Farming Smarter Association, Lethbridge, Alberta

Project 2012F083R: Night Spraying - Pesticide Efficacy with Night Time Application (2012 – 2014)

Final Project Report

Farming Smarter Association, Lethbridge, Alberta
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Executive Summary

This study was initiated to examine night and dawn time applications as a practical alternative to the day time spray application. Poor day time conditions, such as, hot and windy conditions with low humidity and high rates of volatilization and photodegradation, among others, can greatly reduce herbicides' efficacies. Because, producers rely on pesticides, especially under zero-tillage systems, any reduction in herbicides' efficacies can quickly diminish financial returns on their substantial investments. Financial stakes could even be higher in Alberta due to our short growing seasons because about 70% of the 9,621,606 ha of land farmed for crops in the province is maintained with commercial herbicides. At a cost of $10 - $20/ac depending on rates, farmers in Alberta collectively spend between $72-138/ac each year on herbicides.

Our short growing seasons can often force growers to operate under less than the recommended conditions because most crops have to be seeded and sprayed in a very short time frame. For the same reason, waiting for the ideal conditions for spraying pesticides could cause significant economic and environmental consequences. Therefore, producers are increasingly inclined to complete their spray operations using night and/or dawn time applications. Because of cooler temperatures, less wind, higher humidity and lower evaporation potential, night and dawn time applications are perceived to potentially improve efficacy due to greater absorption while providing a feasible alternative to poor daytime conditions. However, scientific research is limited and huge knowledge gaps exist in this area. There are hardly any studies available which could provide producers with objective information and tools necessary to make an informed choice and determine if night/dawn time applications could be used as practical alternatives to the day time application. Therefore, this project was designed to determine if there was a real potential for night or dawn time spraying. This study evaluated day (12-2pm), night (12pm-1am) and early morning (4-5am) spray timings for preseed burndown (PSBD) and in-crop herbicide applications. Specifically, the study tried to answer three questions, (a) Determine if applying herbicides at night is a practical option for producers, (b) Generate unbiased data on the efficacy and tolerance of night applications of herbicides and (c) Uncover possible issues/complications associated with night spraying.

Research plots were established at three locations across Alberta, Lethbridge, Bonnyville and Falher. In preseed burndown (PSBD) trials, plots were sprayed at label-recommended and three quarter-label rates with four herbicides, Prepass (Florasulam), Rounndup (Glyphosate), Aim (Carfentrazone) and Heat (Saflufenacil) according to the experimental design using hand held sprayers equipped with two meter booms and CO2 propellant at three different timings, day (12-2pm), night (12pm-1am) and early morning (4-5am). In-crop trials plots were sprayed at three quarter-label rate with the herbicides, Liberty (Glufosinate-ammonium), TM Muster + Select (Ethametsulfuron-methyl + Clethodim), Vantage™ Plus MAX II (glyphosate), Odyssey (Imazamox, Imazethapyr), Select (Clethodim), OcTTain (fluroxypyr, 2,4-D LV ester), Everest (Flucarbazone-sodium), Axial + Infinity (Pinoxaden + Prasulfotole, bromoxynil) and Barricade (Thifensulfuron, methyl, tribenuron methyl) depending on the target crop and experimental design, using similar equipment and spray timing as mentioned above in the PSBD trials.

The major conclusions drawn from our study are:

- The herbicides in PSBD and in-crop trials performed most effectively when applied in the day time (12-2 pm). Night time (12pm-1am) gave better results than the least effective Dawn time (4-5 am). We saw a substantial advantage of Day and Night time applications over the Dawn time application

- Although, Night time application performance was less often effective than Day time application, it performed better more often than Dawn time and, therefore, it could be useful as an alternate spray application timing when opportunities for Day time application are limited
- The results also suggest that moisture-stressed plants or a major rainfall event shortly after herbicide application could also reduce efficacies potentially rendering the herbicides totally ineffective, upsetting the performance patterns most often seen in our study

Since our study results showed a substantial advantage of both day and night time applications over the dawn time application, night time application could be used as alternative spray application timing for optimizing herbicide use in Alberta, particularly, when the opportunities for day time application are limited. Because in a short growing season as in Alberta, application timing is very critical for optimal herbicide performance, it is anticipated that the night time application of pesticides would significantly expand the opportunity time window for the producers. It would help producers to avoid potential economic and environmental consequences resulting from waiting for ideal conditions required for day time application. It would also reduce economic losses from high application rates, unintended damage to off target crops as well as environmental pollution of surface and subsurface water bodies. Relatively calmer and cooler environmental conditions at night would be potentially favorable in limiting off target drifts, reducing high evaporative losses and improving upon plant deposition and adsorption.

Our findings would greatly improve the producers' options to select from when faced with difficult choices about which pesticides to spray, how to spray and when to spray (e.g., a producer may select a more effective herbicide if the danger of spray drift to adjacent crops is lower). It would also provide producers with the opportunity of expanding the application acreage in same window of time and assist the Alberta agri-food industry in enhancing public perception of its environmental stewardship. Our study of comparative performance of day, night and dawn time applications of pesticides would help producers to make informed decisions, especially on regional basis. Our study also filled the knowledge gaps and provided producers with unbiased reliable information on efficacy and tolerance for common herbicides sprayed on common crops in Alberta.

Acknowledgement(s)

We thankfully acknowledge the funding for this project from the Alberta Canola Producers Commission (ACPC) and the Alberta Barley Commission (ABC). We also thank our partners, the Lakeland Agricultural Research Association (LARA), Bonnyville and the Smoky Applied Research and Demonstration Association (SARDA) in Falher, Alberta, for their help and making this study a success.

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1 Introduction

Producers rely on pesticides, especially under zero-tillage systems. Growers try to farm more acres using the same equipment, and sometimes stretch the boundaries of recommended application conditions. Timing is critical for optimal herbicide performance (Ramsey et al., 2005). Night spraying may provide a feasible alternative to poor daytime conditions and could potentially improve efficacy due to greater absorption. Growing seasons are short and most crops are seeded and sprayed in a very short time frame. Weather conditions including temperature and wind speed can further limit ability to apply pesticides at the correct time.

Applying pesticides in hot and windy conditions with low humidity causes spray droplets to evaporate quickly on the leaf surface decreasing absorption time and potentially affecting efficacy (Ramsey et al., 2005). Volatilization and photodegradation is also at its highest under these conditions (McInnes et al., 2000). At night, evaporation potential is lower because of cooler temperatures, less wind and higher humidity. Dew on the leaf cuticle may increase absorption of the pesticides through better cuticle hydration time when plants are growing most actively.

Scientific research is limited in this area. Ramesy et al. (2005) noted that among environmental factors, temperature and relative humidity have the biggest effect on herbicide uptake; however, broad conclusions about the exact mechanisms for herbicide/species/humidity/temperature interactions are difficult because of the scope required. While a study showed that paraquat was more effective at controlling one weed species at 8pm than 2pm, another study showed it was more effective at controlling different weed species at 9am and 3pm than 9pm or 3am (Fausey & Renner, 2001). The main hazard is the potential for a temperature inversion. Inversions are most likely to happen at night when a layer of cooler air is trapped near the earth's surface. Under these conditions it is possible for fine particles to be suspended in a layer above the ground and later deposited in a non-intended location. Inversions may be less of a concern in windy regions and in the early spring compared to later summer and fall.

Demonstration plots were established at the Farming Smarter Field School in 2011. Liberty, Glyphosate, Solo and Gramoxone herbicides were sprayed on pea, barley and camelina (as weeds) during the day and at night. Night spraying did not reduce efficacy and some plots showed slightly better visual control. Dr. Bob Blackshaw (weed specialist with AAFC) and Don Boles (farmer in Three Hills, AB) lead the module and discussed how the development of new technology like GPS and autosteer has aided implementation. Boles noted he has been spraying at night for a number of years with little to no adverse effects on his crops and at times saw improved efficacy. He also noted that in some situations night spraying has allowed him to lower his water volumes.

1.1 Objectives

The main goal of the study is to provide detailed scientific information on the effects of night spraying using herbicides currently registered in Alberta on common weeds and crops for the area. Objectives are to: (a) determine if the application of herbicides at night is a practical option for producers, (b) generate unbiased data on the efficacy and tolerance of night applications of herbicides and (c) uncover possible issues/complications associated with night spraying.

1.2 Deliverables

This project was designed and delivered with producers, industry and other stakeholders in mind to: (a) evaluate phytotoxicity (crop tolerance) and efficacy (weed control) of herbicides with differing modes of action applied at various times of day (12-2pm, 12pm-1am and 4am-5am), (b) utilize long-term weather records to determine average and annual variability in daytime and nighttime hours suitable for spraying each week at different locations in Alberta, (c) calculate the increase in acres that could be sprayed in "optimum" spray conditions per sprayer and (d) distribute information to growers via farming smarter and partner associations' magazine, newsletters, crop walks, tours, workshops/conferences, media, websites (www.farmingsmarter.com, ropintheweb, www.areca.ab.ca) social media etc., which would give them the tools necessary to make an informed choice.

This trial was designed to determine if there was real potential for night spraying. Should positive results be found, a more comprehensive research program may be devised that includes multiple herbicide rates, reduced water volumes and field scale testing.

2 Materials and Methods

2.1 Site Selection and Trial Setup

Research plots of slightly different sizes were established at three locations, 1.93 m x 6 m at the Farming Smarter Association (FSA) site in Lethbridge, 1.14 m x 6 m at the Lakeland Agricultural Research Association (LARA) site in Bonnyville and 1.37 m x 5 m at the Smoky Applied Research and Demonstration Association (SARDA) in Falher, Alberta. All trials were designed as randomized split-plots with four replicates. A total of 344 plots were set up under FSA, 96 plots in two preseed burndown (PSBD) trials and 248 in 8 in-crop trials under 4 crops, LL-canola, RR- canola, peas and wheat. Four in-crop trials were set up at LARA and SARDA with 2 trials each under two crops, LL-canola and wheat with a total of 160 plots. Plots were sprayed using hand held sprayers equipped with two meter booms and CO_2 propellant. Low drift nozzles were used at all locations to minimize drift. Herbicide labels were consulted for rates and application timing and other considerations. Nozzles were spaced 50 cm apart and held 50 cm above the canopy. Plot dimensions, number of rows, row spacing etc. were adjusted as necessary to accommodate different seeding and spraying equipment.

