oat management is perhaps most challenging in oat crops because the genetic similarity between the two species precludes selective control with herbicides. However, it may be possible to utilize new technology with current herbicides to better manage wild in oat crops. My program has built a shrouded inter-row sprayer that can be used to spray non-selective herbicides between the crop rows with little to no damage to the crop. Weed wicks also allow application of a non-selective herbicide to sensitive crops, and control any weeds taller than the crop canopy by simply rubbing them with herbicide. We hypothesize that coupling our inter-row sprayer with a weed wick can be used to significantly reduce wild oat in oat crops. By spraying a non-selective herbicide between the crop rows, and using a weed wick (with glyphosate) to manage wild oat taller than the crop canopy, we may finally have chemical control of wild oat in oat crops.

A wider row spacing makes the commercialization of inter-row spraying easier by increasing the margin of error when spraying. In addition wider row spacing in a no-till cropping system has several potential advantages including better residue flow around the seed openers during seeding, reduced cost and improved efficiencies by allowing producers to utilize a wider air seeder without increasing the tractor size thereby increasing the potential acres that can be seeded in a day. In addition a wider row spacing can facilitate the seeding of the crop in between the stubble rows of the previous crop improving seed bed conditions for germination and emergence. However, a decrease in grain yield and loss of weed control will occur at some point as the row spacing is widened. In a weed free environment the row spacing was increased to 35 cm with little impact on oat yield and quality. Unfortunately, oat fields are not always weed free so before a wider row spacing can be utilized, the interaction of weeds and row spacing in oat needs to be studied to ensure we recommend a combination of agronomic practices that support a highly competitive oat crop.

However, we recognize that even with the best combination of agronomic practices some wild oat will emerge within the crop row, at the same time as the crop, and thus will not be controlled by the weed wick. Here, more competitive oat cultivars could offer potential for growers to further minimize losses from wild oat. However, research on oat cultivars has produced mixed results. Willenborg et al. (2005c) found relatively few differences in competitive ability between oat cultivars, whereas Wildeman (2004) indicated a forage oat, CDC Bell, had greater competitive ability than most of the other cultivars tested. Unfortunately, only one of the cultivars tested by Wildeman (2004) is still grown. Competitive cultivars are an important option for growers, as they generally do not incur any additional costs (Andrew et al. 2015). Crops or cultivars can compete with weeds by maintaining their seed yield through tolerance of weed interference and/or by suppressing weed growth and weed seed production (Jacob et al. 2016). The use of competitive wheat cultivars in Greece has been demonstrated to allow for a 50% reduction in herbicide rates (Travlos 2012). Assessing current cultivars for competitive traits, including their ability to compete and withstand competition from wild oat, would help breeders select for more competitive cultivars. It is important, therefore, to understand if differences in competitive ability exist among oat current cultivars.

6. **Objectives and the *progress towards meeting each objective***

Objectives (*Please list the original objectives and/or revised objectives if Ministry-approved revisions have been made to original objective. A justification is needed for any deviation from original objectives)*	**Progress (e.g. completed/in progress)**
1) To determine if combining inter-row spraying and weed wicking with non-selective herbicides can be used to improve wild oat control in oat crops	Study is in progress. Second year of field research carried out at three sites last year, two near Saskatoon and one near Melfort.
2) To evaluate the competitive ability (ability to suppress and withstand weed competition) of modern oat cultivars and to rank cultivars based on their competitiveness	Study is in progress. Second year of field research carried out at three sites last year, two near Saskatoon and one near Melfort.
3) To determine the impact of competitive cultivars and row spacing on oat competitive ability	Study is in progress. First year of field trials for this study were initiated in 2022 at Saskatoon and Indian Head.

Please add additional lines as required.

7. **Methodology:**

Competitive Ability of Modern Oat Cultivars

Experimental Design: The experiment was conducted at 3 locations in 2022, two near Saskatoon (Kernen and Goodale Research Farms) and one at Indian Head, SK. The experimental design was a split-block with four replications per treatment. Weed density comprised the main plot treatments while subplot treatments were comprised of oat cultivars. Cultivars were planted in 2 x 12-m main plots, with subplots being 2 x 6 m in size.

Prior to plot establishment, all plots received a glyphosate application at 950 g a.e. ha^{-1} to control emerged weeds. The experiment was sown on canola stubble at both locations. Half of each block was kept weed-free while the other half contained volunteer canola. Volunteer canola was used as a surrogate weed and was seeded in the weedy treatments to ensure uniform weed densities. Volunteer canola was sown perpendicular to the oat at the time of oat sowing. The target density for surrogate weed species was 25 plants m^{-2}. Seventeen diverse oat cultivars were seeded within the presence or absence of weeds. Proposed cultivars include Camden, AC Morgan, Summit, Souris, CDC Ruffian, AC Mustang, CDC Dancer, CDC Nasser, CDC SO-1, CDC Baler, CDC Haymaker, ORE3542M, CDC Morrison, CDC Arborg, CDC Endure, AAC

Oravena (organically-bred) and AAC Kongsore (organically-bred). The organically-bred cultivars were included to assess whether they differ in their response to competitors compared with conventionally-bred cultivars. Cultivars were chosen on the basis of diversity in pedigree and to provide variation in traits that could be important to competitive ability. Oat was planted to achieve a recommended density 300 plants m^{-2} and at a depth of 2 cm. Fertilizer was banded at seeding based on soil test recommendations. Weeds in the weed-free block not controlled by the herbicide application were removed by hand.

Crop density was measured as stated above. Height was taken at the front and back of each plot, and then averaged on a per plot basis. Plots will be harvested with a small plot combine with the grain sample dried to a constant moisture, weighed, and cleaned with a dockage tester to obtain a clean yield. This also allowed us to separate the model weed seed from the crop to determine dockage.

Data were analyzed using an analysis of variance (ANOVA) using mixed models in R. Each location was analyzed separate from each other due to the significant differences in results between sites. The experiment was analyzed as a randomized complete split block design. Many comparisons were made between treatments and all interactions among these effects. The fixed effects were treatment (weedy vs. weed free) and Oat Variety. The random effects were replication/ block, Variety (as they were randomized throughout each block). No significant results were obtained at the Goodale site, likely due to environmental conditions. Given this, and the differences between locations, all analyses were conducted within sites.

Inter-row spraying and wicking of non-selective herbicides to control wild oat

Experimental Design: The experiment utilized a randomized, complete block design and each treatment was replicated four times. Treatments consisted of factorial arrangements of inter-row spraying and weed wicking at various crop stages. The experiment was conducted at 3 locations in 2021, two near Saskatoon (Kernen and Goodale Research Farms) and one near Melfort. Plots were 2m wide by 6m long.

The experiment was established on land having a background population of wild oat. To that, 150 seeds m^{-2} of wild oat were broadcast along the soil surface at the time of sowing to supplement the native population. Camden oats were planted across the trial to achieve a target density of 300 plants m^{-2}. Camden was used as it is the most widely grown oat cultivar across the prairies. Treatments included an unsprayed control, inter-row spraying at the 2, 4, 6 crop leaf stages, a combination of inter-row spraying and wicking at the 2, 4, 6 crop leaf stages, and a multiple pass combination treatment of inter-row spraying and wicking at the 2&4, 2&6, 4&6 crop leaf stages. Herbicide choice for the inter-row sprayer was 600 g ai ha^{-1} of glufosinate + 45 g ai ha-1 clethodim. Glyphosate (540 g/L formulation) was applied through the weed wick, which was set to run immediately above the crop canopy.

