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, 2021 to Dec. 31, 2021.

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 2021. All sites experienced drought, with the most problematic being Goodale and Melfort. Data from both locations was inconsistent as a result. Differences seem to exist between varieties with respect to competitive ability. Varieties such as Souris seem to exhibit few changes in yield when weeds are present. Other varieties such as Oravena and Morgan 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 2- and 4-leaf crop stages provided the best combination of crop yield and minimum wild oat in the harvested sample. 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. First year of field research was initiated 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. First year of field research was initiated at three sites last year, two near Saskatoon and one at Indian Head. However, drought impacted both Saskatoon sites. However, drought impacted both Saskatoon sites, and the Goodale site did not produce accurate data.
3) To determine the impact of competitive cultivars and row spacing on oat competitive ability	Field trials for this study will be initiated in 2022.

Please add additional lines as required.

7. Methodology:

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 was 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.

Competitive Ability of Modern Oat Cultivars

Experimental Design: The experiment was conducted at 3 locations in 2021, 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).

8. Results and discussion

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

A lack of wild oat emergence at Melfort precluded treatment initiation and experimental results. Likewise, drought at Goodale resulted in almost no wild oat emergence and thus, we will discuss results at the Kernen site only.

Oat yield was significantly affected by spray treatments (*P<0.001)*. Wicking had very little impact on wild oat control when carried out at the 2- and 4-leaf stage of crop growth, primarily because emergence of wild oat was delayed in 2021 and wild oats did not tower above the crop canopy (Table 1). Wicking alone at the 6-leaf stage was only moderately successful. In contrast, inter-row spraying had the greatest impact on wild oat control when carried out at the two leaf stage. In fact, this provided the greatest level of control at 7-10 days after treatment of any treatment combination, above 80%. Treatments that combined wicking with inter-row spraying generally provided suppression of wild oat, with 70-76% wild oat control. Given that no herbicides are available to control wild oat in cultivated oat, this in encouraging.

Substantial variation was observed between treatments for oat yield. Inter-row spraying at the 2- or 4-leaf stage increased yields above the unsprayed control plots (Table 2). Likewise, an inter-row spray application in combination with wicking at the 4 and 6 leaf stage also provided significantly greater crop yield (Table 14). Inter-row spraying tended to reduce crop yield as it was delayed due to injury to the crop. We operate a manual inter-row sprayer and it is difficult to be perfectly accurate. We suspect that advanced or robotic sprayers operating with RTK technology would likely be able to keep between crop rows. No significant differences were observed between treatments with regard to wild oat in the harvested sample. However, it should be noted that the late application of inter-row spraying at the 4-6 leaf, combined with wicking at that same time, more than halved the percentage wild oat in the harvested sample.

Table 1: Wild Oat control ratings of each treatment 7-10DAT and 21-24 DAT at Kernen, Goodale and Melfort in 2021.

TREATMENT NO.	TREATMENT	W.O. PHYTOTOXICITY RATING 7-10 DAT			PHYTOTOXICITY RATINGS 21-24 DAT		
		Kernen	Goodale	Melfort	Kernen	Goodale	Melfort
1	Control	0	0	--	0	0	--
2	Wick – 2 Leaf	0	0	--	0	0	--
3	Wick—4 Leaf	18.75	0	--	31.25	0	--
4	Wick—6 Leaf	55	0	--	58.75	0	--
5	Spray—2 Leaf	81.25	0	--	67.5	0	--
6	Spray – 4 Leaf	68	0	--	63.75	0	--
7	Spray – 6 Leaf	71.25	0	--	71.25	0	--
8	W+S—2 Leaf	70	0	--	62.5	0	--
9	W+S—4 Leaf	65	0	--	63.75	0	--
10	W+S—6 Leaf	53.75	0	--	67.5	0	--
11	W+S—2+4 Leaf	70	0	--	66.25	0	--
12	W+S—2+6 Leaf	70	0	--	83.75	0	--
13	W+S—4+6 Leaf	76.25	0	--	78.75	0	--

Table 2. Oat Yield and percentage wild oat in the harvested sample at Kernen, Goodale and Melfort in 2021. LSD at Kernen = 336 kg/ha for yield and 1.6 for wild oat %.