2.2 Data Collection and Processing

2.2.1 Preseed Burndown (PSBD) Trials

The PSBD trial was conducted only at the FSA site in Lethbridge. It was a randomized split-plot design with 4 replicates. The main plots were herbicides and the subplots were spray application timings. Plots were sprayed at label-recommended and three quarter-label rates with four herbicides (Table 1), Prepass (Florasulam), Rounndup (Glyphosate), Aim (Carfentrazone) and Heat(Saflufenacil) according to the experimental design using hand held sprayers equipped with two meter booms and CO_2 propellant at three different timings, day (12-2pm), night (12pm-1am) and early morning (4-5am).

Table 1. List of the herbicides used in the preseed burndown (PSBD) trials.

Herbicide Trade Name	Chemical Name	Group	Activity
Prepass TM	Florasulam	group 4/9	systemic
Rounndup	Glyphosate	group 9	systemic
Heat	Saflufenacil	group 14	contact
Aim	Carfentrazone	group 14	contact

Site selection included known weedy areas including both broad leaf and grassy weeds. If these sites were not readily available, weeds were seeded to ensure an effective study. In order to ensure an appropriate range of spray conditions, two trials were conducted with two spray application dates, an early-season date and the most practiced (normal) date.

Environmental data were recorded before and after spray applications including air temperature, soil temperature, wind speed and direction, relative humidity, cloud cover, and precipitation. Dew period and evapotranspiration were also measured. Weed control ratings were conducted at 7 DAS (days after spraying), 14 DAS and 21+ DAS. Weed biomass was taken as fresh weights from natural weed infestations using four ¼ m^2 quadrats at 21 DAS. The top 5 most prevalent weeds were noted for each plot. Other data collection included growth stage, weeds present and pictures.

2.2.2 In-Crop Trials

In crop trial locations included FSA, Lethbridge; SARDA, Falher and LARA, Bonnyville, Alberta. These trials were randomized split plots with herbicide as the main plot and spray timing as the sub plot. The three spray timings were day (12-2pm), night (12pm-1am) and early morning (4-5am). Four trials were seeded to barley/wheat, peas, LL-Canola and RR-Canola as early as possible and four additional trials were seeded at a later date to ensure variations in spray conditions. For the same reason, two additional trials were seeded to LL-Canola and RR-Canola on even a later (third) date at the FSA site in Lethbridge. Seeding rates were 300 seeds m^2 for barley/wheat, 100 seeds m^2 for peas and 5lbs/ha for canola. Tame oats (150 seeds m^2) and tame mustard (50 seeds m^2) were seeded across the plots in all trials to simulate weeds.

Herbicides were selected based on the mode of action, activity, selectivity and use in Alberta (Table 2). Trial plots were sprayed at three quarter-label rate with the herbicides, Liberty (Glufosinate-ammonium), TM Muster + Select (Ethametsulfuron-methyl + Clethodim), Vantage™ Plus MAX II (glyphosate), Odyssey (Imazamox, Imazethapyr), Select (Clethodim), OcTTain (fluroxypyr, 2,4-D LV ester), Everest (Flucarbazone-sodium), Axial + Infinity (Pinoxaden + Prasulfotole, bromoxynil) and Barricade (Thifensulfuron, methyl, tribenuron methyl) depending on the target crop and experimental design, using similar equipment and spray timing as mentioned above in the PSBD trials.

The crop tolerance and weed control ratings were conducted at 7 - 10 DAS, 14 - 17 DAS and 21-28 DAS. Crop and weed biomass were sampled as fresh weights using four ¼ m^2 quadrants around 21 DAS. Other data collection included growth stage, weeds present, pictures and yield when possible. Environmental data were also recorded before and after spray applications including air temperature, soil temperature, wind speed and direction, relative humidity, cloud cover, and precipitation. Dew period and evapotranspiration were also measured.

2.3 Data Analysis

Trials' data were analysed with the PROC GLM procedure of SAS (SAS Institute Inc., Cary, NC) for ANOVA to detect significant differences ($p<0.1$) among the treatment means. Treatment means with significant differences were separated with the Tukey's Studentized Range (HSD) Test ($p=0.1$). Two indices, Efficacy rating (ER) and Weed biomass ratio (WBR), were used for performance comparisons of the selected herbicides. The ER is a visual rating system on the scale of 0 (Control) to 100, with 0 denoting no weed control and 100 indicating a complete weed-eradication. The WBR was calculated as a percent ratio of the weed biomass collected per unit area from each treatment with weed biomass per unit area from the Control (WBR=100%).

Table 2. List of the herbicides used in the in-crop trials.

Crop	Herbicide Trade Name	Chemical Name	Group	Activity	Target Weeds
Peas	Select	Clethodim	group 1	systemic	Controls grasses in Canola, Flax, Field Peas, Lentils, Desi and Kabuli Chickpeas, Dry Onions, Potatoes, Mustard, Soybeans, Seedling Alfalfa, Sunflower and Dry Beans http://www.cropscience.bayer.ca/~/media/Bayer%20CropScience/Country-Canada-Internet/Products/Centurion/select_label.ashx
	Odyssey	Imazamox, Imazethapyr	group 2	systemic	Controls broadleaf as well as grassy weeds from Canola, Lentils, Field Peas and Soybeans (https://agro.basf.ca/West/Products/Related_Files/ODYSSEY%20DLX%20V2_Tech%20Sheet.pdf)
Wheat	Barricade	Thifensulfuron, methyl, tribenuron methyl	group 2	systemic	Control broadleaf weeds in wheat (spring, winter and durum), spring barley and oats not under seeded to legumes or grasses, and in certain grasses for forage or seed production (http://www.dupont.ca/content/dam/dupont/products-and-services/crop-protection/cereals-protection/documents/cp_PSD-18_29544-20140929-sib2014-2048&2014-2126-BarricadeSG-Label-EN.pdf)
	Everest	Flucarbazone-sodium	group 2	partially systemic	Controls grassy and broadleaf weeds (http://www.uap.ca/products/documents/Everest2.0.pdf)
	OcTTain	fluroxypyr, 2,4-D LV ester	group 4	partially systemic	Controls broadleaf weeds including cleavers, kochia and wild buckwheat in spring wheat, durum wheat, winter wheat and spring barley (http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0901/0901b80380901e2c.pdf?filepath=ca/pdfs/noreg/010-22282.pdf&fromPage=GetDoc)
	TM Axial + Infinity	Pinoxaden +	group 1	systemic	Controls grassy weeds - Wild Oats, Green Foxtail, Yellow Foxtail, Barnyard Grass Volunteer Oats, Volunteer Canary seed and Proso Millet in Spring Wheat, Winter Wheat and Barley (http://www.syngentafarm.ca/pdf/msds/Axial_BIA_30431_en_msds.pdf)
		Prasulfotole, bromoxynil	group 6/27	partially systemic	Broadleaf weeds in Wheat, Barley, Triticale, Timothy (seed production only) (http://www.cropscience.bayer.ca/~/media/Bayer%20CropScience/Country-Canada-Internet/Products/Infinity/Infinity%20-%20MSDS.ashx)
Canola LL	Liberty	Glufosinate -ammonium	group 10	contact	Controls grassy and broadleaf weeds in Canola varieties, Corn hybrids and Soybean varieties that are specially developed to be tolerant to glufosinate ammonium (for example LibertyLink® seeds) (http://www.cropscience.bayer.ca/~/media/Bayer%20CropScience/Country-Canada-Internet/Products/Liberty%20150/liberty150_msds.ashx)
	TM Muster + Select	Ethametsulfuron-methyl +	group 2	systemic	Canola, Rapeseed, Condiment Mustard, Sunflower, Brassica Carinata, Laurentian Rutabaga (http://www.dupont.ca/content/dam/dupont/products-and-services/crop-protection/oilseed-crop-protection/documents/cp_PSD-42_23569-20140716-%20font%20correction-Muster-Label-EN.pdf)
		Clethodim	group 1	systemic	As above
Canola RR	VPMII	glyphosate	group 9	systemic	Many annual and perennial grasses, broadleaf weeds, and woody brush and trees when applied as recommended by the manufacturer (http://www.ivmexperts.ca/pdfs/Vantage_Plus_Max_II_Label_English.pdf)

3 Results and Discussion

3.1 Preseed Burndown (PSBD) Trials

The preseed burndown (PSBD) trials were conducted only at the FSA site in Lethbridge, Alberta. Based on the results from the three project years (2012-2014), we conclude that:

Tables 3, 4 and 5 present the analysis results for 2012, 2013 and 2014, respectively. Each table compares the performance of the four selected herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two PSBD trials conducted with two different spray application dates, an early date and the most practiced (normal) date. Treatment means with the same letter are not significantly different at a probability level of 0.1 ($p<0.1$).

Table 3, shows that ERs for both Day time and Night time applications ranked better than the Dawn time application for 75% of the time (three of the four herbicides) in trial-1 and 100% of the time (all four herbicides) in trial-2. Similarly, in 75% of the occurrences, WBRs for both Day and Night time applications ranked better than the Dawn time application in both trials. In summary, Table 3 shows that in majority of the instances in 2012, both Day time and Night time spray applications were more effective than Dawn application.

Results were different, however, in 2013 compared to 2012, particularly in trial-1, where Dawn time application ER and WBR ranked better than both Day and Night times in 75% of the instances (Table 4). However, similar to the 2012 results, both ER and WBR for Day time application in trial-2 ranked better than both Night and Dawn application times in 50% and 75% of the instances, respectively. From Table 4, it could be concluded that, while ER and WBR for the Dawn time application on the average scored better than the Day and Night time applications in trial-1, results from trial-2 were similar to 2012 favoring the Day time application over the Night time and Dawn time applications.