Data collection included crop and wild oat phytotoxicity ratings. Wild oat efficacy was assessed by visual ratings taken at 7-10 and 21-28 after the treatments (DAT). Visual ratings were taken by comparing treated plots to untreated check plots. Ratings were conducted based on the Canadian Weed Science Society (CWSS) 0-100% scale (Canadian Weed Science

Society, 2018), where values greater than 80% indicate acceptable control. Oat crop phytotoxicity was evaluated by visually rating plots on the CWSS scale at 7-10 and 21-28 DAT (Canadian Weed Science Society, 2018). Each treatment was assigned a rating from 0-100% with a rating of 0% indicating no injury and 100%, indicating complete mortality. Initial damage of up to 10% is considered acceptable.

Crop stand counts were conducted 2 to 3 weeks after crop emergence by counting the total number of seedlings present in two samples of paired 1-m rows from each plot, excluding border rows. Oat yield was determined from whole plots using a plot combine. All seed samples were cleaned and weighed to determine grain yield. Following this, manual removal of all wild oat seed allowed for determination of percentage wild oat in the harvested grain sample. Thousand seed weight was determined by counting and weighing 1000 seeds from each cleaned yield sample. The percentage of thin kernels in each grain sample was recorded as the portion of the mass passing through a 1.95-mm by 8.33-mm (5/64″ by 3/4″) slotted sieve after shaking for 90 s, and the percentage plump kernels as the portion of the mass retained on a 2.15-mm by 8.33-mm (5.5/64″ by 3/4″) slotted sieve after shaking for 90 s (Willenborg et al., 2005c).

Data was analyzed using an analysis of variance (ANOVA) using mixed models in R. Each location was analyzed separate from each other because of varying wild oat presence and results between experiment locations. The experiment was analyzed as a randomized complete block design. Many comparisons were made between treatments and all interactions among variables. The fixed effects analyzed were spray treatment, yield and percentage of wild oat. The random effect used in this analysis was replication. Some plots lacked wild oats and thus represented outliers in the data set. All outliers were identified and removed. Experimental sites differed significantly in results and for that reason was analyzed separately. Due to lack of wild oat plants and environmental conditions at the Goodale site, the site was omitted.

Competitive ability of oat as row spacing increases

The experiment was conducted at two locations in 2022, one near Saskatoon and one near Indian Head SK. The experimental design was a split-block with four replications per treatment. Weed density (0, 13 and 26 canola seeds m^{-2}) comprised the main plot treatments and the subplot treatments were comprised of two oat cultivars (AC Morgan and CDC Endure) and five row spacings (25, 30, 35, 40, and 50 cm). Cultivars were planted in 4 x 32 m main plots, with subplots being 4 x 10.75 m in size.

Prior to plot establishment, all plots will received a glyphosate application at 950 g a.e. ha^{-1} to control emerged weeds. Canola was sown to act as a pseudo weed and was will prior to the oats; oats were cross seeded across the plots within a short period of time after seeding the canola. Oat was planted to achieve a recommended density 300 plants m^{-2} and at a depth of 2 cm. Fertilizer was banded at seeding. P, K and S applications were based on soil test recommendations with a nitrogen target of 120 kg ha^{-1} (combining soil residual N from 0-60cm and fertilizer N).

Data collection will included soil test results @ 0-6 inches, 6-24 inches, N bulked across reps, P, K, and S bulked across the test. In addition, we collected oat density, canola density, tiller density, plant height, lodging, oat and canola biomass, grain yield, dockage, test weight, 1000 kernel weight, % plump kernels, and % thin kernels. Not all collected data are reported on in the current report.

8. Results and discussion

Competitive Ability of Modern Oat Cultivars

After observing unusual data in some plots (notably higher yields in weedy plots then weed-free plots) outliers were present, most in block four and for that reason it was omitted from the analysis. There was a competition effect on oat biomass ($P<0.05$) and yield (*P=0.001*) at the Kernen site (Table 1). However, the effect of variety and the competition by variety interaction did not affect oat either oat biomass or yield *(P>0.05*). This indicates that weed competition did have an impact on oat biomass and yield, but overall, the way in which the different oat varieties responded to competition was similar at Kernen in 2022. Weed competition reduced oat biomass by 10% and yield by 13% on average (Tables 2, 3). Although not statistically significant, CDC Baler had greater biomass in both weedy and weed-free plots (data not shown). Competition with weeds had the greatest impact on the grain yield of CDC Morrison (*p=0.0392*) and ORE3542M (*p=0.0464*). Single degree of freedom contrasts indicted CDC and ORE3542M produced 706 kg/ha and 681 kg/ha greater yields, respectively, in the weed-free compared with weedy plots (Table 4). Although not statistically significant, CDC Ruffian and Baler yielded exhibited only minor yield reductions under weedy compared with weed-free conditions.

Table 1: P-values derived from ANOVA on oat yield (OYLD), weed seed production (WSP), weed biomass (WBM), and oat biomass (OBM) for Kernen in 2022.

Source	OYLD	WSP	WBM	OBM
Location	2e-16***	---	---	---
Cultivar	0.153	0.00376*	0.286	0.138
Competition	0.00160***	0.298	0.115	0.0439 **
Cultivar*Competition	0.997	0.0037*	0.286	0.515
Block	4.28x10-7 ***	1.37x10-6	0.232	0.162
Block*Competition	0.156	1.37x10-6	0.000111 ***	0.298

Table 2: Multiple comparison of competition effect on oat yield at Kernen in 2022. Similar letters indicate no significant difference based on $HSD_{0.05}$.

	Mean	SE	Lower	Upper	LSD
Weed-free (No Competition)	3318	59.2	3153	3484	A
Weedy (Competition)	2882	59.2	2716	3047	B

Table 3: Multiple comparison of competition on oat biomass at Kernen in 2022. Similar letters indicate no significant difference based on $HSD_{0.05}$.

	Mean	SE	df	lower.CL	upper.CL	Group
WEED-FREE	642	17.5	2.99	587	698	A
WEEDY	577	17.5	2.99	521	633	B

Table 4: Single degree of freedom contrasts on the difference in oat yield between weed-free and weedy plots.

Variety	$Yield_{WF} - Yield_{W}$	P value
AAC Kongsore	640.1	0.0607
AC Morgan	553.2	0.103
AC Mustang	418.5	0.216
Camden	640.1	0.0608
CDC Arborg	284.6	0.399
CDC Baler	155.8	0.643
CDC Dancer	475.4	0.161
CDC Endure	343.4	0.309
CDC Haymaker	441.8	0.192
CDC Morrison	706.1	0.0392
CDC Nasser	188.7	0.575
CDC Ruffian	50.7	0.88
CDC S01	474.8	0.161
ORE3542M	681	0.0464
Souris	480.1	0.157
Summit	450.9	0.183

Weed seed production differed significantly between oat varieties at Kernen (*P=0.011*, Table 1). For example, 435% more weed seed was found in plots of ORE4542M (76.6 kg/ha) than in CDC Baler (14.3 kg/ha) (Figure 1, Table 5). In fact, the greatest weed seed production across all oat varieties was observed in ORE3542M, while CDC Baler and CDC Haymaker had the lowest weed seed production across varieties. CDC Nasser and Endure exhibited similar reductions to Baler and Haymaker for weed seed production, which is surprising given that the former are forage varieties but the alter are not. All other varieties were intermediate to ORE3542M and CDC Baler/Haymaker, and did not differ significantly.

