Date Received
For Administrative Use Only

PROJECT FINAL REPORT

Instructions:

- **Please note that making changes to the project without prior written consent from the funder(s) could constitute sufficient grounds for termination of funding.**
- This report must be a stand-alone report, *i.e.,* must be complete in and of itself. Scientific articles or other publications cannot be substituted for the report.
- A signed electronic copy of this report must be forwarded to the funders' representative on or before the due date, as per the investment agreement.
- A detailed, signed statement of revenues received and expenses incurred during the entire funding period of the project must be submitted along with this report, as per the investment agreement.
- For any questions regarding the preparation and submission of this report, please contact the funders' representative.

Section A: Project overview

1. Project number: 2016F017R
2. Project title: Mitigating herbicide resistance – investigating novel integrated weed management systems
3. Abbreviations: IWM – integrated weed management; AICc – Akaike's Corrected Information Criterion; HWSC – harvest weed seed control.
4. Project start date: (2016/04/01)
5. Project completion date: (2021/04/15)

6. **Final report submission date:** (2021/04/30)	
7. Research and development team data	
a) Principal Investigator: (Requires personal data sheet (refer to Section 14) only if Principal Investigator has changed since last report.)	
Name	**Institution**
Breanne Tidemann	Agriculture and Agri-food Canada Lacombe
b) Research team members (List all team members. For each new team member, *i.e.*, joined since the last report, include a personal data sheet. Additional rows may be added if necessary.)	
Name	**Institution**
Kelly Turkington	AAFC, Lacombe
Charles Geddes	AAFC, Lethbridge
Newton Lupwayi	AAFC, Lethbridge
Emma Stephens	**AAFC, Lethbridge**
Greg Semach	AAFC, Beaverlodge
Cindy Gampe	AAFC, Scott
Steve Shirtliffe	U of S, Saskatoon
Chris Willenborg	U of S, Saskatoon
Eric Johnson	U of S, Saskatoon
Rob Gulden	U o M, Winnipeg
Hiroshi Kubota	AAFC, Lacombe

Section B: Non-technical summary (max 1 page)

Herbicide resistance is increasing globally, as well as more locally in western Canada. While herbicides are still mostly effective, ongoing research has tried to identify tactics and systems which can be used to manage problem weeds. This project builds on previous research conducted by Neil Harker who looked at integrated weed management tactics for wild oat. This project investigated similar tactics, added chaff collection as a harvest weed seed control option, and branched out from wild oat, to wild oat, wild buckwheat, and locally important broadleaf weeds at each location. For example, Lacombe included cleavers in the project as a problem weed in the area, while Lethbridge included kochia.

Treatments included combinations of increasingly diverse crop rotations (canola-wheat, fababeans-barley-canola, peas-winter wheat-canola, silage barley-winter triticale-silage barley, silage barley-fall rye-canola, alfalfa-alfalfa-alfalfa), with various combinations of with and without herbicides, typical or increased seeding rates, and with and without chaff collection. As a five year study the first year was seeded into a 2x seeding rate of wheat with 0 herbicides applied, and weeds were seeded to allow populations to establish. The middle three years were where the above crop rotations were implemented, followed by a final year to compare weed populations all in the same crop, in this case a 2x seeding rate of wheat, with 0 herbicides.

Wild buckwheat populations were not significantly affected by any of the crop rotations or integrated weed management techniques tested on average across locations. This is an

important difference compared to wild oat results shown previously as well as discussed below from this study. It is likely that the twining/climbing nature of buckwheat allows it to be less affected by the IWM strategies used in this study, which rely heavily on increased competitiveness to affect weed populations. It will be very important for species such as buckwheat and cleavers to determine which IWM techniques are effective, but also to develop new techniques with better efficacy.

Wild oat results were not as promising as shown in Dr. Harker's previous IWM research on wild oat. While early cut barley silage, winter cereals, perennials, and increased seeding rates all were shown to have positive impacts on wild oat management, the wild oat densities at most locations would be unacceptable in a commercial field. One possible source of variation between the studies is the initial wild oat population when IWM strategies are implemented. It's possible that IWM strategies are less effective on high density weed populations. This is an area that requires more research in the future.

Analyses still need to be conducted on chaff collection (harvest weed seed control) for the various broadleaf weed species. However, while not statistically significant in most cases there are some trends that suggest adding chaff collection to a full herbicide regime does still provide improved weed management. This is another area of potential future research.

It became clear in weed biomasses that the grass weeds, and in particular wild oat, tended to be more competitive than the broadleaf weeds. In some of our low diversity, no herbicide treatments, the lowest broadleaf biomass was recorded. This is not as a result of fewer broadleaf weeds necessarily, but a side impact of high, and competitive, wild oat populations reducing the size and impact of the broadleaf weeds.

There are many additional analyses to come including to investigating the impact of the treatments on the various individual weeds each location selected, an economic analysis, analysis on soil microbial communities and the weed seedbank.