TREATMENT NO.	TREATMENT	YIELD (Kg/Ha)			WILD OAT %		
		Kernen	Goodale	Melfort	Kernen	Goodale	Melfort
1	Control	1698.7	922.2	4072.92	2.49	0.01	0
2	Wick – 2 Leaf	1795.5	932.66	--	1.62	0.02	0
3	Wick—4 Leaf	1599.1	989.3	--	2.86	0.03	0
4	Wick—6 Leaf	1356.3	952.9	--	2.27	0.01	0
5	Spray—2 Leaf	1784.3	893.2	3999.48	1.25	0.03	0
6	Spray – 4 Leaf	1822.57	978.5	4126.18	1.57	0.04	0
7	Spray – 6 Leaf	1706.3	928.9	3893.25	1.60	0.05	0
8	W+S—2 Leaf	1632.9	886.3	--	2.55	0.05	0
9	W+S—4 Leaf	1633.9	897.3	--	1.62	0.02	0
10	W+S—6 Leaf	1587.9	902.8	--	1.94	0.07	0
11	W+S—2+4 Leaf	1763.4	955.5	3931.95	1.59	0.04	0
12	W+S—2+6 Leaf	1594.0	837.24	4100.03	1.16	0.01	0
13	W+S—4+6 Leaf	1214.3	840.1	4091.50	1.06	0.01	0

Competitive Ability of Modern Oat Cultivars

Oat Biomass

Early oat biomass differed between weedy and non-weedy treatments (*P<0.01)* and between varieties (*P<0.01)* at Kernen, but not at Goodale (Table 3, Fig. 1). There was no biomass response to variety x weed interaction at either experiment locations.

Table 3: ANOVA of the interaction between variety and treatment and its effect on oat biomass

	DF	F VALUE	P VALUE
KERNEN			
Variety	16	2.5276	0.003
Weed	1	8.8126	0.004
Variety: Weed	16	1.4761	0.124
GOODALE			
Variety	16	0.7772	0.702
Weed	1	0.032	0.858
Variety: Weed	16	1.2715	0.251

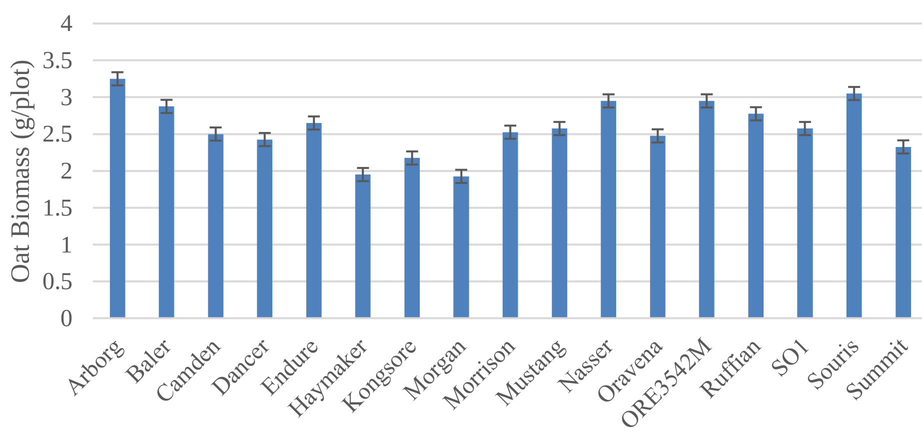

Figure 1: Oat biomass (g) calculated on five average plants per plot for various oat varieties at Kernen 2021.

Plant Height

Oat varieties displayed differences in matured plant height at both experiment locations. At Kernen, the main effects variety impacted plant height *(P<0.01).* Similar results were observed at determined at only Goodale (Table 4). Among oat varieties CDC Endure and AAC Oravena were the tallest at Kernen and Goodale respectively (Figure 2).