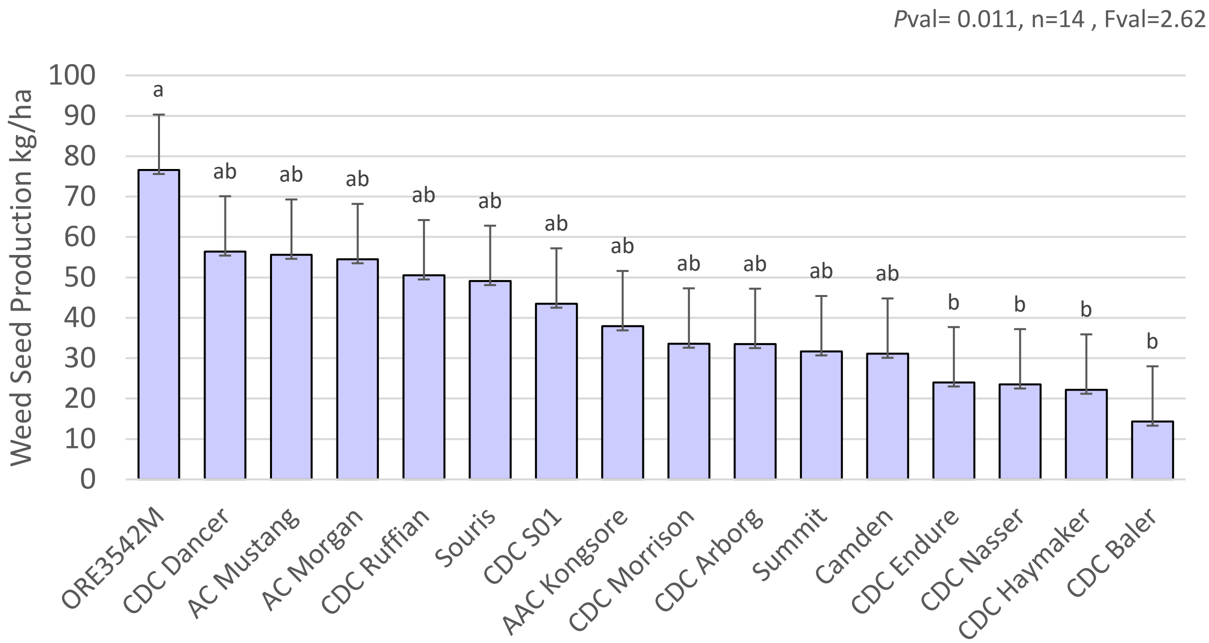


Figure 1: Weed seed production of cultivars at the Kernen 2022 site. Error bars represent the standard error of the least squares means. Similar letters indicate no significant difference based on $HSD_{0.05}$.

Table 5: Multiple Comparison of weed seed production of cultivars at the Kernen site in 2022. Similar letters indicate no significant difference based on $HSD_{0.05}$.

Variety	Mean WSP	SE	df	Lower CL	Upper CL	Group
ORE3542M	76.6	13.7	7.68	44.762	108.5	A
CDC Dancer	56.4	13.7	7.68	24.575	88.3	AB
AC Mustang	55.6	13.7	7.68	23.75	87.5	AB
AC Morgan	54.5	13.7	7.68	22.625	86.4	AB
CDC Ruffian	50.5	13.7	7.68	18.595	82.3	AB
Souris	49.1	13.7	7.68	17.262	81	AB
CDC S01	43.5	13.7	7.68	11.675	75.4	AB
AAC Kongsore	37.9	13.7	7.68	6.031	69.8	AB
CDC Morrison	33.6	13.7	7.68	1.748	65.5	AB
CDC Arborg	33.5	13.7	7.68	1.659	65.4	AB
Summit	31.7	13.7	7.68	-0.15	63.6	AB
Camden	31.1	13.7	7.68	-0.761	63	AB
CDC Endure	24	13.7	7.68	-7.872	55.9	B
CDC Nasser	23.5	13.7	7.68	-8.352	55.4	B
CDC Haymaker	22.2	13.7	7.68	-9.65	54.1	B
CDC Baler	14.3	13.7	7.68	-17.569	46.2	B

1.3 Indian Head

In contrast to the site at Kernen, differences were observed in crop yield at Indian Head. Both the main effects of competition *(P=<0.001*) and Variety (*P=<0.001*), as well as the variety interaction (*P=<0.01*) differed significantly (Table 6). AC Morgan (5574 kg/ha) produced significantly greater yields than Souris, CDC Baler and CDC Haymaker (Table 7). Both Souris and CDC Baler exhibited greater yields and CDC Haymaker, the lowest yielding variety. All other varieties were intermediate to these. CDC Haymaker (2837 kg/ha), the lowest yielding variety, produced only half the yield of Morgan. resulting in a 96.5% increase in yield for AC Morgan (Table 7). No surprisingly yield of oat varieties was lower when competition was present (Table 8). Differences between varieties in weed-free vs weedy plots varied widely. For example, CDC Ruffian exhibited roughly have the yield loss of AC Mustang (412 vs 202 kg/ha). The varieties whose yield was least impacted by competition from weeds were CDC Dancer, CDC Baler CDC Arborg and AC Mustang (Figure 5).

Table 6: P-values for oat yield (OYLD) and weed seed production (WSP) for the Indian Head site in 2022.

Source	OYLD	WSP
Location	2e-16***	---
Cultivar	2.82x10-9***	0.000221***
Competition	7.08x10-09 ***	2e-16 ***
Cultivar*Competition	0.04113 *	0.00221 ***
Block	0.170	0.505
Block*Competition	0.108	0.120

Table 7: Multiple comparison of oat variety mean yields, at the Indian Head 2022 site. Similar letters indicate no significant difference based on HSD0.05.

Variety	Mean	SE	df	lower CL.	upper CL.	Group
AC Morgan	5574	231	86.9	5116	6033	A
CDC Endure	5095	231	86.9	4637	5554	AB
Camden	4984	231	86.9	4526	5443	AB
CDC S01	4952	231	86.9	4494	5411	AB
CDC Ruffian	4899	231	86.9	4440	5357	AB
CDC Arborg	4882	231	86.9	4423	5340	AB
Summit	4870	231	86.9	4412	5329	AB
ORE3542M	4725	231	86.9	4266	5183	AB
AAC Kongsore	4656	231	86.9	4198	5114	AB
AC Mustang	4545	231	86.9	4087	5003	AB
CDC Dancer	4544	231	86.9	4086	5003	AB
CDC Nasser	4540	231	86.9	4082	4998	AB
CDC Morrison	4452	231	86.9	3994	4911	AB
Souris	4298	231	86.9	3839	4756	B
CDC Baler	4120	231	86.9	3662	4578	B
CDC Haymaker	2837	231	86.9	2379	3296	C

Table 8: Multiple comparison of competition effect on oat yield *(P=<0.001)* at Indian Head 2022.