Results from the two trials in 2014 (Table 5) were very similar to the two trials of 2012 (Table 3) and trial-1 in 2013 (Table 4). The ERs for both Day time and Night time applications ranked better than the Dawn time application for 100% of the time (all four herbicides) in both trials. Similarly, WBRs for both Day and Night time applications ranked better than the Dawn time application 75% of the time in both trials. Based on the results listed in Table 3 it was concluded that on the average in about 88% of the instances in 2014, both Day time and Night time spray applications were more effective than Dawn application.

Table 6 shows a summary of the ER and WBR values from Tables 3, 4 and 5 for the Day time application. It shows that on an average, PSBD with the Day time application of the selected herbicides was more effective than the Dawn application in 75% of the instances when examined using ERs and about 67% of the time based on the WBRs over the three years, 2012, 2013 and 2014. However, when averaged over the two years with similar results, 2012 and 2014, the ERs and WBRs values increased from 75% and 67%, respectively, to 94% and 75%; which also indicated a substantial increase in the number of instances in which PSBD with the Day time application of the selected herbicide performed better than the Dawn time application. The PSBD Results similar to those noted in 2012 and 2014 showing the Day time application being better than the Dawn time were also observed in a pilot project conducted as a proof of concept prior to this study.

3.1.1 Influence of Prevailing Weather Conditions on PSBD Trials

Similarities between the herbicides' performance patterns with respect to the application timings (Day, Night and Dawn) between 2012 and 2014 trials and the absence of those patterns in the 2013 trials' results could be attributed to the prevailing weather conditions at the time of herbicide application. Several studies have reported a reduction in herbicide efficacy under both dry soil conditions and the occurrence of a rainfall event shortly after a spray application (Anderson et al., 1994; Kudsk and Kristensen, 1992; Johnson et al., 2004). Under dry conditions, low soil moisture could cause high moisture stress in plants which could reduce translocation and hence the efficacy of the post-emergence herbicides. Moisture stress can also result in changes in the plant form and structure, such as, leaf rolling or thickening of cuticles possibly causing reduction in the amount of herbicide entering the plant. Similarly, washing away of unadsorbed herbicide from the leaf surface by a rainfall event shortly after a spray application could also reduce its efficacy.

Figures 1 through 3 compare daily instantaneous, accumulated and long term normal rainfall for April and May in 2012, 2013 and 2014 at the Lethbridge Demo Farm, Lethbridge, Alberta. Figures 4 through 9 show hourly records of the instantaneous precipitation (mm), accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%)on the dates of the respective trials in 2012, 2013 and 2014 at the Lethbridge Demo Farm. A close examination of the weather data in 2013 clearly showed that both moisture conditions, low soil moisture and rainfall event(s) shortly after the spray application occurred around the dates of the trials- 1 and 2, respectively. As seen in Figures 2, only 24 mm of precipitation had accumulated between April 1 and May 10, 2013, (52% below normal), indicating a very dry period at the time of the herbicides' application in trial-1 (May 9 and 10, 2013) compared to the 85 mm between April 1 and May 7 (79% above normal) in trial-1 in 2012 (Figure 1) and 60 mm between April 1 and May 8 (23% above normal) for trial-1 in 2014 (Figure 3). Apparently, the impaired performance of all four herbicides because of the dry conditions in trial-1, 2013, not only left WBRs very close to Control (100%) indicating almost no weed kill, an increase in weed biomass compared to the Control was noticed in at least two of the instances (Table 4) – indicating a total loss of herbicide efficacy. In trial-2, 2013, with precipitation accumulation (43 mm) still 47% below normal, it was again dry at the time of herbicides application between 27th and 28th May, 2013. Also, however, about 16 mm of rainfall occurred between May 28 and 29 (Figure 2). Apparently, because the weather conditions as discussed above in 2013, rendered the herbicides almost totally ineffective in weed kill in trial-1 and -2, their results could not match the herbicides' performance patterns observed with respect to the spray application timings in 2012 and 2014.

Table 7, shows a performance comparison of the four selected herbicides, and with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the PSBD trials presented earlier in Tables 3, 4 and 5 above. These results show that with the highest scoring ERs and the lowest WBRs (except in trial-1, 2014) over the three project years, the Vantage Plus Max II (VPMII) herbicide was significantly ($p<0.1$) more effective than the other three selected herbicides examined in our PSBD trials. Table 7, also shows that the Day time spray application was more effective than Night and Dawn timings in two of the three years (66% of the time) in the trials sprayed on an early date and for all three years (100% of the time) in the trials sprayed on normal (most practiced) dates during the season. These results showing the Day time spray application being more effective than Night and Dawn time applications also corroborate with the results presented in Tables 3 through 6 discussed above while examining each of the selected herbicides separately.

3.2 In-Crop Trials

3.2.1 Data Analysis and Results for the FSA Site, Lethbridge

3.2.1.1 Project Year 2012

3.2.1.1.1 Prevailing Weather Conditions

Figure 10 shows the daily instantaneous, accumulated and long term normal rainfall from May 25 to July 31, 2012, at the FSA project site in Lethbridge, Alberta. The site had received nearly 16 mm of rainfall during the last week of May, by the time trial-1 was treated on May 31 - June 1. By the time we treated Trial-2 on June 21-22, the area had accumulated an additional rainfall of around 90 mm. A further amount of 49 mm of rainfall had fell by the time we treated trial-3 on July 24-25, bringing the total amount of rainfall above normal for that period. Because of the relatively wet conditions, we believe soil moisture conditions prevented plant moisture-stress at any time. Figures 11, 12 and 13 also show that there were no major rainfall events shortly after the treatment of the three trials.

3.2.1.1.2 Results

Tables 8 and 9 compare the ER and WBR means with respect to three distinct application timings for seven selected herbicides applied on oats and mustard in four crops in 2012. As mentioned before, there were three trials set up in 2012 with Trial-1 and -2 with four crops and Trial-3 with two crops. Each trial was a split plot randomized design with herbicide as a main plot and spray application timing as sub-plots. The three trials were treated separately on three different spray application dates, i.e., Trial-1 on May 31-June (an early season date), Trial-2 on June 21-22 (the most practiced date) and Trial-3 on July 24-25 (a date relatively late in the season).

Summary in Table 8 for oats shows that in Trials -1 and -2, Day time application produced the highest ER scores (57, 71) and the lowest WBRs (71, 75) in majority of the instances compared to the Night time application ranking in the middle and Dawn time application scoring the lowest. However, Day time application in Trial-3 scored lower than the Night time application that was still higher than Dawn time application. Also, as seen in Table 9 for mustard, the Day time application showed the highest ER scores in all three trials (100, 100, 100) compared to the Night time and Dawn time applications.

Tables 10 and 11 give the ANOVA results of the combined data from the three trials described in Tables 8 and 9 for oats and mustard weeds, respectively. Treatment means with the same letter are not significantly different (p=0.1). Table 10 shows that herbicides, (TM Muster + Select, VPMII, Select and TM Axial+Infinity) were the most effective in eradicating oats from Canola (LL), Canola (RR), Peas and Wheat, respectively. These also had the highest ER scores and lowest WBRs compared to the Control with the Day time application in 100% of the instances. We also had similar ANOVA results for mustard (Table 11). The Day time application performed better in 100% of the instances compared to 50% and 0% for Night time and Dawn time applications, respectively, with respect to the ER scores.

The results from 2012 presented in Tables 8 and 9 clearly demonstrate that the selected herbicides were most effective in eradicating oats and mustard weeds when applied in the Day time. The ANOVA results given in Tables 10 and 11 also show that in 2012 the Day time application trials were the most frequently effective spray timing for most of the selected herbicides used in eradicating oats and mustard in the four crops examined.

3.2.1.2 Project Year 2013

3.2.1.2.1 Prevailing Weather Conditions

Figure 14 shows June 2013 daily instantaneous, accumulated and long term normal rainfall at the FSA project site in Lethbridge, Alberta. The site received nearly 21 mm of rainfall during the first week of June by the time we treated Trial-1 on June 5-6. An additional rainfall of around 52 mm accumulated by June 17-18 when trial-2 was sprayed, bringing the total amount of rainfall above normal for that period. Because of adequate rainfall, we expected that soil moisture conditions were good and the plants were not under any moisture stress and actively growing. Figures 15 and 16 show that while there was no major rainfall event shortly after the treatment of Trial-1, over 40 mm of rainfall fell in two major events between June 17 and 18, within 6-8 hours of the Day time application in Trial-2.

3.2.1.2.2 Results

Tables 12 and 13 show the results from the two trials each set up for oats and mustard in 2013. We treated Trial-1 June 5-6 and Trial-2 June 17-18. We set up all trials with the same experimental design, herbicides and crops used in 2012. For oats in Trial-1, the Night time application performed better more frequently than the Day time and Dawn time applications. The Dawn time application showed the greatest frequency of effectiveness in WBR compared to the Night and Day time applications in Trial-2. We noted similar results in the mustard trials (Table 11) with Dawn time application rarely doing better than the other two timings (Table 12).

We suspect that the major rain events around the herbicide application time caused Trial-2 Day time application results out of synchronization with 2013 Trail-1 results and majority results from 2012 trials. As indicated before, Figure 16 shows that on June 17, 2013, Trials-2 received over 40 mm of high intensity heavy rainfall in two events within 6-8 hours after the Day time herbicide application. Because it was highly likely that the unadsorbed herbicides washed off the leaf surfaces, efficacy of the herbicides rendered the Day time application ineffective compared to Night time and Dawn applications. Also, because the rainfall events were apparently a weather anomaly, an objective comparison of application timings was not possible. Therefore, we deemed data from Trials-2 in 2013 unreliable for making any inferences and eliminated it from further statistical analysis.