Section C: Project details

1. Background (max 1 page)

Weed resistance to herbicides is increasing rapidly and the efficacy of some of our best herbicide tools are in jeopardy (Beckie et al. 2020; Heap 2021; Powles and Yu 2010). Cropping systems that effectively manage weeds with less herbicide applications are urgently required to decrease the selection for more resistance and to provide management tools in the face of new resistance (Harker et al. 2012). However, in many weed research programs in North America, truly integrated weed management (IWM) research is still overshadowed by herbicide efficacy research (Harker and O'Donovan 2013). Previous research has shown that integrated weed management methods can control weeds. In particular, rotations including winter cereals and early-cut silage barley were highly effective at reducing wild oat populations without the use of herbicides (Harker et al. 2016). The effects of these rotations and agronomic management techniques on broadleaf weed populations have not been determined.

Harvest weed seed control has been highly adopted in Australia as a way to prevent weed seed-bank inputs at harvest (Walsh et al. 2018). Adoption elsewhere has been limited. One method of harvest weed seed control used in Australia is use of a chaff cart. Chaff collection has the potential to reduce weed populations, and in combination with other weed suppressing agronomic practices, can preserve the efficacy of herbicides (Walsh et al. 2013). The idea of using a chart cart for weed control was first conceived in Canada (Shirtliffe and Entz 2005), but it was felt to be inconvenient and was not widely adopted in Canada. Australian farmers have rapidly adopted chaff cart weed seed control (Walsh et al. 2013) not by choice, but out of necessity when weed resistance problems became severe. Chaff collection efficacy on weed populations is assumed to be equivalent to other mechanisms of harvest weed seed control (impact mills, etc.) but is by far one of the easiest options to put into practice at a plot research scale.

In this study, we combined chaff collection with some of the best cultural weed management techniques [high seeding rates, winter cereal crops, early-cut silage, perennial forage (alfalfa)] in standard and innovative crop rotations. Combining several weed management tactics improves ecologically-based weed management (Anderson 2005; Blackshaw et al. 2008; Liebman and Gallandt 1997, Harker et al. 2009; O'Donovan et al. 2007). Utilizing these alternative tactics should allow us to decrease herbicide applications in our cropping systems. Decreasing herbicide applications in our agricultural systems will decrease the selection for herbicide resistant weeds and make producers less vulnerable to losses from herbicide resistant weeds by providing other management methods. Furthermore, any time herbicide use frequency is reduced, there can be positive environment, human health, marketing and societal outcomes.

2. Objectives and deliverables (max 1 page)

Objectives:

1) To determine if chaff collection integrated with other non-chemical weed control methods can provide broadleaf and grass control equivalent to typical 100% herbicide application systems in a 5-year study.
2) Determine the utility of chaff collection for broadleaf and grass control
3) Determine possible weed shifts associated with the imposed treatments

Deliverables

1) Knowledge contributions and improved management practices – Knowledge of practices that can effectively reduce herbicide use and herbicide-resistance selection pressure
2) Knowledge of chaff collection contributions to IWM
3) Three scientific peer-reviewed publications

3. Research design and methodology (max 4 pages)

The trial was conducted from 2016-2020 at 6 locations: Lethbridge, Beaverlodge and Lacombe, AB, Scott and Saskatoon, SK, and Carman, MB. The project was designed as a randomized complete block design with 14 treatments and 4 replicates at each location. Weeds were seeded in year one when no herbicides were applied to allow populations to establish/naturalize prior to IWM strategies being implemented. Wild oat and wild buckwheat were used as common weeds to all locations (seeded at all sites) and additional weeds were included as made sense by location (e.g. cleavers in Lacombe, kochia at Lethbridge, shepherd's purse at Scott). A formatted treatment list is included in the appendix for easier viewing, listing the 14 rotational treatments used throughout the study and the IWM tactics used in each one. 100_Herb indicates full herbicide rates were used, 0_herb means no herbicides were applied, 1.5x or 2x seeding rate means the seeding rate of that crop was increased by half or doubled, respectively, leave chaff means chaff was not collected, collect chaff means chaff collection occurred, N/A chaff means that chaff collection wasn't an option in that crop (i.e. the crop was silaged).

Fertility was based on soil sample recommendations for the various crops in each year at each location. Recommendations came from soil laboratories based on residual soil nutrients and optimum amounts needed to reach target yields. Insecticides and fungicides were only sprayed on an as needed basis at each location, use was not prescribed.

Weed densities were assessed by species each year in two 0.5 m^2 quadrats per plot. Those quadrats were staked to be used for biomass later in the season, and the locations of the quadrats shifted each year so as not to have results confounded by removal of the weeds from the previous year's biomass. Crop and weed biomass occurred around the end of July, around barley silage timing. Plot grain yield was collected each harvest as was % moisture. A subsample of the yield was cleaned for percent dockage and a true crop weed-free yield. In the final year soil microbial diversity and leaf disease sampling (including leaf sample assessment and assessment for fusarium damaged kernels) was also conducted.