	Mean	SE	df	lower.CL	upper.CL	Group
WEED-FREE	5313	81.5	7.83	5125	5502	A
WEEDY	3934	81.5	7.83	3745	4122	B

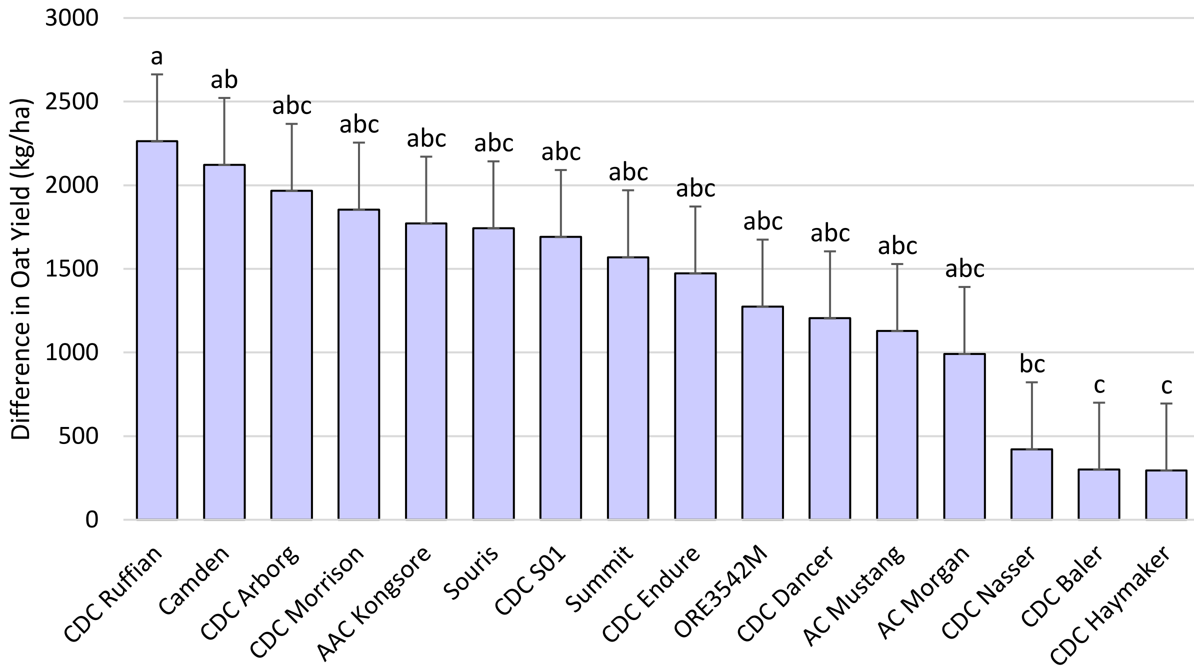


Figure 5: Contrast of variety-competition interaction effect on yield from Indian Head 2022. Method= pairwise, alpha=0.05. Similar letters indicate no significant difference.

1.3.2 Weed Seed Production

Weed seed production differed significantly between varieties at Indian Head (Table 6). Weed seed production ranged from 412 kg/ha (CDC Ruffian) to 202 kg/ha (AC Mustang) (Figure 6). The greatest weed seed production was observed in CDC Ruffian and Souris, and both of these varieties were among the lowest yielding and most affected by weed competition Figure 5). The lowest weed seed production was observed in AC Mustang, which also tended to be less affected by competition (Figure 6).

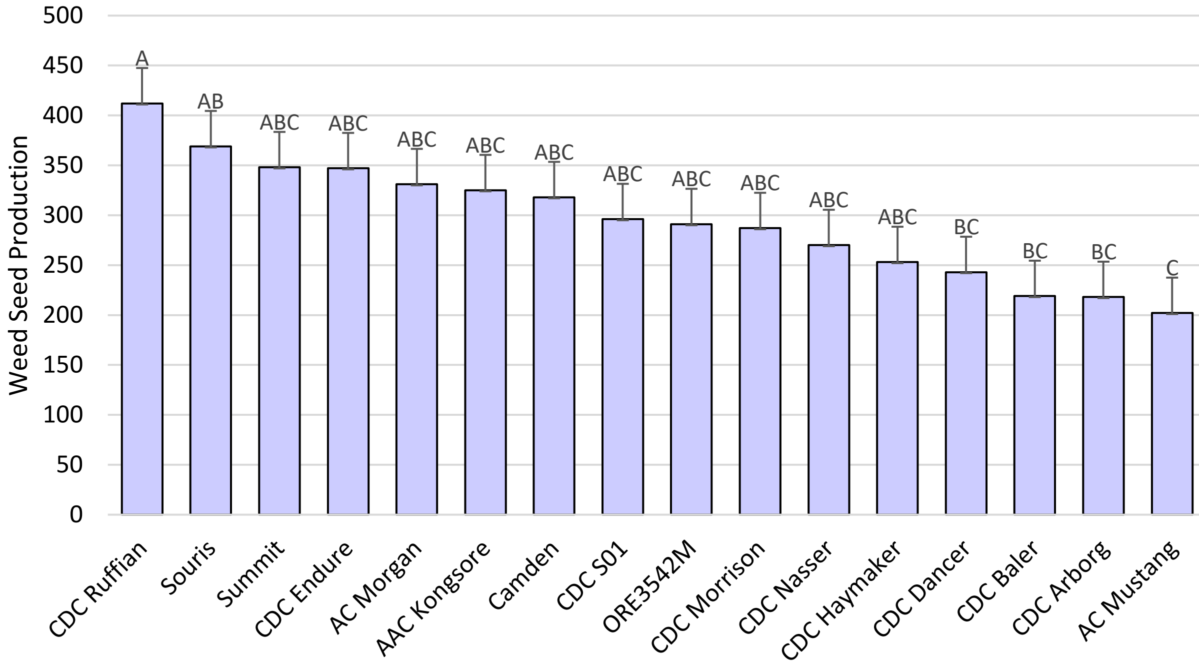


Figure 6: Weed seed production of cultivars at the Indian Head 2022 site. Error bars represent the standard error of the least squares means. Similar letters indicate no significant difference based on $HSD_{0.05}$.

1.4 Ability to Withstand Competition and Ability to Compete

Ability to withstand competition (AWC) measures tolerance to weed interference and was calculated as: AWC=100(Yield $_{weedy}$/Yield $_{weed\text{-}free}$). Ability to compete (AC) was calculated as (100 - % dockage). Percent dockage was calculated as the amount of weed seed in each harvested sample. The ability to withstand competition (AWC) differed significantly among varieties at Indian Head but not at Kernen (Table 9). AWC values ranged from 62.8 to 98.6 and this represented a yield loss that ranged from 1.4% to 37.2%. CDC Baler exhibited significantly higher AWC value than other cultivars indicating that the variety was better at withstanding the presence of competitors than other varieties (Table10). This variety was also one of the least affected by competition at Kernen. Surprisingly, CDC Arborg and Ruffian had the lowest AWC at Indian Head, but the highest at Kernen. This is difficult to explain but may be due to the ability of environmental conditions to impact relative competitive ability between oat and wild oat. Kernen tended to be much drier than Indian Head in both years.

Ability to compete (AC) measures the weed suppressive ability of the different varieties and is referred to as competitive effect. Significant differences in AC were only observed at the Kernen 2022 location (Table 9). CDC Baler had the highest AC values and therefore was the best variety at supressing weeds, whereas ORE3542M had the lowest AC value and thus was the least competitive of varieties. All other varieties were intermediate to these.