Tables 14 and 15 list the ANOVA results of only Trial-1 (Tables 12 and 13) for oats and mustard, respectively. Treatment means with the same letter are not significantly different (p=0.1). Table 14 shows that the herbicides, Liberty, VPMII, Select and TM Axial+Infinity, performed significantly better than other herbicides in Canola (LL), Canola (RR), Peas and Wheat crops, respectively. It also shows that the Day time and Night time applications were substantially more effective than the Dawn time application in terms of both ER scores (75 and 75% versus 25%, respectively) and WBRs (50 and 100% versus 0%, respectively). Table 15 shows similar ANOVA results from Trial-1 for mustard – the Day time and Night time applications performed better, more often than the Dawn time application. Table 15 also shows that while each of the single herbicide applied to Canola (LL), Canola (RR) and Peas crops was significantly effective in destroying mustard weed, performance of TM Axial + Infinity herbicide among the four herbicide applied to Wheat crop was significantly better compared to the Control than the others - showing the highest ER scores and lowest WBR, as observed in the oats trials (Table 14) the same year and both oats and mustard trials in 2012.

The results in 2013 listed in Tables 12 and 13 with treatment means and Tables 14 and 15 with ANOVA outcome, clearly demonstrate consistent trends with 2012 showing that on the average the Day time application performed better, more often than the Night time and Dawn time applications and the Dawn time application performed best.

3.2.1.3 Project Year 2014

3.2.1.3.1 Prevailing Weather Conditions

Figure 17 shows the daily instantaneous, accumulated and long term normal rainfall for May and June 2014, at the FSA project site in Lethbridge, Alberta. The site received only 40 mm of rainfall during the 4-week period ending by June 3-4 when we treated Trial-1., which indicated a relatively prolonged dry period immediately before Trial-1. However, an additional rainfall of around 150 mm fell by June 23-24 when we sprayed Trial-2, bringing the total amount of rainfall above normal for this period. There were no major rainfall events shortly after the treatment of Trials -1 and -2 (Figures 18 and 19).

3.2.1.3.2 Results

Tables 16 and 17 list treatment means from the trials set up for oats and mustard in 2014. We treated Trial-1 for both oats and mustard June 3-4 and Trial-2 June 23-24. We used the same set up as 2012 and 2013 for all trials. The results from Trial-1 for oats show that, in terms of the ER scores, the Night time application was the most frequently (71% of the occurrences) effective application timing compared to both Day time and Dawn time application (29% of the time). For the WBRs, however, the frequency of the Dawn time application performing better exceeded those of the Day and Night time applications (71% versus 14% and 29%, respectively). However, results from Trial-2 (Table 16) were quite opposite to Trial-1, which indicated that in terms of the two indices, ERs and WBR, the Day time application performed better more often than both Night and Dawn time applications. This result was also consistent with the similar trends in majority of trials discussed before.

For mustard Trial-1 (Table 17), the Day time application scored better ERs than the other two timings (57% versus 14% and 43%, respectively), but ranked between the Night and Dawn time application for WBRs (43% versus 71% and 29%, receptively). In Trial- 2, however, the Day time application was the most effective compared to the Night time and Dawn time applications in terms of both indices - ERs and WBRs. These results, indicating that the Day time application performs better than other timings most of the time, were consistent with Trial-2 for oats the same year and the majority of trials discussed above.

Prevailing dry weather and low soil moisture conditions around the dates of the trial treatments may explain the difference between the trends seen in the results of Trials-1 for oats and mustard in 2014 and the majority of trials discussed before. Figure 18 shows that the project site did not have any significant rain until about 14 mm of rain fell between 4 and 6 pm June 2, i.e., less than 24 hours before we applied herbicides in the Day time application (12-2 pm) June 3. However, the dry conditions ended with an additional 150 mm of rainfall received over the next 20 days by the time we treated Trials-2 June 23-24, which would also cause substantial improvement in soil moisture conditions by that time.

It seemed quite possible that the low soil moisture conditions due to dry weather for over a month might have also caused moisture stress in oats and mustard plants while slowing down and limiting active growth. Although, plants can recover from moisture stress within 24 hours, it was very likely that by the time we applied the Day time application, the oats and mustard plants did not have enough time after the rainfall to rehydrate and recover from moisture stress. As mentioned in the commentary on the PSBD trials before, because high moisture stress in plants under dry conditions could reduce the uptake and translocation of the post-emergence herbicides, the efficacy of the selected herbicides applied between 12 -2 pm June 3 might have been reduced rendering them ineffective in the Day time application. Because the dry weather conditions had possibly compromised the performance of the herbicides in Trial-1 in 2014, we deem an objective comparison of the application timings and any inferences hardly possible. For the same reason, we eliminated Trial-1 for oats and mustard in 2014 from further analysis.

Tables 18 and 19 give the ANOVA results of only Trial-2 for oats and mustard weeds. Treatment means with the same letter are not significantly different (p=0.1). Table 18 for oats shows that the herbicide blend TM Muster + Select, VPMII, Select and TM Axial+Infinity were the most effective herbicides in Canola (LL), Canola (RR), Peas and Wheat crops, respectively. It also shows the Day time application with the highest ER scores in 100% and the lowest WBRs with 75% of the instances, was the most frequently effective herbicide application timing compared to the Night time and Dawn time applications. The Night time placed second with ERs and WBRs better than the Dawn time application in 100 and 50% of the instances. We also noted similar ANOVA results for mustard in Trial-1 as listed in Table 159. The Day time and Night time applications performed better than the Dawn time application in 100% instances in terms of both indices, ERs and WBRS. Table 19 also showed that while each of the single herbicide applied to Canola (LL), Canola (RR) and Peas crops was significantly effective compared to Control, performance of TM Axial + Infinity herbicide was significantly better than the others among the four herbicides applied to Wheat crop - showing the highest ER scores and lowest WBR.

The results from Trials-2 in 2014 (Tables 16 through 19) were also similar to those discussed earlier and clearly showed that the Day time application of the selected herbicides was the most effective application timing compared to the Night time and Dawn time applications.

3.2.1.4 Results Summary, FSA, Lethbridge

Based on our three project years (2012-2014) results at the FSA project site discussed above, we conclude:

- The selected herbicides for the crops studied at the FSA site performed most effectively when applied in the Day time (12-2 pm). Night time (12pm-1am) gave better results than the least effective Dawn time (4-5 am). We saw a substantial advantage of Day and Night time applications over the Dawn time application.
- Although, Night time application performance was less often effective than Day time application, it performed better more often than Dawn time and, therefore, it could be useful as an alternate spray application timing when opportunities for Day time application are limited
- The results also suggest that moisture-stressed plants or a major rainfall event shortly after herbicide application could also reduce efficacies potentially rendering the herbicides totally ineffective, upsetting the performance patterns discussed above

3.2.2 Data Analysis and Results for the SARDA, Falher, Alberta

3.2.2.1 Project Year 2012

3.2.2.1.1 Prevailing Weather Conditions

Figure 20 shows the daily instantaneous, accumulated and long term normal rainfall for June 2012 at the Ballater weather station about 25 km south of the SARDA project site in Falher, Alberta. The site had received around 90 mm of rainfall by June 20 when we treated Trial-1 with no additional rainfall by June 27 when we sprayed Trial-2. This indicated that soil moisture conditions were probably good and the plants were not under moisture stress. Figures 21 and 22 also show that there were no significant rainfall evens shortly after the treatment of the two trials.

3.2.2.1.2 Results

Tables 20 and 21 give treatment means from the trials set up for oats and mustard in 2012, respectively. We treated Trials-1 for both oats and mustard June 20-21 and Trials-2 June 27-28. We conducted all trials with the same set up as described under the FSA trials' results. The results from both Trial-1 and -2 for oats (Table 20) show that in terms of the ER scores, the Day time application was the most frequently (50 and 75% of the occurrences) effective application timing compared to both Night time and Dawn time application (25 % of the time). For the WBRs, the frequency of the Day time application also exceeded those of the Night and Dawn time applications (25% each) in Trial-1, but fell in the middle of the Night time (75%) and Dawn time (25%) applications in Trial-2. On the average however, the Day time application was the most often effective timing, followed by the Night time and Dawn last.

For mustard Trial-1 (Table 21), the Day time application scored ERs better than the other two timings in both trials (80% versus 40% and 20%, respectively, and 60% versus 40% each, respectively). For WBRs however, the Day time application exceeded the other timings in Trial-1 (80% versus 40% and 20%), but ranked the same as the Night time (60%) in Trial-2 with both timings performing better than the Dawn time application. In general, similar to results for oats discussed above, the Day time application was the most effective application timing for mustard treatment.

Tables 22 and 23 give the ANOVA results of the two trials for oats and mustard described in Tables 20 and 21, respectively. Treatment means with the same letter are not significantly different (p=0.1). Table 22 for oats shows that the herbicide blends TM Muster + Select and TM Axial+Infinity were the most effective herbicides in Canola (LL) and Wheat crops, respectively. It also shows the Day time application with the highest ER scores in 100% of the instances exceeding the other two timings. However, for oats they performed similar to Night time and Dawn time applications with respect to WBRs. For mustard however, the ANOVA results in Table 23 indicate that the Day time application was the most effective in 100% of the instances compared to the Night time and Dawn time applications at 50% and 0%, respectively for both indice - ERs and WBRs. Table 23 also shows that, as before for oats, TM Axial+Infinity was most effective herbicide for mustard in Wheat crop.

These results, indicating that the Day time application performing better than other timings most of the time, were also consistent with the majority of results from the Lethbridge FSA site trials discussed above.

3.2.2.2 Project Year 2013

3.2.2.2.1 Prevailing Weather Conditions

Figure 23 shows the daily instantaneous, accumulated and long term normal rainfall for June 2013 at the Ballater weather station. In 2013, the project site received over twice as much rainfall (70 mm) between June 1 and 22 when we treated Trial-1. An additional 27 mm fell between June 24 and 26 around the time when we treated Trial-2 (Figure 24). As seen in Figure 24, no rain fell shortly after the spray applications in Trial-1. However, Figure 25 shows that all 27 mm of rainfall occurred between 5 pm June 25 and 4 pm June 26, shortly after the Day time application (12-2pm) and through the Night time and Dawn applications in Trial-2. Because the site received adequate rainfall in June, we believe the soil moisture conditions were good and the plants were not moisture-stressed.