Weed seedbank samples were collected in 2020 as well. The original plan was to process seedbank samples similar to previous work with wild oat (Harker et al. 2016) and to use a washing process through sieves to remove the weed seeds. While this protocol was developed and tested, including testing with small seeded weeds, the soil used had a lower sand content than our actual field locations. When the true soil seedbank samples were received, and washed, the sand remaining with the samples was much more than in our test samples. As a result removing very small weed seeds with accuracy (i.e. shepherd's purse and kochia) became incredibly difficult. As a result, the decision was made in fall of 2020 to switch to a washing and grow out protocol. Large seeded weeds such as wild oat were still removed from samples via a washing technique. Because of dormancy characteristics, this is a more efficient measure of wild oat populations. The finer fraction of the sample was subsampled and mixed with potting soil and grown out in a grow/freeze cycle (grow for 3 weeks, freeze for 3 weeks, etc.). Unfortunately, due to limited controlled growth capacity at AAFC Lacombe, and the sheer amount of time required for this type of procedure, this component of the study is ongoing. Currently, we expect to complete grow out of the seedbank samples in October 2021 with analysis of results to proceed after that time. This delay was not due to Covid impacts (so no agreement amendment was sought) but due to planned protocols not being effective, and newer, extended time period protocols being required instead.

Similarly, between changing project members due to a retirement, unexpected Covid impacts due to personal circumstances (which is why no agreement amendment was sought), and all project members simply trying to keep up with additional duties and meetings scheduled virtually, this has delayed economic analysis on this study, although data collation and analysis is now currently under way. Soil microbial analysis has been somewhat delayed by back-ups in the commercial labs in terms of availability to get samples tested, but also by samples being delayed in terms of sending from some sites to the soil microbiologist collaborator on the project. Analyses are now ongoing.

Statistical analysis of wild oat and wild buckwheat densities, as well as crop, grassy weed and broadleaf weed biomasses were conducted in Proc Glimmix in SAS 9.4 using distribution selection based on AICc. All data is backtransformed using appropriate link functions. Treatments were compared to the canola-wheat rotation with 100% herbicides (as a spring annual, traditional rotation using full herbicides and limited integrated weed management techniques) with a Dunnett's test. While an across location analysis was completed and will be presented, significant site*treatment interactions also required investigation and analysis of treatments by location. This is not surprising for grass weed and broadleaf biomass where the species varied by location and could easily respond to the treatments differently. It is slightly more surprising for specific species (buckwheat and wild oat) and warrants examination into trends and treatment differences by site.

4. Results, discussion and conclusions (max 8 pages)

Present the project results and discuss their implications. Discuss any variance between expected targets and those achieved. Highlight the innovative, unique nature of the new knowledge generated. Describe implications of this knowledge for the advancement of agricultural science. For ease of evaluation, please structure this section according to the objectives cited above.
NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

Wild oat and wild buckwheat were seeded at all locations to allow for comparisons of a common grass and broadleaf species across sites. Densities of those two weeds are evaluated specifically here.

Wild buckwheat density across locations was not significantly different in any treatment compared to the canola-wheat 100% herbicide rotation (Figure 1). Density was relatively low averaging 7 plants per square meter across locations. This is significantly different than the results found in Harker et al. (2016) for wild oat. Wild buckwheat was specifically chosen as a broadleaf of interest as it's a common weed across the prairies, and as a twining weed may not be as susceptible to integrated weed management strategies that are mostly effective as a result of increased competition. This would include strategies such as those tested here based on increasing seeding rates, and potentially use of winter cereals as well; winter cereals provide diversity in terms of lifecycle growth, but part of their benefit is also the early season competition. This highlights a potential significant need for additional integrated weed management strategies for twining weeds like wild buckwheat.

Wild oat density across locations was significantly increased in almost all treatments that were herbicide free for 3 years (Figure 2). The only non-herbicide treatments that effectively maintained wild oat densities as not significantly different than the canola-wheat 100% herbicide treatment include those with barley silage twice in the three year rotations, or a combination of a barley silage and either fall rye or winter triticale. None of the treatments successfully reduced wild oat densities compared to the canola-wheat 100% herbicide treatment. Within sites there was a lot of variability in terms of effectiveness and effective treatments. The three year alfalfa treatment and the 2 years of silage combined with a winter cereal treatments without herbicides tended to reduce or not show significant increases in wild oat density at the various locations. The treatments that removed herbicides without including the silage or winter cereal rotational phases tended to result in no significant differences or significant increases to wild oat densities across sites. In comparison to Harker et al. (2016), wild oat densities were significantly higher at nearly all locations, with exceptions of low populations at Saskatoon, and similar densities at the Lethbridge location. However, reduced efficacy of some of the treatments including alfalfa, and the inclusion of a single year of winter cereals may be related to the high wild oat densities compared to the Harker et al. (2016) paper. This is of significant concern as many farmers will likely not begin to incorporate integrated weed management strategies until herbicide options are very limited, at which time densities are likely to be elevated. There is some suggestion in what was observed in the fields and in the differences in results compared to Harker et al. (2016) that these strategies may be less effective on high wild oat populations. This is an area of potential future research.