Table 9: P-values indicating significance of cultivated oa tvarieties to withstand competition (AWC) as well as their ability to compete (AC). Data are from Kernen and Indian Head in 2022.

	AWC	AC
Kernen 2022		
Cultivar	NS	0.0267*
Indian Head 2022		
Cultivar	0.00586**	NS

Table 10: Values for ability to withstand competition (AWC) and ability to compete (AC) for cultivated oat varieties grown in Kernen and Indian Head in 2022. Data are means derived from calculations, as laid out in the text, between weedy and weed-free plots.

	AC		AWC	
Variety	Kernen	Indian Head	Kernen	Indian Head
AAC Kongsore	98.9	82.4	81.2	69.1
AC Morgan	98.4	86.4	83.7	83.7
AC Mustang	98.3	89.8	86.5	78.3
Camden	99	83.4	78	65
CDC Arborg	99	74.8	93.5	64.1
CDC Baler	99.6	88.9	96.9	98.6
CDC Dancer	98.1	87.7	85.4	76.7
CDC Endure	99.2	83.6	91.6	74.6
CDC Haymaker	99.2	81.3	87.9	90.2
CDC Morrison	99	83.5	79	66.1
CDC Nasser	99.3	87.3	96.3	93.2
CDC Ruffian	98.3	78.2	103.3	62.8
CDC S01	98.6	85.5	87.9	70.7
ORE3542M	97.6	85.5	79.9	77.6
Souris	98.4	78.3	84.9	66.5
Summit	99	82.5	85.8	72.4

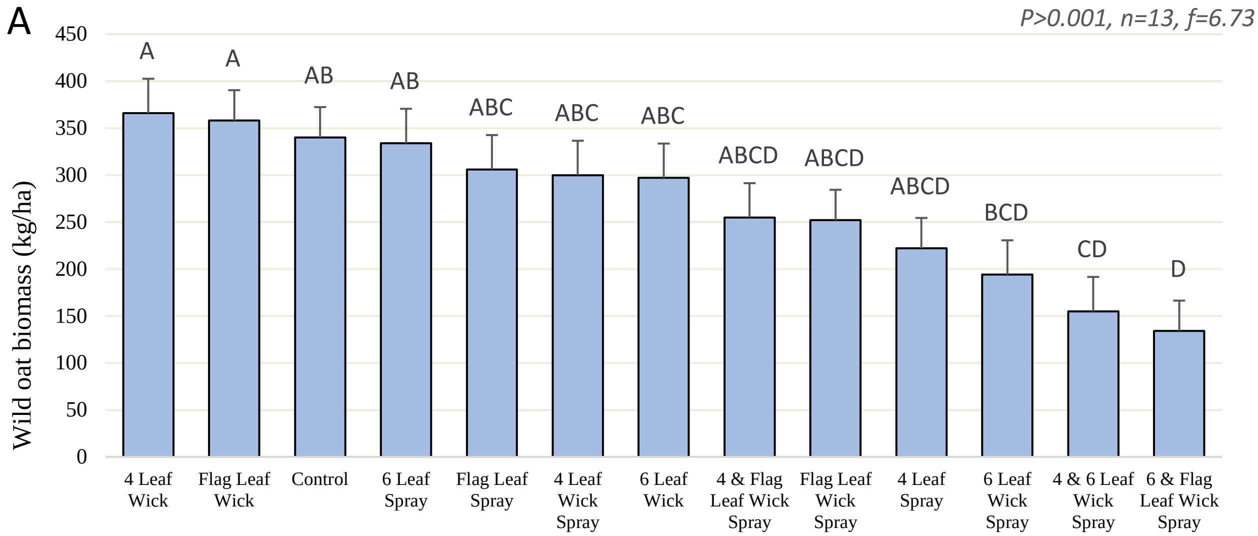
Inter-row spraying and wicking of non-selective herbicides to control wild oat

Kernen

At the Kernen site in 2022 there was a significant difference among treatments in the percentage of wild oat and plump grains in the harvested oat grain sample (Table 11).
Treatments consisting of combinations of wicking and inter-row spraying at either the 4- & 6-leaf or the 6- & flag-leaf were significantly better at reducing wild oat biomass than wicking at the 4 leaf or flag leaf timing or inter-row spraying at the 6-leaf stage (Figure 7A). These differences were rather large, as the combination treatment of wicking and spraying at the 6-leaf and flag-leaf stages reduced wild oat by 63% compared to the wicking at the 4-leaf stage (Figure 7A). Wicking and spraying at the 6-leaf stage also reduced wild oat seed production significantly compared with these treatments. Few treatments had an impact on percent wild oat in the harvested sample (Table 11). Combination treatments of wicking and inter-row spraying at either the 4- & 6-leaf or the 6- & flag-leaf reduced percent wild in the oat grain sample significantly more than wicking alone at either the 4 or flag leaf stage. These combination treatments also tended to increase the percentage of plump kernels over the control treatment, as well as wicking at the 4-leaf stage. In fact, there was a 24% increase in percent plump grains between the control and the 4&6 Leaf Wick and Spray herbicide treatment (Figure 8). There was no significant difference between herbicide treatments for oat yield. Likewise, herbicide treatment had no significant effect on thousand kernel weight (TKW) and test weight (TW) (Table 11).

Table 11: P-values for Oat Yield (OYLD), wild oat biomass (WO), Percent Wild Oat (WOP) in the grain sample, Wild oat Thousand Kernel Weight (TKW) (kg/ha), Test Weight (TW) and Percent Plump Grains (PPG) for Kernen in the 2022 Season.

Source	OYLD	WOP	WO	TKW	TW	PPG
Herbicide Treatment	0.0631	0.00189 ***	1.68x10-5 ***	0.166	0.135	0.000474 ***
Block	3.284x10-05 ***	0.00155***	0.0377*	0.870	0.884	0.227



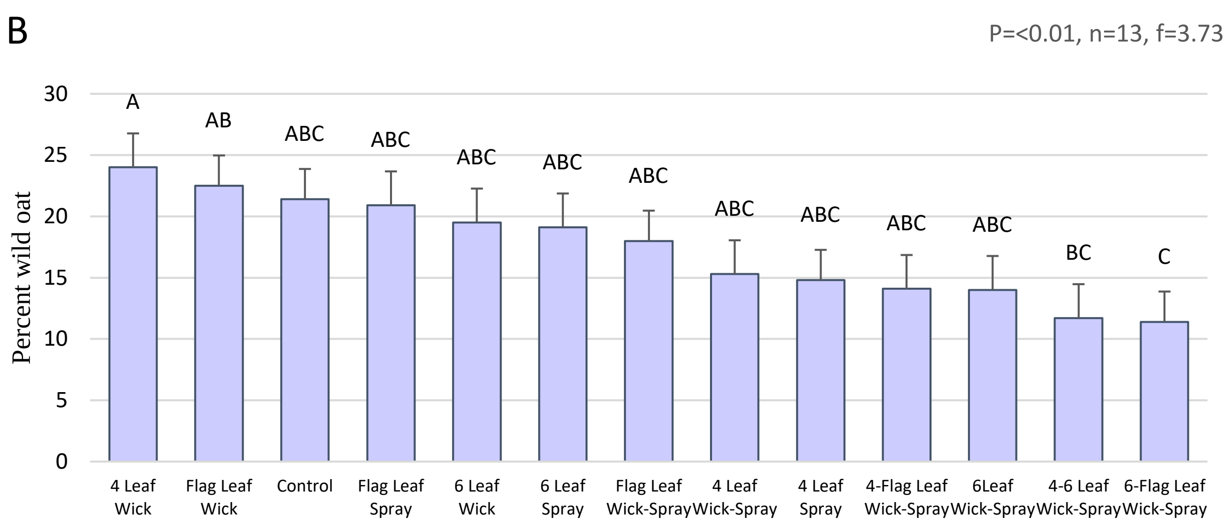


Figure 7: Wild oat biomass (A) and percent wild oat (B) of herbicide treatments at the Kernen site in 2022. Error bars represent the standard error of the least squares means. Similar letters indicate no significant difference based on $HSD_{0.05}$.