Table 4*: ANOVA of the interaction between variety and treatment and its effect on plant height*

	DF	F VALUE	P VALUE
KERNEN			
Variety	16	3.6979	0.001
Weeds	1	2.7434	0.101
Variety: Weeds	16	0.8617	0.614
GOODALE			
Variety	16	2.8871	0.002
Weeds	1	7.3835	0.009
Variety: Weeds	16	0.8578	0.617

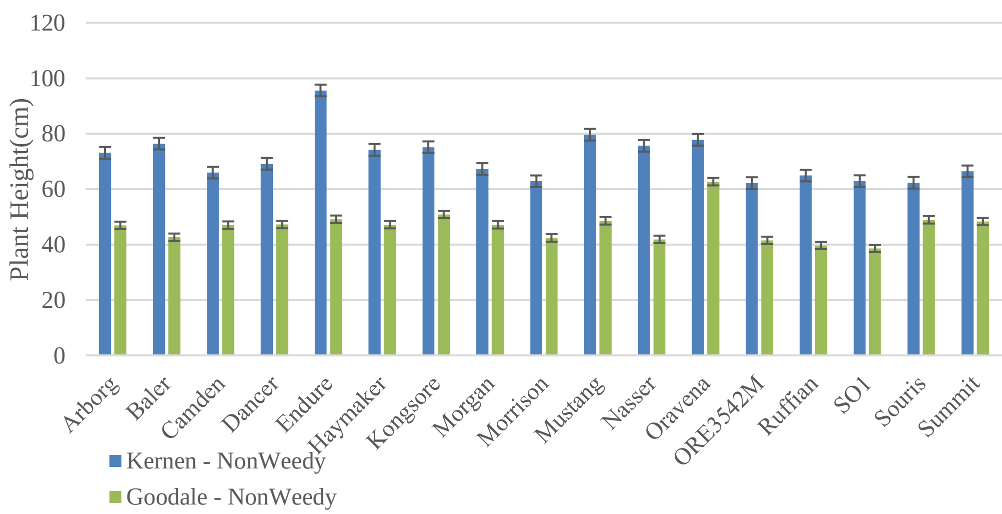

Figure 2: Average height of oat varieties Kernen and Goodale in 2021.

Oat Yield

Both main effects of weed presence and variety significantly impacted oat yields at both sites (Table 5). However, because of significant drought at Goodale, means will not be shown as they are illogical in nature. Yields were substantially greater at Indian Head than at Kernen in 2021, most likely due to the severe drought experienced in the Saskatoon area during the summer of 2021. Oat varieties differed significantly (*P<0.001*) in yield at Kernen (Figure 3) (Table 5). There was no variety by weed presence interaction at any location, indicating there were no differences among varieties for oat yield between weedy and weed free treatments. At Kernen, the varieties Arborg, Morgan and Ruffian yielded the highest under weed-free conditions (Figure 4). Both Arborg and Ruffian maintained yields under competition with weeds, but Morgan yielded substantially less than under-weed free conditions. Morgan and Ruffian were also among the highest yielding cultivars at Indian Head in 2021, both under weedy and weed-free conditions (Figure 4).

Table 5: ANOVA of the interaction between variety and treatment and its effect on yield.

	DF	F VALUE	P VALUE
KERNEN			
Variety	16	8.8704	0.001
Weeds	1	17.2793	0.001
Variety: Weeds	16	0.4172	0.975
GOODALE			
Variety	16	2.4286	0.001
Weeds	1	4.038	0.050
Variety: Weeds	16	1.173	0.320