Crop biomass across locations was significantly reduced in treatments that did not include herbicides, and also did not include silage barley and winter cereals as 2/3 differentiating rotational phases (Figure 3). Crop biomass was increased in treatment 8 which included peas, winter wheat and canola with 100% herbicide use in the differentiating rotation years. Within locations locations there was a similar trend where removal of herbicides, without including silage and winter cereals resulted in reduced crop biomass. Crop biomass was significantly increased at Scott in the alfalfa treatment, the canola-wheat 100% herbicide plus chaff collection treatment, and the pea-winter wheat-canola 100 % herbicide treatment, indicating that additional diversification (via crop rotation or the addition of harvest weed seed control), in addition to herbicide treatments can aide in effective weed management.

Grass weed biomass was not significantly different from the canola-wheat 100% herbicide rotation in any other treatments when averaged cross locations (Figure 4). At Beaverlodge grass weed biomass was reduced in the treatments that included 2 years of silage barley and a winter cereal. In Lacombe grass weed density was reduced in the alfalfa treatment and the silage barley-fall rye – canola, 100% herbicide and chaff collection treatment. Grass weed density in Lacombe increased in all zero herbicide treatments except those including silage barley twice and winter triticale. In Lethbridge density was maintained only in those treatments that included herbicides, or two years of silage barley in combination with winter triticale. In Saskatoon grass weed biomass was reduced by 3 years of alfalfa or including winter wheat into a spring annual rotation with 100% herbicide use. Similarly in Scott only the winter wheat addition to the spring annual rotation with 100% herbicide use reduced grass weed density. Overall 2 years of silage plus a winter cereal was the only consistent treatment that allowed reduction of herbicide use while still maintaining or reducing densities.

Broadleaf weed biomass gave us some very interesting, and initially confusing results (Figure 5). Across locations there were no significant differences between any of the treatments and the canola-wheat 100% herbicide treatment. However, in Lethbridge, Lacombe and Beaverlodge some of the treatments that had no herbicide applications showed significant reductions in broadleaf weed biomass, even when few if any integrated weed management strategies were used. This initially seemed very counterintuitive. However, further investigation into the treatments with low broadleaf weed biomass, revealed they are the treatments that had increased and high levels of grass weed biomass. I suspect the grass weed densities (primarily dominated by wild oat) got so high and so competitive that they actually reduced the broadleaf weed densities through competition. Broadleaf weed biomass was also reduced in the alfalfa treatment at the Carman location, although this is likely due to treatment effects, not other weed competition.

Similar to crop biomass, wheat yield was reduced at Carman, Lacombe, Lethbridge and Scott in treatments that did not have herbicide applications (data not shown). In Saskatoon yields were increased in diversified cropping systems with full herbicide applications. However, integrated weed management strategies alone (without the use of herbicides) were generally not effective enough on the weed populations to maintain yield.

Impacts on wheat quality measures such as kernel weights and protein were limited across all sites (data not shown). Treatments also did not significantly affect wheat disease incidence on the flag leaf (data not shown). Soil microbial analysis, economics, fusarium damaged kernels, and soil seedbank analysis is all ongoing.

Overall there is some concern that the integrated weed management techniques had limited impact on the weed populations when herbicides were not used, particularly on the grass weeds. It is not encouraging that the majority of reductions in broadleaf biomass is simply from grass weed biomass being so elevated and competitive. We will be doing additional analyses by location to look at any shifts through time in the various rotations to see if certain species (i.e. cleavers or wild buckwheat) become more dominant as a result of being less impacted by the integrated weed management strategies incorporated in this study. This will be a multivariate analysis and the Project Lead is still determining the best type of multivariate analysis to use for this specific data, which will be based on weed density counts that were done by species, as well as the weed seedbank density counts which are still ongoing.