3.2.2.2.2 Results

Tables 24 and 25 list the treatment means for oats and mustard trials in 2013. We treated Trial-1 for both oats and mustard June 22-23 and Trial-2 June 25-26. Researchers conducted all trials with the same set up as described in 2012. The results for oats (Table24) show that in Trial-1 the Day time application was similar to the Night time and exceeded the Dawn time for ER scores, but did better than both timings in terms of the WBRs. However, the Dawn time application ranked better than the Day and Night time applications in Trial-2 for ER and WBR (67% versus 33% each respectively). As discussed before, the diminished performance of the Day time application in Trial-2 could be due to multiple rainfall events starting around 4 pm, shortly after the spray application between 12-2 pm June 25. As stated before, heavy rains shortly after herbicide application could reduce its efficacy by washing away the unadsorbed portion from plant leaves. For mustard trials (Table 25), the performance of the Day time with respect to ER scores and WBRs was very similar to the Night time application with both exceeding the Dawn time performance in about 100% of the instances.

Tables 26 and 27 give the ANOVA results of the two trials for oats and mustard described in Tables 24 and 25, respectively. Treatment means with the same letter are not significantly different (p=0.1). Table 26 for oats shows that the herbicide blends TM Muster+Select and TM Axial+Infinity were the most effective herbicides in Canola (LL) and Wheat crops, respectively. Furthermore, the table indicates that except the Night time application performance for WBRs, the three application timings showed a similar performance with respect to both indices, ERs and WBRs. For mustard however, the Day and Night time applications were 100% more effective than the Dawn time application for ER scores, but only 50% of the time for WBRs (Table 27). Barricade was the most effective herbicide on mustard in Wheat crop.

The results from 2013 as discussed above also indicated that, overall, the Day time application was the most effective spray application timing for the selected herbicides and crops used in these trials. These results were also consistent with the majority of trial results from 2012 from the same site as well as from the FSA site in Lethbridge.

3.2.2.3 Project Year 2014

3.2.2.3.1 Prevailing Weather Conditions

Figure 26 shows the daily instantaneous, accumulated and long term normal rainfall for June 2014 at the Ballater weather station about 25 km south of the SARDA project site in Falher, Alberta. The site received around 33 mm of rainfall by June 18 when we treated Trial-1 and an additional 10 mm by June 25 when we sprayed Trial-2. This indicates that the soil moisture conditions were fair and the plants were not moisture-stressed. Figures 27 and 28 also show no major rainfall events shortly after the treatment of the two trials.

3.2.2.3.2 Results

The treatment means for oats and mustard trials in 2014 are in Tables 28 and 29. We treated Trials-1 for both oats and mustard June 18-19 and Trials-2 June 25-26. All trials used the same set up as the previous two years. Table 28 for oats shows that in both trials, the Day time application performed better than the Dawn time in 75% of the instances considering both indices - ER scores and WBRs. Dawn time was more effective than the Day time only 25% of the time. As before, the Night time fell in the middle of the two other timings with ER scores and WBRs of 25%, 50% and 75% in Trials -1 and -2. For mustard trials (Table 29) also the Day time application was more effective than the other two timings in most of the instances except for WBR in Trial-1.

Tables 30 and 31 give ANOVA results for oats and mustard described in Tables 28 and 29, receptively. For oats (Table 30), both the Day and Night time applications were more effective than the Dawn time in 50% of the instances considering the two indices - ER scores and WBRs in both trials. However, the Dawn time application was also better than the other two timings equally often at 50% of the time. Furthermore, Liberty was the most effective herbicide on oats in Canola (LL). In mustard trials (Table 31), the Day time application was better than the Dawn time in 100% of the instances and the Night time in 50% of the instances for ER scores. For WBRs, however, the Day time and Dawn time applications performed better than each other equally often with the later exceeding the Night time application by 50%. The ANOVA results for mustard also showed that, as in oats, Axial+Infinity performed substantially better on mustard than other herbicides in Wheat crop.

The results from 2014 also show that, as before, the Day time application was in general the most effective spray application timing for the selected herbicides and crops used in these trials at the SARDA site. Furthermore, these results showed similar patterns as the majority of trial results from previous years at the same site and from the Lethbridge FSA site.

3.2.2.4 Results Summary, SARDA, Falher

For the three project years (2012-2014) discussed above, the SARDA site gave very similar conclusions to the FSA site. However, these conclusions applied to only two crops, Canola (LL) and Wheat.

3.2.3 Data Analysis and Results for the LARA, Bonnyville, Alberta

3.2.3.1 Project Year 2012

3.2.3.1.1 Prevailing Weather Conditions

Figure 29 shows the daily instantaneous, accumulated and long term normal rainfall for June 2012 at Dupre weather station about 15 km north of the LARA project site in Bonnyville, Alberta. The site received around 30 mm of rainfall in last two weeks (May 25-June 7) when we treated Trial-1 June 7-8 with an additional 49 mm of rainfall by June 21 when we sprayed Trial-2. This indicates that the soil moisture conditions were good and plants were not under moisture stress. Figures 30 and 31 also show no major rainfall evens shortly after the two trial treatments.

3.2.3.1.2 Results

The treatment means for oats and mustard trials in 2012 are in Tables 32 and 33. We treated Trials-1 for both oats and mustard June 7-8 and Trials-2 June 21-22. We conducted all trials with the same set up as the described for the FSA and SARDA project sites in Lethbridge and Falher. Table 32 for oats shows that in Trial-1 the Day and Night time applications did not have any advantage over the Dawn time application for both ER scores and WBRs. However, Trial-2 the Dawn time application was more effective than the other two timings in 67% and 100% of the instances for ER scores and WBRs, respectively. For mustard (Table 33), the Dawn time application performed better more often than the Day and Night time applications for both indices, ER scores and WBRs. In Trial-2 however, only Day time application did better more frequently than the Dawn time for ER scores, but all three timings performed similar in terms of the WBRs.

Tables 34 and 35 contain the ANOVA results for oats and mustard described in Tables 32 and 33, receptively. For oats (Table 34), both the Day and Night time applications did not have any advantage over the Dawn time for ER scores. However, the Dawn time was more effective 100% of the time than the two other timings in terms of WBRs. Furthermore, TM Muster+Select with respect to ER and TM Axial+Infinity with respect to both ER and WBR, were the most effective herbicides on oats in Canola (LL) and Wheat crops, respectively. For mustard trials (Table 35), the Day time application performed similar to the Dawn time, but both timings were better than the Night time application in 50% of the instances. The Liberty and TM Axial+Infinity were the most effective herbicides on mustard in Canola (LL) and Wheat, respectively.

The results from 2012 at the LARA site could be described as mixed at best. The three application timings did not show any advantage over each other for both oats and mustard. Apparently, the performance patterns showing the Day time application performing most often superior to the other two timings did not hold at LARA site in 2012. However, as before, herbicides TM Muster+Select and TM Axial+Infinity turned out to be the most effective ones in Canola (LL) and Wheat, respectively.

3.2.3.2 Project Year 2013

3.2.3.2.1 Prevailing Weather Conditions

Figure 32 shows the daily instantaneous, accumulated and long term normal rainfall for June 2013 at the Dupre weather station near Bonnyville, Alberta. The site received around 10 mm of rainfall in the two weeks before we treated Trial-1 July 2-3 with an additional rainfall of 32 mm by July 14-15 when we sprayed Trial-2. Adequate rainfall indicates that the soil moisture conditions were good and the plants were actively growing. Figures 33 and 34 also show that there were no major rainfall events shortly after we treated the two trials.

3.2.3.2.2 Results

Table 36 shows that for oats in Trial-1, the Day and Night time application had advantage over the Dawn time for ER scores, but not for WBRs. However, the Dawn time application showed slight advantage over the other two timings in Trial-2 for ER. For mustard, however, both Day and Night time applications were more effective than the Dawn time in all instances (Table 37).

Tables 38 and 39 give ANOVA results for oats and mustard described in Tables 36 and 37. For oats (Table 38), both the Day and Night time applications performed better than the Dawn time 50% and 100% of time, respectively, for the ER scores in Trial-1. However, none of the application timings showed any advantage over one another for WBRs. Liberty and TM Axial+Infinity were the most effective herbicides on oats in Canola (LL) and Wheat crops, respectively. For mustard trials (Table 39), the Day and Night time applications performed better than the Dawn time 100 and 50% of the instances, respectively, in terms of ER scores and 100% of the time for WBRs. The Dawn time did not show any advantage over the other two timings. The Liberty and TM Axial+Infinity were the most effective herbicides on mustard in Canola (LL) and Wheat, respectively.

Similar to 2012, the 2013 results for oats at the LARA site could also be described as mixed at best. However, results for mustard follow the same patterns, the Day and Night time applications having advantage over the Dawn time, as seen most often at the FSA and SARDA sites. However, as before, TM Axial+Infinity turned out to be the most effective herbicide on both oats and mustard in Wheat.

3.2.3.3 Project Year 2014

3.2.3.3.1 Prevailing Weather Conditions

Figure 35 shows the daily instantaneous, accumulated and long term normal rainfall for June and July 2014 at the Dupre weather station near Bonnyville, Alberta. The site received above average rainfall through the entire period with over 55 mm of rainfall falling in the two weeks before we treated Trial-1 June 24-25. An additional 59 mm of rainfall occurred by July 14-15 when we sprayed Trial-2. Adequate rainfall suggests good soil moisture conditions with the plants growing without moisture stress. However, as Figures 36 and 37 show that there were no major rainfall events shortly after trials were treated.

3.2.3.3.2 Results

Table 40 shows that for oats, the Day and Night time applications had an advantage over the Dawn time for both indices, ER scores and WBRs, in most instances in both Trials -1 and -2. However for mustard, both Day and Night time applications were more effective than the Dawn time in all instances (Table 41).

Tables 42 and 43 give the ANOVA results for oats and mustard described in Tables 40 and 41, respectively. Similar to the results listed in Table 40, the ANOVA results in Table 42 for oats show that none of the timings had any advantage over another, because all timings were effective in an equal number of instances in terms of ER scores and WBRs. Table 42 further shows that Liberty and TM Axial+Infinity were the most effective herbicides on oats in Canola (LL) and Wheat crops, respectively.