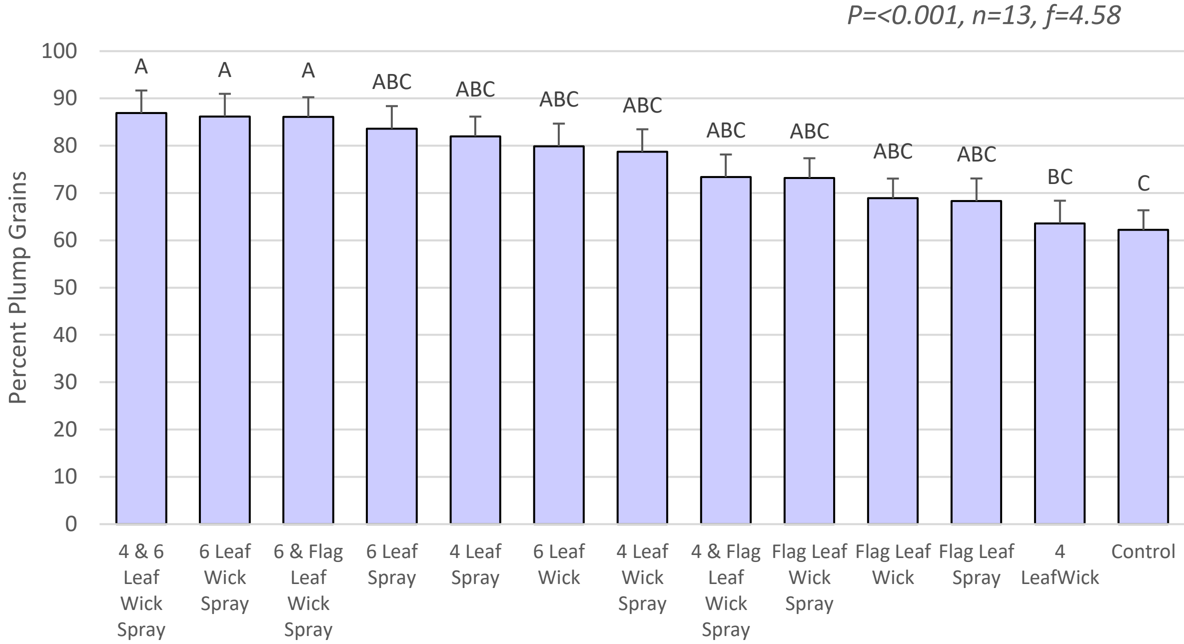


Figure 8: Percent plump grains of herbicide treatments at the Kernen site in 2022. Error bars represent the standard error of the least squares means. Similar letters indicate no significant difference based on $HSD_{0.05}$.

Melfort

At the Melfort site in 2022 there was no significant difference in oat yield, percent wild oat in the oat grain sample, thousand kernel weight (TKW) or weight (TW) (Table 12). The only variable impacted by the timing and type of herbicide application was the percentage of plump kernels. The percentage of plump kernels was greatest in the unsprayed control and when inter-row spraying was conducted at the flag leaf stage (Table 13). However, plump kernels decreased significantly (3%) when wicking and spraying were carried out at the 4-6 leaf stage. All other treatments were intermediate to these.

Table 12: P-values for Oat Yield (OYLD), wild oat biomass (WO), Percent Wild Oat (WOP) in the grain sample, Wild oat Thousand Kernel Weight (TKW) (kg/ha), Test Weight (TW) and Percent Plump Grains (PPG) for Melfort in the 2022 Season.

Source	OYLD	WOP	TKW	TW	PPG
Herbicide Treatment	0.0468*	0.779	0.156	0.139	0.00992 **
Block	0.154	0.173	1	1	0.898

Table 13: Multiple comparisons of treatments means for precent plump kernels at Melfort in 2022. Similar letters in the column 'group' indicate no significant difference based on $HSD_{0.05}$.

Treatment	Mean	SE	df	Group
Control	95.1	0.579	39	A
Flag Leaf Spray	95	0.579	39	A
6 Leaf Wick	94.7	0.579	39	AB
Flag Leaf Wick & Spray	94.6	0.579	39	AB
4 Leaf Wick	94.6	0.579	39	AB
Flag Leaf Wick	94.5	0.579	39	AB
4, Flag Leaf Wick & Spray	94.2	0.579	39	AB
4 Leaf Wick & Spray	94	0.579	39	AB
6 Leaf Spray	93.6	0.579	39	AB
6, Flag Leaf Wick and Spray	93.3	0.579	39	AB
4 Leaf Spray	93	0.579	39	AB
6 Leaf Wick & Spray	92.7	0.579	39	AB
4,6 Leaf Wick & Spray	92.1	0.579	39	B

Wild oat seed production and percentage in the harvested grain sample were greatest in the control plot and treatments at the 4-leaf and flag-leaf wicking treatment at Kernen. No differences were observed between these treatments, which suggests wicking alone between the 4 leaf and flag leaf stage is not a successful wild oat management strategy, at least not in this year. A small reduction in wild oat seed production was observed when both wicking and spraying were carried out at the 6-leaf stage, but this did not result in a meaningful reduction in the percentage wild oat in the harvested grain sample. However, by combining a wicking and inter-row spraying application at either the 4-6 leaf stage or the 6-flag leaf stage, both wild oat seed production and percentage in the oat grain sample dropped by 40-50%, which was not only significant but also represents a sizeable reduction. These treatments also produced plumper seeds, although test weight was unaffected. A similar effect on plump kernels was noted at Melfort, but treatments had no impact on any other variable at that site. It is possible that late harvest resulted in much of the wild oat shattering, thereby reducing the likelihood of observing differences between treatments. Given that no herbicide options are available for wild oat, the results at Kernen suggests real potential for the wick and inter-row spray at stages beyond four leaves. However, the efficacy of the wicking treatment would depend on emergence timing of wild oat, as late-emerging wild oat would not be controlled with the wick. This is not a problem for wild oat between the row, which can be sprayed using the inter-row sprayer. Such conditions would result in most of the yield loss occurring from wild oat emerging within the oat row. Because wicking involves very little herbicide, the cost of wicking is relative minor, and by spraying between the rows less herbicide should be needed since only half the field would be sprayed in this case. Therefore, when combined with other agronomic factors such as seeding rate and competitive cultivars, among others, it may be possible to achieve even better management of wild oat with the tools provided here.