The biggest conclusion drawn to date is that the IWM methods previously studied for wild oat control, including increased seeding rates, inclusion of a winter cereal or barley silage, may not always prove effective for wild oats, and for other species. In this study, for example at the Lacombe location, even where wild oat densities or biomass of grass weeds (primarily wild oat) were not significantly different than the canola-wheat 100% herbicide rotation, I can confidently say farmers would not be pleased with the densities of wild oat in their fields. At the Lacombe location there were no treatments that didn't include herbicides where you could accurately say the wild oat populations were under control. It is imperative we understand why our control levels were so much lower than those observed in the Harker et al. (2016) study. If, as we currently suspect, initial wild oat densities at the implementation of the integrated weed management strategies significantly affects control, this could critically impact the way we message and encourage farmers to adopt these strategies. If we were to show that waiting until resistance establishes (and densities increase) to implement integrated weed management strategies results in management failure and loss of control, we may be able to encourage earlier adoption of these strategies and stop a worst case scenario from occurring. This is a significant area of additional research that has emerged from this project. We will have a number of other significant conclusions, including impacts on twining weed species populations from integrated weed management strategies that rely on competition when the multi-variate and seed bank analyses are completed, however at this point we believe additional IWM tactics will be needed for weed types of this morphology. We will also look at the economics of the rotations – two years of silage barley in combination with a winter cereal may be an effective management strategy but if the economics don't work out then it will be a hard sell to farmers. Silaging can already be difficult to offer to producers as a weed control option if they don't run a mixed operation and have a use for the silage. Additional integrated weed management strategies are still needed. We have also not completed an analysis on the impact of adding the chaff cart to the integrated weed management strategies, although it did show up as decreasing weed biomass in a few instances where herbicides were used, indicating that it's incorporation can increase weed management efficacy beyond our standard reliance on herbicides. This analysis will be included in the multivariate analysis, in case impacts of the chaff carts vary by species, which is highly likely based on variations in weed seed retention by species. Inclusion of harvest weed seed control measures would also reduce selection pressure for herbicide resistant biotypes, as well as possibly reducing spread of resistant biotypes by not broadcasting them with a combine. Further analysis on this point is still required. We will also be delving into the impacts of low winter cereal survival and the need to reseed to spring barley at some locations. This anomaly has not been investigated in detail yet in the analysis to date.

Overall, this project clearly demonstrates benefits to diversity in IWM tactics studied, although herbicides may not be able to be fully eliminated while maintaining control over the populations. In combination with previous research results and number of new questions have been highlighted and some gaps in our understanding of the implementation of the integrated weed management tactics have also been highlighted. We've also identified a potential area of concern of lower responsiveness to current recommended IWM tactics for twining/climbing weeds, and a need to focus on these types of weed species in future research and weed management system development. The IWM systems studied to date are not a silver bullet or the solution to herbicide resistance. They can aid in management of the weeds, but increasing diversity in management strategy early, while herbicides are still effective, is crucial to maintaining control of our weed populations long term.

5. Literature cited

Anderson RL (2005) A multi-tactic approach to manage weed population dynamics in crop rotations. Agron J 97:1579-1583.

Beckie HJ, Shirriff SW, Leeson JY, Hall LM, Harker KN, Dokken-Bouchard F, Brenzil CA (2020) Herbicide-resistant weeds in the Canadian prairies: 2012 to 2017. Weed TEchnol 34: 461-474.

Blackshaw RE, Harker KN, O'Donovan JT, Beckie HJ, Smith EG (2008) Ongoing development of integrated weed management systems on the Canadian Prairies. Weed Sci 56: 146-150.

Harker KN, O'Donovan JT (2013) Recent weed control, weed management and integrated weed management. Weed Technol 27: 1-11.

Harker KN, O'Donovan JT, Irvine RB, Turkington TK, Clayton GW (2009) Integrating cropping systems with cultural techniques augments wild oat (*Avena fatua*) management in barley (*Hordeum vulgare*). Weed Sci 57:326-337.

Harker KN, O'Donovan JT, Turkington TK, Blackshaw RE, Lupwayi NZ, Smith EG< Johnson EN, Pageau D, Shirtliffe SJ, Gulden RH, Roswell J, Hall LM and Willenborg CJ (2016) Diverse rotations and optimal cultural practices control wild oat (*Avena fatua*). Weed Sci 64: 170-180.

Heap I (2021) The international survey of herbicide resistant weeds. Online. Accessed: April 30, 2021, Available at: www.weedscience.org

Liebman M and Gallandt ER (1997) Many little hammers: ecological management of crop-weed interactions. Pages 291-343 in Jackson LE ed. Ecology in Agriculture. Academic Press, San Diego, CA.

O'Donovan JT, Blackshaw RE, Harker KN, Clayton GW, Moyer JR, Dosdall LM, Maurice DC, Turkington TK (2007) Integrated approaches to managing weeds in spring-sown crops in western Canada. Crop Protect 26: 390-398.

Powles SB, Yu Q (2010) Evolution in action: plant resistance to herbicides. Ann Rev Plant Biol 61:317-347.

Shirtliffe SJ and Entz MH (2005) Chaff collection reduces seed dispersal of wild oat (*Avena fatua*) by a combine harvester. Weed Sci 53: 465-470.