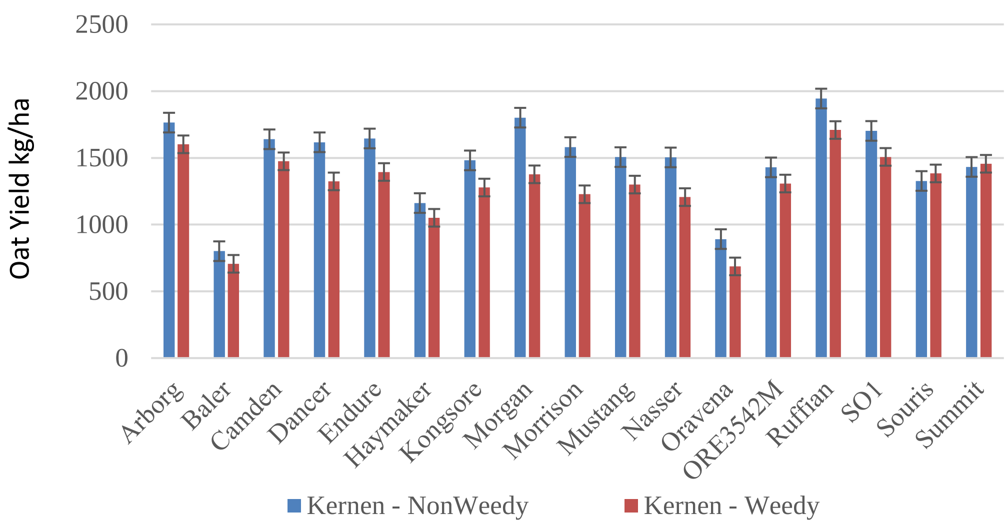

Figure 3: Oat yield of in the presence and absence of weeds at Kernen in 2021.

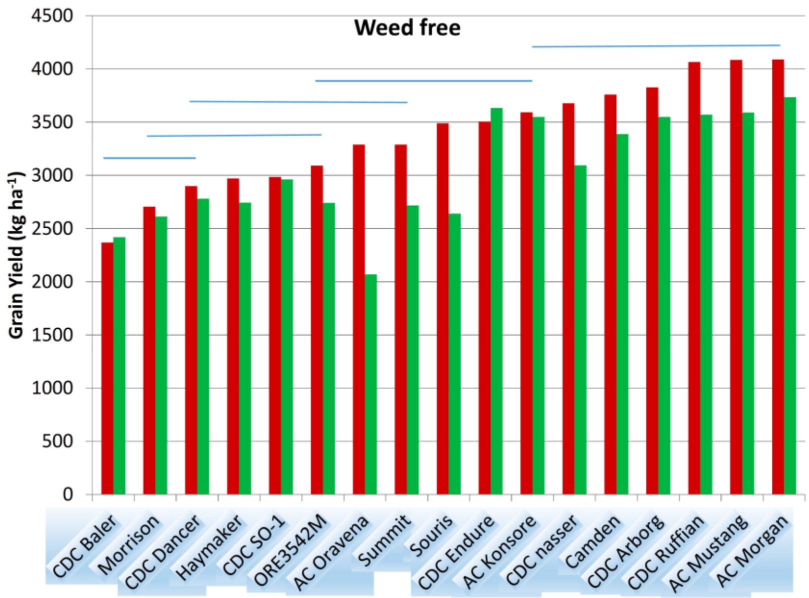

Figure 4: Oat yield of in the presence and absence of weeds at Indian Head in 2021.

Most oat varieties at the two locations experienced a negative change in yield in response to the presence of weeds (Figure 5). At Kernen, the oat varieties Morgan and Morrison experienced the greatest negative response in yield to weed presence. Summit and Souris, on the other hand, both experienced a minor positive change in yield in response to weeds (Figure 5). Different response among oat varieties were observed at Indian Head, however. Here, Oravena and Souris exhibited the greatest negative response to the presence of weeds, while Endure and Baler showed a slight increase in yield (Figure 6). It is important to note that a decrease in yield is shown the net negative change in yield at Kernen (Figure 5) and the decrease in yield at Indian Head (Figure 6). Differences between the sites are interesting, and may be due to the effects of drought experience in 2021.