Competitive ability of oat as row spacing increases

At both Indian Head and Saskatoon oat plant density was impacted by row spacing (Tables 14 and 15). The target plant density was 300 plants m^{-2} . At Indian Head the plant density decreased from 366 to 227 plants m^{-2} as the row width increased from 25 to 50 cm (Table 16). A similar trend occurred at Saskatoon with a decrease from 166 to 99 plants m^{-2} as the row width increased from 25 to 50 cm (Table 17). This was expected as the field mortality of the crop tends to increase as more seed is crowed together in the row as the row width is increased. At Indian Head with good environmental conditions for germination and emergence the estimation of field mortality was too high while at Saskatoon it was too low due to the drought conditions that occurred at Saskatoon in 2022.

At Saskatoon the weed density was affected be the canola seeding rate (Table 18); however, at Indian Head the zero canola seeding rate was not measure due to an error in communication and the two other canola seeding rates ended up with the same canola density (Tables 14 and 16). At Indian Head the canola density in the 13 and 26 seeding rates were 34 and 37 canola plants m^{-2} while at Saskatoon the canola density increased from 8 to 24 to 44 plants m^{-2} as the canola seeding rate increase (Table 17). The row spacing and the cultivar had no impact on the canola density.

At both locations the plant height of the oat was impacted by the weed density (Tables 14 and 15). At both locations the oat responded to the canola by increasing its height by 3 to 4 cm (Tables 16 and 17). At Indian Head AC Morgan was slightly greater than CDC Endure (Table 16). At Saskatoon the row spacing x cultivar interaction also impacted plant height (Table 15). At Saskatoon the cultivars differed in their response to the widening row spacing. AC Morgan only decreased its height at the widest row spacing 50 cm (Table 18) while CDC Endure was taller at the 25 and 35 row spacings compared to the other row spacings. It appears that the oat plants are adapting to the weed competition by increasing their height and there is a general decrease in height as the row spacing widen.

Crop biomass was impacted by the row spacing at both locations and by weed density at Saskatoon (Tables 14 and 15). At both locations as the row width widened the biomass of the oat decreased. In addition at the location with the drought stress, Saskatoon the crop biomass decreased as the weed density increased. At Indian Head the large biomass indicates that weed density did not limit oat biomass under these environmental conditions. Weed or canola biomass was affected by row spacing at Indian Head. At Saskatoon the effect of weed biomass was not quite significant (P= 0.07). At Indian Head the widest row spacing, 50 cm, had the highest weed biomass.

Grain yield was impacted by row spacing at both locations (Tables 14 and 15). In addition, cultivar impacted grain yield at Indian Head while at Saskatoon the row spacing x cultivar interaction impacted grain yield. At Indian Head grain yield was higher at the 30 cm spacing than any of the other row spacings with the 35 cm spacing having the lowest numerical grain yield indicating that there was no clear trend at Indian Head from row spacing. At Saskatoon, AC Morgan had the highest yield at the 35 cm row spacing with all the other spacings having a similar yield (Table 18). CDC Endure had a similar grain yield at two row spacings, 25 and 35 cm. CDC Endure had a lower yield than AC Morgan at the 35 and 50 cm spacings.

Test weight was only affected by row spacing at Indian Head (Tables 14 and 5). The test weight declined as the row spacing widened from 229 to 223 g $0.5L^{-1}$. A similar numerical trend occurred at Saskatoon but with a lot of variation. Kernel weight was impacted by weed density at Indian Head and the row spacing x cultivar interaction at Saskatoon (Tables 14 and 15). At Indian Head the kernel weight increased as the weed density increased. This may indicate that the stress from the weed density was greater earlier in the growing season but eased and the oats compensated by increasing the test weight. There was a large rainfall on July 18 that greatly reduced the moisture stress on these plots and all other yield components except grain yield were fixed by the time this rain occurred. At Saskatoon the kernel weight of AC Morgan was not affected by row spacing while CDC Endure had a greater kernel weight at the 25 and 35 cm spacings compared to the other row spacing (Table 18). In addition, at the 25 and 35 row spacings CDC Endure had a greater kernel weight than AC Morgan.

The plumps and thins were impacted by weed density, row spacing and cultivar while at Saskatoon plumps and thins seed were affected by Row spacing (Tables 14 and 15). Also the row spacing x cultivar interaction had an effect on plump seed and the weed density x cultivar had an effect on thin seed. At Indian Head, plump seed increased and thin seed decreased as the weed density increased (Table 16). In addition, as the row spacing widened plump seed decreased and thin seed increased. CDC Endure had more plumps and less this than AC Morgan. At Saskatoon, thin seed of AC Morgan was 3.9, 3.5 and 3.9 % as the weed density increased while thin seed of CDC Endure decrease 4.2, 3.9 and 3.6% (LSD = 0.4) as the weed density increased.

Table 14. Analysis of variance for the effect of weed density, row spacing and cultivar on the development, yield and quality of oat at Indian Head in 2022

	Plant Density	Canola Plants	Plant Height	Crop Biomass	Canola Biomass	Grain Yield	Test Weight	Kernel weight	Plumps	Thins
					P value					
Weed density	0.0597	0.6897	**0.0046**	0.3322	0.3232	0.186	0.2408	**0.0041**	**0.0048**	**0.0109**
Row spacing	**0.0001**	0.5207	0.3981	**0.0001**	**0.0001**	**0.0062**	**0.0004**	0.2653	**0.0024**	**0.0007**
weed density x row spacing	0.5485	0.7738	0.5249	0.2753	0.4653	0.0691	0.172	0.1849	0.2839	0.3381
cultivar	0.067	0.2863	**0.0084**	0.2566	0.2107	**0.0312**	0.3272	**0.0132**	**0.0387**	**0.0215**
weed density x cultivar	0.9011	0.5028	0.961	0.3304	0.9569	0.5573	0.2269	0.1012	0.0832	0.1825
Row spacing x Cultivar	0.9012	0.5621	0.92	0.2441	0.2388	0.9864	0.1596	0.8084	0.2956	0.1465
weed density x row spacing x cultivar	0.1596	0.3755	0.3572	0.9805	0.9872	0.2297	0.5521	0.5404	0.8124	0.2305

Table 15. Analysis of variance for the effect of weed density, row spacing and cultivar on the development, yield and quality of oat at Saskatoon in 2022

	Plant Density	Canola Plants	Plant Height	Crop Biomass	Canola Biomass	Grain Yield	Test Weight	Kernel weight	Plumps	Thins
					P value					
Weed density	0.7083	**0.0017**	**0.062**	**0.0338**	**0.0098**	0.2937	0.1689	0.6263	0.0723	0.138
Row spacing	**0.0001**	0.4208	0.3404	**0.0004**	0.0733	**0.0001**	0.4231	**0.0045**	**0.0061**	**0.0045**
weed density x row spacing	0.4231	0.209	0.1959	0.303	0.7424	0.1345	0.3329	0.5608	0.0612	0.3244
cultivar	0.1214	0.329	0.0577	0.8049	0.6547	0.0665	0.3872	0.0596	0.2927	0.6122
weed density x cultivar	0.5475	0.8181	0.9599	0.2046	0.6886	0.1200	0.2253	0.4047	0.2841	**0.0467**
Row spacing x Cultivar	0.277	0.1456	**0.0015**	0.224	0.0873	**0.0432**	0.4528	**0.0025**	**0.0034**	0.0621
weed density x row spacing x cultivar	0.1458	0.3155	0.4777	0.0756	0.1381	0.3192	0.3503	0.1286	0.2629	0.549

Table 16. The effect of weed density, row spacing and cultivar on oat development, grain yield and grain quality at Indian Head in 2022.