Walsh MJ, Broster JC, Schwartz-Lazaro LM, Norsworthy JK, Davis AS, Tidemann BD, Beckie HJ, Lyon DJ, Soni N, Neve P, Bagavathiannan MV (2018) Opportunities and challenges for harvest weed seed control in global cropping systems. Pest Manag Sci 74:2235-2245

Walsh M, Newman P, Powles S (2013) Targeting weed seeds in-crop: A new weed control paradigm for global agriculture. Weed Technol 27:431-436.

6. Project team (max ½ page)

Breanne Tidemann – The project lead and site lead for Lacombe. Breanne took over from the original applicant Dr. Neil Harker after his retirement.

Kelly Turkington – Kelly developed the disease assessment protocols and his lab completed the disease assessments in the final year.

Newton Lupwayi – Developed the protocol for soil microbial assessments and his lab is completing the analysis and conclusions from those samples.

Emma Stephens – Emma replaced Elwin Smith as the agricultural economist at Lethbridge upon his retirement. Emma is completing the economic analysis for the project.

Greg Semach – Greg was the site lead at Beaverlodge, AB.

Cindy Gampe – Cindy was the technician in charge of the Scott, SK site.

Steve Shirtliffe/Chris Willenborg/ Eric Johnson – Both the Shirtliffe and Willenborg labs collaborated on this project at the University of Saskatchewan. Eric also collaborated in the project design. Between the three men they were the site leads for Saskatoon and ensured the project and protocol was completed at that location.

Rob Gulden – Rob was the site lead for the Carman, MB site.

Hiroshi Kubota – Hiroshi joined AAFC Lacombe as the Sustainable Cropping Systems Scientist partway through the project. Hiroshi's lab and Breanne's lab work jointly together and so his lab has assisted in completion of the project. He has also weighed in and provided advice and guidance on decisions that needed to be made throughout the project.

7. Benefits to the industry (max 1 page; respond to sections *a)* and *b)* separately)

a) Describe the impact of the project results on the Alberta or western Canadian agriculture and food industry (results achieved and potential short-term, medium-term and long-term outcomes).
   This project may have highlighted a significant concern around our current integrated weed management recommendations for wild oat; i.e. waiting to implement them may result in failure of the management strategies due to high wild oat densities. This is a

critical point that needs confirmation with additional research. It has certainly highlighted variability in efficacy of control, and suggests limited impact of competition based integrated weed management strategies for twining weeds such as wild buckwheat. Chaff collection and harvest weed seed control methods improved weed management in a few cases in addition to herbicide use suggesting incorporation of harvest weed seed control may increase weed management potential in the Canadian Prairies.

b) Quantify the potential economic impact of the project results (*e.g.,* cost-benefit analysis, potential size of market, improvement in efficiency, etc.).
Inclusion of early cut barley silage and winter cereals may allow elimination of wild oat herbicides in some years, providing significant benefits considering some producers are paying large amounts of money on herbicide mixtures to manage resistant wild oat. We may also be able to provide future savings on non-effective weed management strategies by highlighting potential concerns around recommended integrated weed management strategies being implemented too late when herbicide resistant biotypes have resulted in an increase in wild oat density. Our results suggest that traditional integrated weed management strategies may not be as effective on twining weeds such as wild buckwheat, indicating a significant need for additional research on non-chemical management strategies of this weed which has remained a top weed in the Prairies since the 1970s. Our preliminary analysis indicates benefits of including harvest weed seed control measures with other weed management strategies and this will become a component of our economic analysis – is the benefit large enough to offset the purchase cost of HWSC machinery?

8. Contribution to training of highly qualified personnel (max ½ page)

Specify the number of highly qualified personnel (*e.g.*, students, post-doctoral fellows, technicians, research associates, etc.) who were trained over the course of the project.

A minimum of two summer students were trained at each location in each year. Multiple technicians (1-4 depending on location) worked on this project at each location each year. A Ph.D. student (Breanne Tidemann) initially was involved in the project design and writing of the proposal, completed her program and took over the project as project lead upon Dr. Neil Harker's retirement. There were no specific graduate students or post-doctoral fellows hired for this project.

9. Knowledge transfer/technology transfer/commercialisation (max 1 page)

Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Please ensure that you include descriptive information, such as the date, location, etc. Organise according to the following categories as applicable:

Most of my recent speaking invitations/requests/interviews have centered around harvest weed seed control. As this project has looked at integrating harvest weed seed control with other integrated weed management tactics, that has been the primary presentation focus and knowledge transfer focus to date. The scope has focussed on the treatment list, the premise behind the experiment, and why we are interested in conducting it. Now that we have more results available we will be focussing on extension of this trial as a whole trial based on integrated weed management, and with less focus on the harvest weed seed control component. We expect significant additional technology transfer to be conducted with finalized results, after the term of this project has ended.

a) Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report
   Scientific publications are currently being prepared for the project, or awaiting completion of final analyses. Publications will include one from the weed management perspective, one from the soil microbial perspective and one from the economic perspective.

b) Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.); attach copies of any publications as an appendix to this final report
   No industry-oriented publications have been completed to date. It is likely that as we finalize results there will be publication of results in agriculture press such as Top Crop Manager, or online with RealAgriculture. Current articles discussing this project have been included under media interactions. Preliminary results of this project have only been presented in a scientific poster which is attached as an appendix. Other presentations only included the study design and a description of what we were doing and why. I have not included these presentations as appendices due to the sheer number and size, but they are available if requested.

c) Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report
   1. Harvest Weed Seed Control. 2017. Invited oral presentation on harvest weed seed control and the potential to use it in Canada and in Canadian cropping systems at the Canadian Weed Science Society Annual Meeting in Saskatoon, SK. November 2017.
   2. Mitigating herbicide resistance: Incorporating integrated weed management strategies. 2020. Poster presentation at the Canadian Weed Science Society Annual Meeting, held virtually, November 2020.

d) Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report
   1. Management of herbicide resistant weeds with diverse cultural practices and harvest weed seed control. 2017. Field Tour Presentation at the Beaverlodge Research Farm Centennial Field Tour in July 2017.
   2. Mechanical Control and Harvest Weed Seed Control. 2018. Invited oral presentation at CropConnect in Winnipeg, MB, February 2018.

3. Harvest weed seed control. 2018. Invited oral presentation at the Herbicide Resistance Summit in Saskatoon, SK, February 2018.
4. Harvest Weed Seed Control. 2019. Speaker at the Harvest Weed Seed Control Station at CanolaPalooza 2019 in Lacombe, AB.
5. Harvest weed seed control in Canada. 2019. Invited oral presentation on harvest weed seed control in Canada at Farm Forum, Saskatoon, SK, December 2019.
6. Depleting the weed seed bank. 2019. Invited oral presentation at the Farming Smarter Annual Conference, Lethbridge, AB, December 2019.
7. Herbicide resistance, integrated weed management, and harvest weed seed control. 2020. Invited oral presentation at the Peace Region Agronomy Update, Fairview, AB, January 2020.
8. Herbicide Resistance, integrated weed management and harvest weed seed control. 2020. Invited oral presentation for Mackenzie Applied Research Associate extension day, Fort Vermilion, AB, January 2020.
9. Harvest weed seed control in western Canada. 2020. Presentation to the Alberta Association of Agricultural Fieldmen's annual conference, held virtually, December 2020.
10. Introducing harvest weed seed control to agronomic crops in western Canada. 2021. Presentation to the North-West Regional Office of the Market and Industry Services Branch of Agriculture and Agri-Food Canada as part of their annual retreat, held virtually, February 2021.

e) Media activities (*e.g.*, radio, television, internet, etc.)
1. Harrington Seed Destructor and Harvest Weed Seed Control. 2018. Interview with Real Agriculture on Harrington Seed Destructor and harvest weed seed control potential in Canadian cropping systems.
2. Mechanical weed control, harvest weed seed control, and the Harrington seed destructor. 2018. Interview with the Western Producer on mechanical weed control, harvest weed seed control, and the Harrington Seed destructor, including incorporation of harvest weed seed control into integrated weed management strategies.
3. Harvest weed management: Updates on new options and rethinking the tried-and-true. 2018. Article for Canola Digest on harvest weed seed control in Canadian cropping systems. Published June 2018.
4. Crushing seed to prevent weeds. 2019. Article in Top Crop Manager on the Harrington Seed Destructor and harvest weed seed control. Published March 2019.
5. Wheat School: Harrington Seed Destructor and Harvest Weed Seed Control. 2019. Interview with RealAgriculture on the Harrington Seed Destructor and Harvest Weed Seed control for Wheat School from CanolaPalooza. June 26, 2019.
6. Harvest weed seed control and the Harrington Seed Destructor. 2019. The Growing Point Podcast from Alberta wheat on harvest weed seed control in western Canada and the Harrington Seed Destructor. Released August 18, 2019.
7. Options for weed seed control at harvest expanding for Canadian Farmers. 2020. Interview with RealAgriculture on harvest weed seed control in western Canada.

8. Harvest weed seed control under evaluation. 2020. Top Crop Manager article on harvest weed seed control in western Canada, September 2020.

f) Any commercialisation activities or patents

N.B.: Any publications and/or presentations should acknowledge the contribution of each of the funders of the project, as per the investment agreement.

g) University Guest Lectures

This project, and the premise behind it, has been presented in guest lectures on weed control at the University of Alberta in AFNS 495: Integrated Crop Protection in 2018, 2020, and 2021.