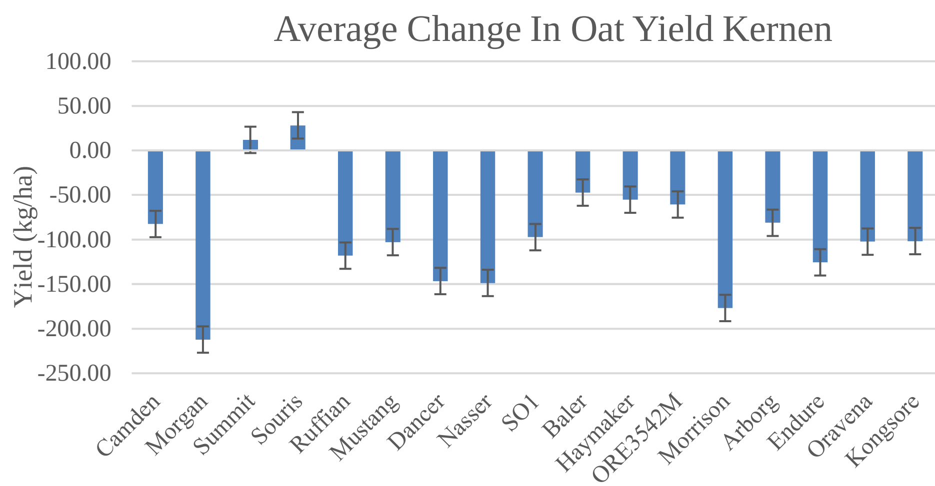

Figure 5: Average oat yield (kg/ha) of weedy treatments relative to their weed free control at Kernen in 2021.

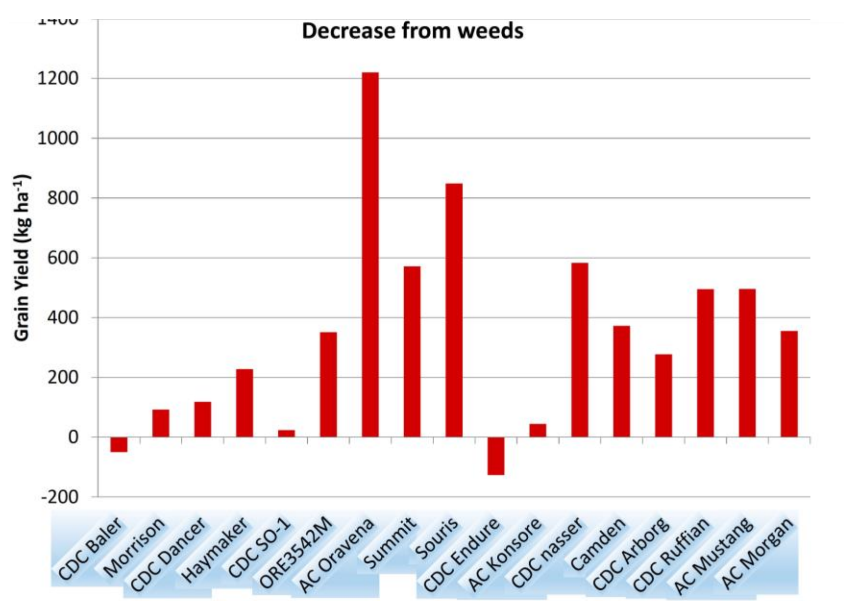

Figure 7: Average decrease in oat yield (kg/ha) between weed free and weedy treatments of oat varieties at Indian Head 2021.

9. Interim conclusions

1. Differences seem to exist between varieties with respect to competitive ability. Varieties such as Souris seem to exhibit few changes in yield when weeds are present. Other varieties such as Oravena and Morgan tended to decline substantially in the presence of weeds, although location had a major impact on results.
2. Ruffian and Morgan were the highest yielding varieties at both sites in the absence of weeds. Ruffian was amongst the highest yielding at both sites even in the presence of weeds.
3. Forage varieties such as Baler and Haymaker tended to have lower yield reductions in the presence of weeds than did other types of oat included in the study.
4. Differences among sites may have been a function of the 2021 drought
5. Early inter-row herbicide applications (2-leaf) provided control of wild oat while maximizing crop yield.
6. Multiple inter-row and wicking applications of herbicides at the 2- and 4-leaf crop stages provided the best combination of crop yield and minimum wild oat in the harvested sample.
7. Inter-row herbicide applications tended to become more injurious to the crop the later they were applied, as the crop canopy filled out.

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

1. None to date

Media

Featured in Western Producer (August 27, 2020) – "Weeding between the rows, finding control of pests". Volume 98, page 49. This article featured the concept being used in this research.

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

None in 2021. The contract was amended to reflect the inability to initiate this research in 2020 due to COVID 19.

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