For mustard trials (Table 43), the Day and Night time applications performed better than the Dawn time in 100% and 50% of the instances, respectively, in terms of ER scores and 100% of the time for WBRs. The Dawn time did not show any advantage over the two other timings. The Liberty and TM Axial+Infinity were the most effective herbicides on mustard in Canola (LL) and Wheat, respectively.

The results for oats from 2014 at the LARA site were similar to 2012 and 2013 described as mixed at best. However, results for mustard followed the same patterns as seen most often at the FSA and SARDA sites with Day and Night time applications having frequent advantage over the Dawn time. Similarly, as before, Liberty and TM Axial+Infinity turned out to be the most effective herbicide on oats and mustard in Canola (LL) and Wheat, respectively.

3.2.3.4 Results Summary, LARA, Bonnyville

For the three project years (2012-2014) discussed above, the LARA site conclusions over the three project years (2012-2014) were mixed at best. No distinct patterns of herbicide performances emerged with respect to the three application timings. However, there were quite a few instances when the Day and Night time applications showed clear advantage over the Dawn time application following the trend consistently seen at the FSA and SARDA project sites in Lethbridge and Falher, Alberta.

3.3 Effect of Diurnal Leaf Movement on Herbicide Efficacy

In addition to some apparent weather conditions, such as, temperature inversions and heavy dew on leaves (Enz et al., 2014), reduced interception of herbicides due to the vertical position of leaves at night could also cause substantial decrease in herbicides' efficacies at night and dawn, especially, in the broadleaf weeds exhibiting diurnal leaf movement (Stopps et al., 2013; Mohr et al., 2007; Martinson et al., 2005; Hartzler, 2003; Sellers et al., 2003; Martison et al., 2002; Norsworthy et al., 1999). In a study examining the effect of the application time-of-day on glyphosate efficacy on velvetleaf, Mohr et al (2007) indicated that leaf angle and time of application accounted for 82 and 18%, respectively, of the biomass change. In a diurnal cycle, plants keep leaves horizontal relative to stem during the daylight with the maximum leaf surface area exposed to the sunlight and fold them in vertical position parallel to stem during the night. Accordingly, efficacy of an herbicide applied during the day time would be higher because plants with the maximum leaf surface area exposed to the sunlight are more likely to intercept greater amounts of herbicide during the day compared to the night application. However, the diurnal leaf movement phenomenon is not as prevalent in grassy weeds (Mohr et al., 2007).

Our results at the FSA (Lethbridge) site also seemed in agreement with the aforementioned studies showing the effect of diurnal leaf movement (day time effect) on the efficacies of the selected herbicides used in our study. Table 44 shows that when the ER and WBR means were averaged over all herbicides and crops for mustard, a broad leaf weed, the Day time application performed better than the Night and/Dawn timing in all four site years. However, as seen in Table 45, for oats, a grassy weed, the Day time application did better than the Night and/Dawn timing in 50 and 75% of the instances with respect to the ER and WBR, respectively.

3.4 Conclusion

Result summaries for PSBD and in-crop trials for all the locations were presented above. However, the major conclusions drawn from our study are given below:

- The herbicides in PSBD and in-crop trials performed most effectively when applied in the day time (12-2 pm). Night time (12pm-1am) gave better results than the least effective Dawn time (4-5 am). We saw a substantial advantage of Day and Night time applications over the Dawn time application

- Although, Night time application performance was less often effective than Day time application, it performed better more often than Dawn time and, therefore, it could be useful as an alternate spray application timing when opportunities for Day time application are limited
- The results also suggest that moisture-stressed plants or a major rainfall event shortly after herbicide application could also reduce efficacies potentially rendering the herbicides totally ineffective, upsetting the performance patterns most often seen in our study

4 Our Contribution to Emerging Agricultural Knowledge, Agri-Extension, and Industry Welfare

Under the extension activities conducted during the three project years, study results were presented on numerous field tours, crop walks, workshops/conferences and producers' gatherings across the province. The study results were also published in the Farming Smarter's and our partner associations' magazines, newsletters, electronic and social media, websites (www.farmingsmarter.com, ropintheweb, www.areca.ab.ca) to provide producers tools necessary to make an informed choice. A list of the pertinent extension activities is given below.

4.1 Yearly Extension Activities

4.1.1 The extension activities conducted in Year 1 (2012)

- Farming Smarter Crop Walk; May 31, 2012 – Bob Blackshaw & Ken Coles presented the PSBD trial (44 attendees)
- Farming Smarter Crop Walk; June 7, 2012 – Ken Coles presented night spraying in-crop date 1 trial (36 attendees)
- Farming Smarter/UFA staff tour; July 19, 2012 – Ken Coles presented the trial to 10 UFA staff members
- Farming Smarter/Ducks Unlimited Tour; July 26, 2012 – Ken Coles presented night spraying date 2 trial (47 attendees)
- Alberta Wheat Commission Regional Meetings; November 16, 19, 21, 22 & 30, 2012 – Ken Coles presented night spraying trial information (100 attendees)
- Farming Smarter Conference; December 3 &4, 2012 – Ken Coles presented preliminary results from night spraying trials (222 attendees)

4.1.2 The extension activities conducted in Year 2 (2013)

- AgroPlus Sales & Service Meeting; February 7, 2013 – Ken Coles presented VRT project (35 attendees)
- MNP Farm Management Group Meeting; February 19, 2013 – Ken Coles presented VRT project (10 attendees)
- Farming Smarter AGM; February 28, 2013 – Ken Coles presented night spraying trial (61 attendees)
- Farming Smarter Crop Walk; May 30, 2013 – Ken Coles discussed the project (54 attendees)
- Farming Smarter Crop Walk; June 6, 2013 – Ken Coles showed night spraying date 2 site (63 attendees)

- SARDA discussed the project during an open house on July 10, 2013 (3 attendees) and July 12, 2012 (50 attendees)
- Farming Smarter AGM; February 28, 2013 – Ken Coles presented night spraying trial (61 attendees)
- Crop Walk; May 30, 2013 – Ken Coles discussed the project (54 attendees)
- Crop Walk; June 6, 2013 – Ken Coles showed night spraying date 2 site (63 attendees)
- Field School; June 25-27, 2013 – Ken Coles presented the study results (~ 300 attendees)
- SARDA discussed the project during an open house on July 10, 2013 (3 attendees)
- Farming Smarter Conference; December 3-4, 2013 (200 attendees from over 300 registrants)

4.1.3 The extension activities conducted in Year 3 (2014)

- Crop Walk; June 5, 2014 – Lethbridge, Ken Coles discussed the night spraying trials (30 attendees)
- Crop Walk; June 12, 2014 – Lethbridge, Ken Coles showed night spraying trial (35 attendees)
- Crop Walk; June 19, 2014 – Lethbridge Ken Coles shared key findings on night spraying (35 attendees)
- Field School; June 24-26, 2014 – Ken Coles presented the study results (over 250 attendees)
- Private tours; June 2014 – Ken Coles also presented the study results to the tours arranged on the request of the producers and the industry; (over 50 attendees)

Farming Smarter with partner applied research associations will continue to communicate the findings of this project to the producers and the agricultural industry via extension and government websites, such as www.farmingsmarter.com, www.agric.gov.ab.ca, through talks and tours during Farming Smarter Conference, Agronomy Update, Crop Walks, Diagnostic Field School, as well as from other outlets including Farming Smarter magazine, Newsletters, social media and popular press. Farming Smarter staff would also be available for advice upon request on one-to-one basis.

4.2 Training of highly qualified personnel

Staff from all three partnering organizations gained invaluable knowledge regarding the complicated interactions between weather conditions and herbicide applications. Farmers and organizations are keenly interested in this information and we have been invited to speak at dozens of production meetings. Knowledge gained in included 2 PhDs, 2 masters, 6 degrees and 6 students across all locations.

4.3 Benefits to the industry

4.3.1 Contributions to Alberta's Agriculture and Agri-Food Knowledge

Our study:

- Alleviats the paucity of information on the comparative performance of the day and night time applications of pesticides and improve the ability of the producers to make informed decisions, especially on regional basis
- Fills the knowledge gaps and provide producers with unbiased reliable information on efficacy and tolerance for common herbicides sprayed on common crops in Alberta

- Updates background research and enhance existing knowledge on plant physiology, herbicide mode-of-action and sprayer technology in relation to night spraying and provide further awareness on determining application rates, selecting proper herbicide and reducing spray off target drifts
- Provides information about the general efficacy (weed control) and crop tolerance (phytotoxicity) of herbicides sprayed at night and
- Explores not only the effectiveness and economic viability of night time spraying of herbicides per se, but also in the context of new practical opportunities arising from the widespread adoption of GPS guidance technology, automatic steering control systems and live video feeds to the cab of tractor currently being used in variable rate application technologies in precision agriculture.

4.3.2 Benefits to Alberta's Agriculture and Agri-Food Industry

In a short growing season as in Alberta, application timing is very critical for optimal herbicide performance. It is expected that the results of our study would help to:

- Significantly expand the opportunity time window for the producers to avoid potential economic and environmental consequences resulting from the waiting for ideal conditions required for day time application
- Reduce economic losses caused by high application rates, unintended damage to off target crops as well as environmental pollution of surface and subsurface water bodies by taking advantage of relatively calmer and cooler environmental conditions at night potentially favorable in limiting off target drifts, reducing high evaporative losses and improving upon plant deposition and adsorption
- Greatly improve the producers' options to select from when faced with difficult choices about which pesticides to spray, how to spray and when to spray (e.g. a producer may select a more effective herbicide if the danger of spray drift to adjacent crops is lower)
- Provide the producers with the opportunity of expanding the application acreage in same window of time and
- Assist the Alberta agri-food industry in enhancing public perception of its environmental stewardship

4.3.3 Benefits to the Environment – Reducing Alberta Agricultural Environmental Footprint

Night time spraying would help in

- Reducing the environmental footprint of agricultural industry in Alberta
- Optimizing the total amounts pesticides used through improved efficacy, lower application rates, lower water volumes, improved herbicide options, reduced off target drifts, less residual herbicide and help in increasing plant uptake and reducing leakage to the environment
- Alleviating detrimental effects on human and animal health, contamination of food products, destruction of beneficial natural insects, contamination of ground and surface waters, loses of off target crops and crop product, fishery losses as well as direct and indirect economic costs associated with these impacts

4.3.4 Potential Economic Impact on the Industry

There are over 9,621,606 ha of land farmed for crops in Alberta of which 6,623,945 ha are maintained with commercial herbicides (Stats Canada 2006). At a cost of $10 - $20/ac (AAFC, 1997) depending on rates, farmers in Alberta collectively spend between $72-138 each year on herbicides.
However, the return on this substantial investment could be greatly diminished by the declining herbicides' efficacies because the producers have to spray most crops in a very short time frame even under poor day time application conditions, e.g., hot and windy conditions with low humidity, and high rates of volatilization and photodegradation, among others. Therefore, waiting for ideal conditions before spraying pesticides is a key problem facing producers and can often cause significant economic and environmental consequences.