Section D: Project resources

1. **Provide a detailed listing of all cash revenues to the project and expenditures of project cash funds in a separate document certified by the organisation's accountant or other senior executive officer, as per the investment agreement.** Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage (CDL); and overhead (if applicable).
2. **Provide a justification of project expenditures and discuss any major variance (*i.e.*, ± 10%) from the budget approved by the funder(s).**

Personnel made up the bulk of the expenditures in each fiscal as expected. Personnel values are lower than budgeted due to partial coverage of student salaries by other budgets, as well as the external institution personnel salaries not being accounted for. Monies transferred to the University of Manitoba and University of Saskatchewan are accounted for in the 'other' category, along with the AAFC Science Service Charge. We do not have access (as those institutions are external to AAFC) to detailed breakdowns of their expenditures and so those funds have been grouped into one category for reporting. So as not to falsely inflate known categories, the full external amounts are accounted for in 'other'.

Travel dollars were higher than initially budgeted, with the exception of the 2020-21 fiscal when events were held virtually, however more extension opportunities around harvest weed seed control and integrated weed management were available, and so additional travel dollars were used in that fashion. In addition, some travel funds are associated with conference registrations which were budgeted under CDL and labelled differently during use. Other locations had higher travel expenditures for travel for seed, sample transfer between locations, etc. than budgeted. As the publications have not yet been completed, those CDL charges are not currently recorded. For future projects I am hoping to add an additional year following completion of the field portion of the study to allow more time for final summary and analysis, and technology transfer to better complete tech transfer associated with a project, as well as complete publications, etc. This has been a learning experience on grants as Principal Investigator that it takes more time than anticipated to get final data from all sites, complete final analyses, write publications, etc.

We did have additional expenses in materials and supplies throughout for items such as creating the chaff collection systems at each sites, needing larger bags due to higher than expected weed biomass, pivoting to seedbank growouts, etc. The delay in seedbank data collection due to needing to grow the samples out has also delayed writing of publications as all the data has not yet been completely collected. Otherwise, although the categories had some variability, the budget was expended fully in each year, aside from funds that were previously discussed to allow for cash management between years, primarily due to student salaries being covered by other projects. In some years you will note that more than the allotted budget was expended. This was dealt with through internal cash management within AAFC resulting in some higher levels of expenditures in previous fiscals and what appears to be an underspend in 2020-2021. However, the amount adds up to the full budget, just with slightly different expenditures throughout the course of the project than anticipated.

Hold back funds, received after this final report, will be used towards publication of results in open access scientific manuscripts, completion of seedbank, soil microbial, economic and any other analyses, and CDL of the final results.

3. **Resources:**
   Provide a list of all external cash and in-kind resources which were contributed to the project.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Agriculture Funding Consortium	$529,000	51%
Other government sources: Cash		%
Other government sources: In-kind	$510,000	49%
Industry: Cash		%
Industry: In-kind		%
Total Project Cost	**$1,039,000**	**100%**

External resources (additional rows may be added if necessary)		
Government sources		
Name (no abbreviations unless stated in Section A3)	Amount cash	Amount in-kind
AAFC Lacombe		90,000
AAFC Beaverlodge		77,000
AAFC Scott		73,000
AAFC Lethbridge		90,000
University of Manitoba		80,000
University of Saskatchewan		100,000
Industry sources		

Name (no abbreviations unless stated in Section A3)	Amount cash	Amount in-kind

Section E: Research Team Signatures and Authorised Representative's Approval

The Principal Investigator and an authorised representative from the Principal Investigator's organisation of employment MUST sign this form.

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

These are attached as separate PDF documents that allowed signatures to be obtained.

Section F: Suggested reviewers for the final report

Provide the names and contact information of four potential reviewers for this final report. The suggested reviewers should not be current collaborators. The Agriculture Funding Consortium reserves the right to choose other reviewers. Under *Section 34* of the *Freedom of Information* *and Protection Act (FOIP)* reviewers must be aware that their information is being collected and used for the purpose of the external review.

<u>Reviewer #1</u>
Name: Shaun Sharpe
Position: Research Scientist
Institution: Agriculture and Agri-Food Canada
Address: 107 Science Place, Saskatoon, SK, S7N 0X2
Phone Number: 306-385-9398
Fax Number:
Email Address: shaun.sharpe@canada.ca

<u>Reviewer #2</u>
Name: Francois Tardif
Position: Professor
Institution: University of Guelph
Address: Plant Sciences Building, University of Guelph, Guelph, Ontario
Phone Number: (519) 824-4120 x53395
Fax Number:
Email Address:ftardif@uoguelph.ca

<u>Reviewer #3</u>
Name: Scott White
Position: Assistant Professor
Institution: Dalhousie University
Address: Department of Plant, Food and Environmental Sciences, Agricultural Campus, Truro, NS, B2N 5E3
Phone Number: 902-893-2773
Fax Number:
Email Address: scott.white@dal.ca

<u>Reviewer #4</u>
Name: Elizabeth Mosqueda
Position: Assistant Professor
Institution: California State University Monterey Bay
Address: 5108 Fourth Avenue, Marina, CA 93933
Phone Number: (831) 582-4791
Fax Number:
Email Address: elmosqueda@csumb.edu