Weed Density	Plant Density plants m^{-2}		Canola Plants plants m^{-2}		Plant Height cm		Crop Biomass kg ha^{-1}		Canola Biomass kg ha^{-1}		Grain Yield kg ha^{-1}		Test Weight g $0.5L^{-1}$		Kernel weight g 1000 $kernels^{-1}$		Plumps %		Thins %	
Canola m^{-2}																				
0	317	a	.		93	b	9175	a	.		5055	a	224	a	40.1	b	97	b	2.1	a
13	299	a	34	a	97	a	9344	a	557	a	5172	a	225	a	41.4	a	98	a	1.6	b
26	323	a	37	a	96	a	8876	a	586	a	4746	a	227	a	42.0	a	98	a	1.4	b
P Value	NS		NS		0.005		NS		NS		NS		NS		0.0041		0.0048		0.0109	
LSD P=.05	19.6		20.4		2.1		652.1		317.7		503.2		3.5		0.9		0.4		0.0	
CV	11.4		80.2		4.0		13.1		78.1		18.4		2.8		3.8		0.8		38.5	
Row spacing (cm)																				
25	366	a	35	a	95	a	9696	ab	324	b	5023	b	229	a	41.9	a	98	a	1.2	c
30	341	ab	35	a	96	a	9937	a	164	b	5178	a	227	a	41.0	a	98	ab	1.7	b
35	328	bc	34	a	94	a	9206	bc	265	b	4886	b	225	b	41.3	a	98	b	1.7	b
40	303	c	41	a	96	a	8916	c	494	b	4967	b	224	b	41.1	a	98	ab	1.5	bc
50	227	d	34	a	96	a	7903	d	1611	a	4901	b	223	b	40.5	a	97	c	2.3	a
P Value	0.0001		NS		NS		0.0001		0.0001		0.0062		0.0004		NS		0.0024		0.0007	
LSD P=.05	30.0		7.4		2.2		533.4		267.7		146.8		2.3		1.3		0.5		0.4	
CV	15.2		32.9		3.6		9.3		74.4		4.7		1.6		5.0		0.8		35.7	
Cultivar																				
AC Morgan	294	a	34	a	96	a	9074	a	622	a	5067	a	225	a	40.1	b	97.6	b	2.0	a
CDC Endure	332	a	37	a	95	b	9189	a	521	a	4915	b	226	a	42.2	a	98.2	a	1.4	b
P Value	NS		NS		0.008		NS		NS		0.031		NS		0.0132		0.0387		0.0215	
LSD P=.05	43.5		6.0		0.7		173.9		128.2		127.5		3.4		1.3		0.5		0.4	
CV	23.9		28.7		1.3		3.3		38.6		4.4		2.6		5.5		0.9		41.7	

Table 17. effect of weed density, row spacing and cultivar on oat development, grain yield and grain quality at Saskatoon in 2022.

	Plant Density	Canola Plants	Plant Height	Crop Biomass	Canola Biomass	Grain Yield	Test Weight	Kernel weight	Plumps	Thins
Weed Density	plants m^{-2}	plants m^{-2}	cm	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	g $0.5L^{-1}$	g 1000 $kernels^{-1}$	%	%
Canola Plants m^{-2}										
0	141	8 c	73	4711 a	0 b	4470	240	35.3	85	4.1
13	139	24 b	77	4422 ab	1058 a	4181	245	34.8	87	3.7
26	137	44 a	76	3796 b	1223 a	3874	245	35.0	87	3.8
P Value	NS	0.017	NS	0.0338	0.0098	NS	NS	NS	NS	NS
LSD P=.05	12.6	13.3	2.8	646.2	691.3	838.0	6.4	1.2	1.9	0.4
CV	16.6	97.4	6.8	27.4	166.2	36.7	4.8	6.2	4.1	17.6
Row spacing										
cm										
25	166 a	23	78	5061 a	560	4429 b	246	35.9 a	87.8 a	3.3 c
30	153 b	21	75	4626 ab	543	3908 c	242	34.6 c	85.1 bc	4.0 ab
35	146 b	28	74	4308 bc	773	5176 a	245	35.7 ab	86.9 a	3.7 bc
40	128 c	33	75	4073 c	884	3753 c	243	34.8 bc	86.5 ab	4.0 ab
50	99 d	20	74	3480 d	1040	3609 c	239	34.1 c	84.4 c	4.3 a
P Value	0.0001	NS	NS	0.0004	NS	0.0001	NS	0.0045	0.0061	0.0045
LSD P=.05	11.2	16.0	4.2	534.3	390.5	452.0	7.8	0.9	1.7	0.5
CV	12.9	101.6	8.8	19.7	81.7	17.2	5.1	4.2	3.2	19.7
Cultivar										
AC Morgan	135	23	77	4340	798	4370	242	34.5	86	3.8
CDC Endure	143	27	74	4279	722	3980	244	35.5	87	3.9
P Value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD P=.05	11.7	12.4	3.5	727.7	488.0	439.2	6.8	1.1	2.4	0.6
CV	14.5	85.1	8.0	29.1	110.5	18.1	4.8	5.6	4.8	27.6

Table 18. The impact of the row spacing x cultivar interaction on oat height, grain yield kernel weight and plump seed at Saskatoon

	Plant Height (cm)				Grain Yield (kg ha^{-1})				Kernel weight (g 1000 kernels^{-1})				Plump Seed (%)			
Row spacing (cm)	AC Morgan		CDC Endure		AC Morgan		CDC Endure		AC Morgan		CDC Endure		AC Morgan		CDC Endure	
25	75.6	a-d	79.7	a	4236.5	bcd	4622.1	bc	34.6	b	37.3	a	85.2	cd	90.5	a
30	79.1	ab	71.6	d	4129.0	cde	3686.7	def	35.1	b	34.2	b	86.6	bcd	83.6	d
35	77.0	abc	72.0	d	5578.3	a	4774.7	b	33.9	b	37.4	a	85.1	cd	88.7	ab
40	79.7	a	70.9	d	3943.7	de	3561.8	ef	35.0	b	34.6	b	87.4	bc	85.6	cd
50	73.2	cd	73.9	bcd	3962.5	de	3255.9	f	33.9	b	34.2	b	84.1	d	84.7	cd

Interim conclusions

1. Differences seem to exist between varieties with respect to competitive ability. In this study year, results varied by location. Treatments with a high ability to withstand competition at Indian Head differed from those at Kernen.
2. At both sites, forage varieties such as CDC Baler and Haymaker tended to have lower yield reductions in the presence of weeds than did other types of oat included in the study.
3. Multiple inter-row and wicking applications of herbicides at the 4-6 leaf and 6-flag leaf crop stages provided the best combination wild oat control and plump grains.
4. Method and timing of wild oat treatments did not impact oat yield relative to the unsprayed control.
5. Yield and quality of oat tended to be more impacted by row spacing than any other variable.

9. List any technology transfer activities undertaken in relation to this project:

1. None to date

Media

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

None. The contract was amended to reflect the inability to initiate this research in 2020 due to COVID 19.

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