Because the results of our 3-year study at three project sites located across Alberta, showed a substantial advantage of both Day and Night time applications over the Dawn time application, Night time application could be used as an alternate spray application timing for optimizing herbicide use in Alberta, particularly, when the opportunities for Day time application are limited. The night spray application can save producers money and time by reducing the environmental impact of herbicides through improved efficacy, lower application rates, lower water volumes, improved herbicide options, lowered drift, less residual herbicide. At night, evaporation potential is lower because of cooler temperatures, less wind and higher humidity. Dew on the leaf cuticle may also increase absorption of the pesticides through better cuticle hydration time when plants are growing most actively.

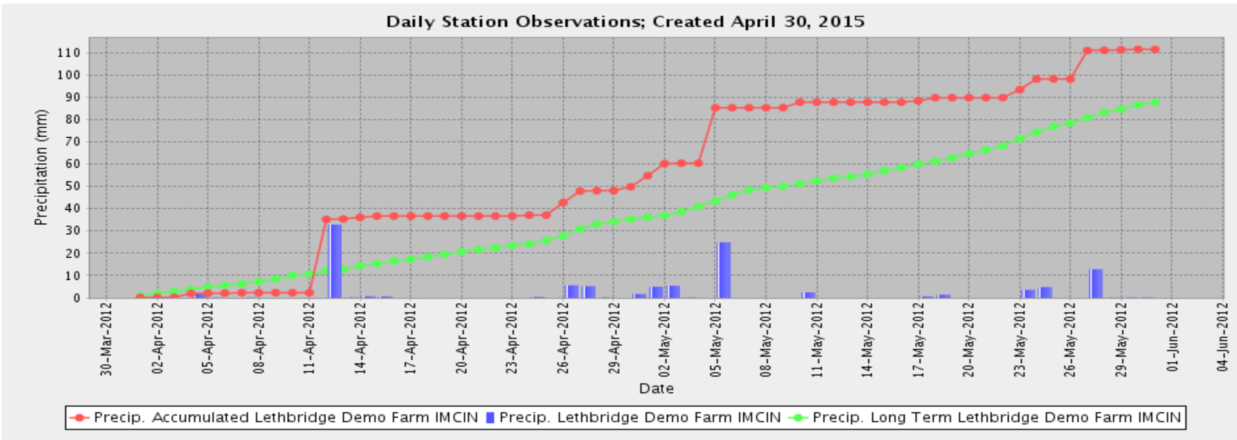

Figure 1. Daily instantaneous, accumulated and long term normal rainfall for April and May, 2012, at the Lethbridge Demo Farm, Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

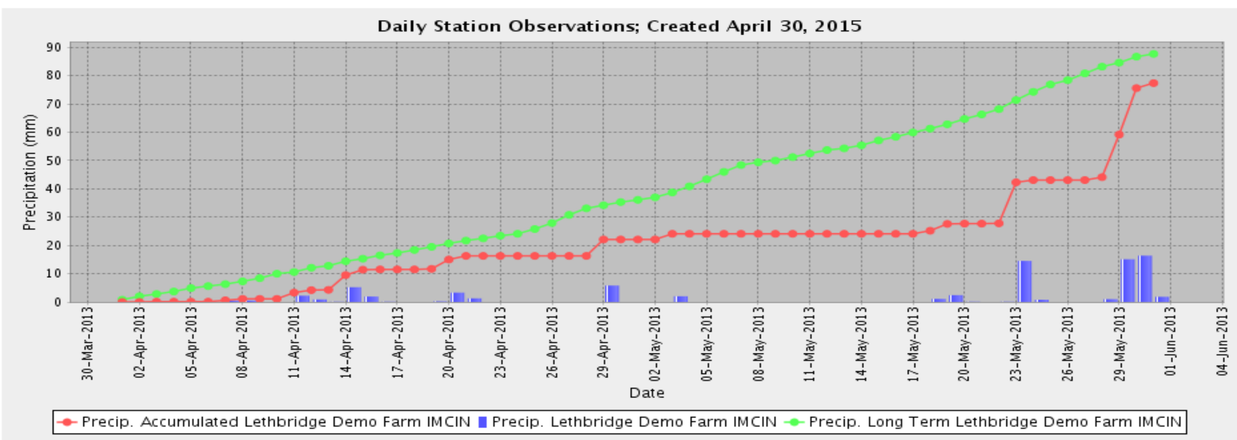

Figure 2. Daily instantaneous, accumulated and long term normal rainfall for April and May, 2013, at the Lethbridge Demo Farm Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

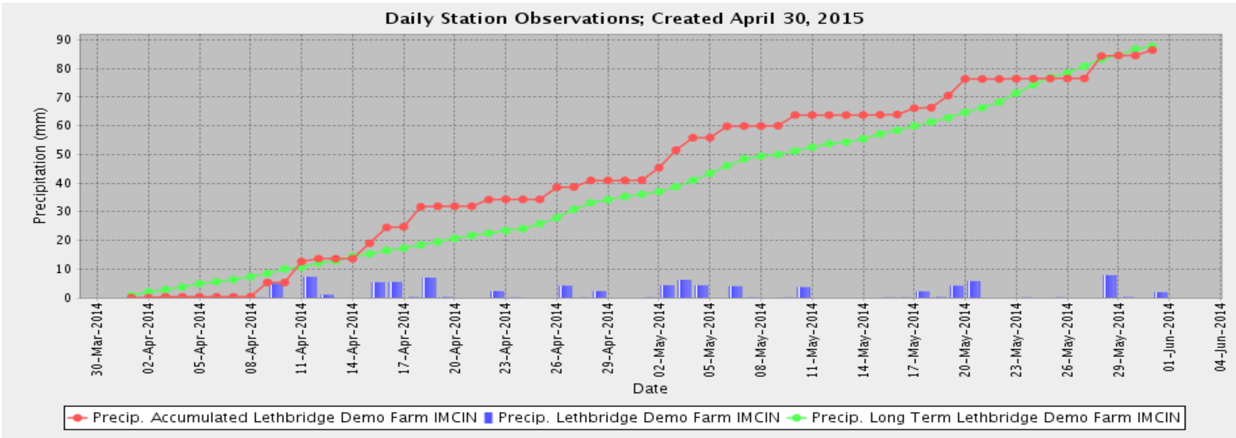

Figure 3. Daily instantaneous, accumulated and long term normal rainfall for April and May, 2014, at the Lethbridge Demo Farm Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

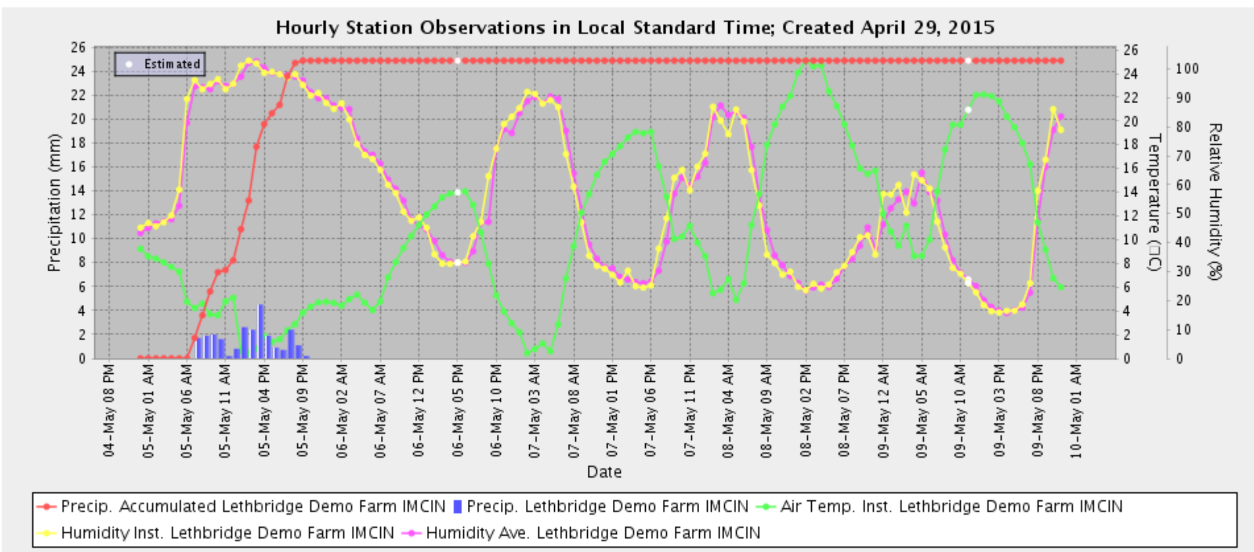

Figure 4. Hourly precipitation (mm), accumulated hourly precipitation (mm), average air temperature (degree C), relative humidity (%) from May 5 to 9, 2012 at the Lethbridge Demo Farm, Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on May 7 between 12-2 pm (Day time) and on May 8 between 12pm-1am (Night) and 4-5am (Dawn).

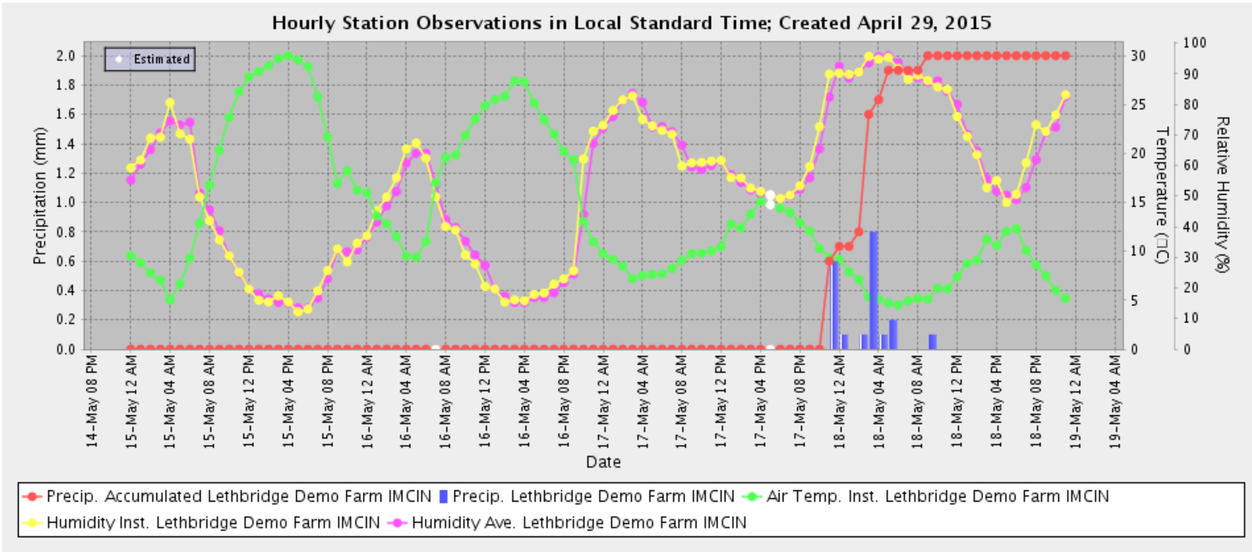

Figure 5. Hourly precipitation (mm), accumulated hourly precipitation (mm), average air temperature (degree C), relative humidity (%) from May15 to 18, 2012 at the Lethbridge Demo Farm, Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on May 16 between 12-2 pm (Day time) and on May 17 between 12pm-1am (Night) and 4-5am (Dawn).

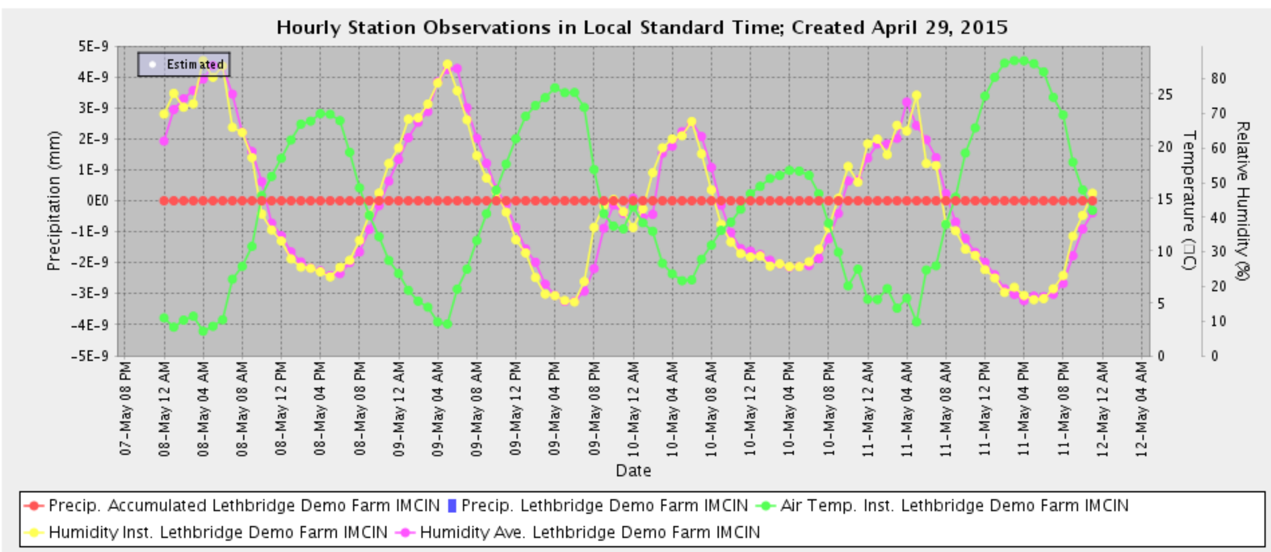

Figure 6. Hourly precipitation (mm), accumulated hourly precipitation (mm), average air temperature (degree C), relative humidity (%) from May 8 to 11, 2013 at the Lethbridge Demo Farm, Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on May 9 between 12-2 pm (Day time) and on May 10 between 12pm-1am (Night) and 4-5am (Dawn).

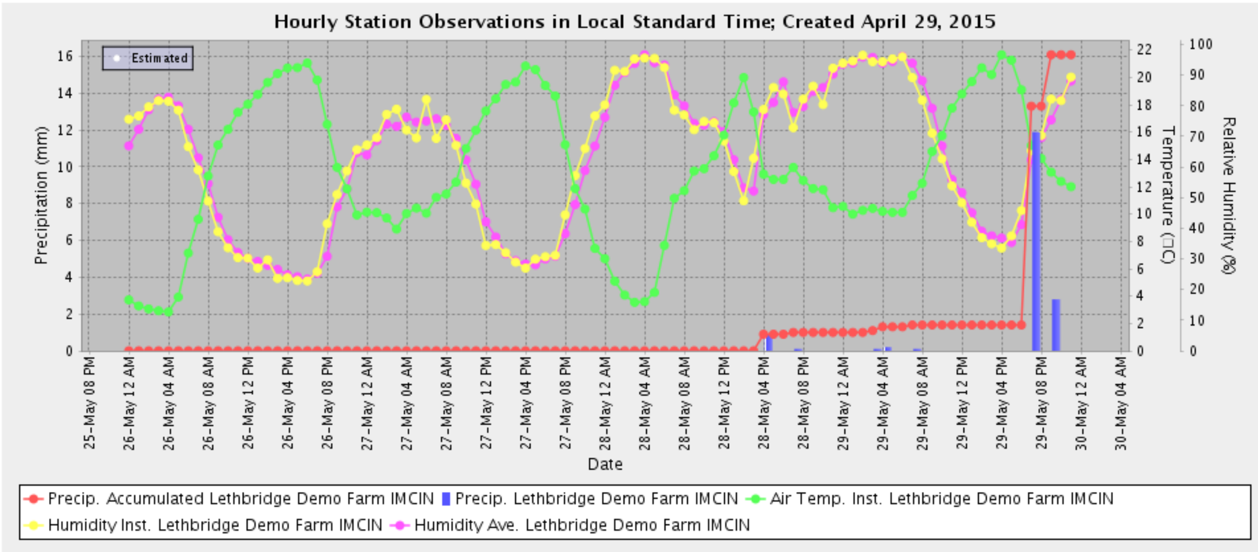

Figure 7. Hourly precipitation (mm), accumulated hourly precipitation (mm), average air temperature (degree C), relative humidity (%) from May 26 to 29, 2013 at the Lethbridge Demo Farm Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on May 27 between 12-2 pm (Day time) and on May 28 between 12pm-1am (Night) and 4-5am (Dawn).

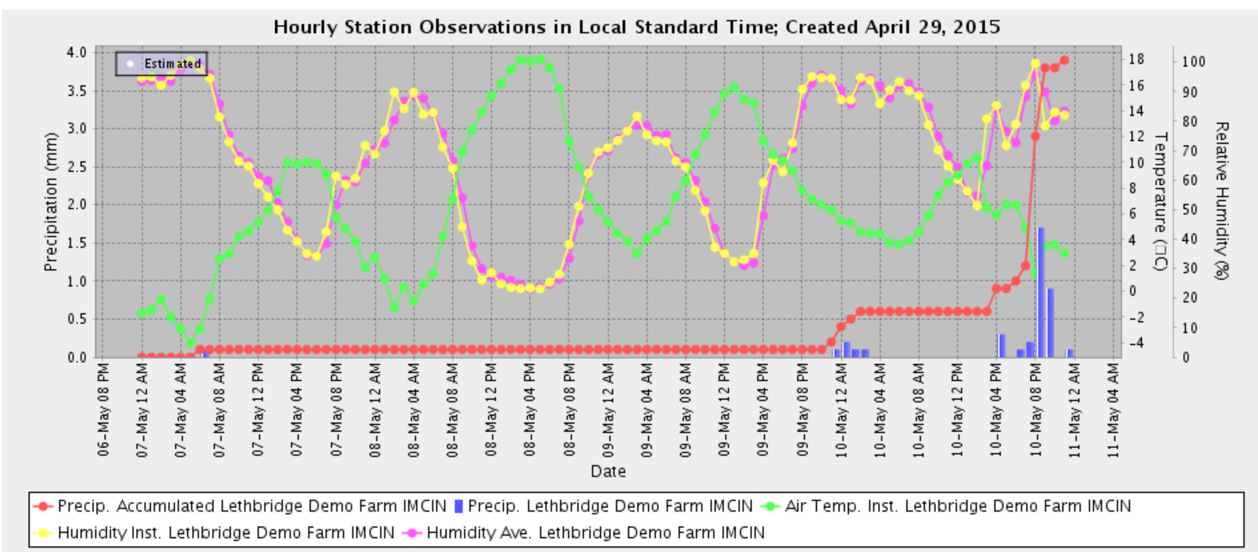

Figure 8. Hourly precipitation (mm), accumulated hourly precipitation (mm), average air temperature (degree C), relative humidity (%) from May 7 to 10, 2014 at the Lethbridge Demo Farm, Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on May 8 between 12-2 pm (Day time) and on May 9 between 12pm-1am (Night) and 4-5am (Dawn).

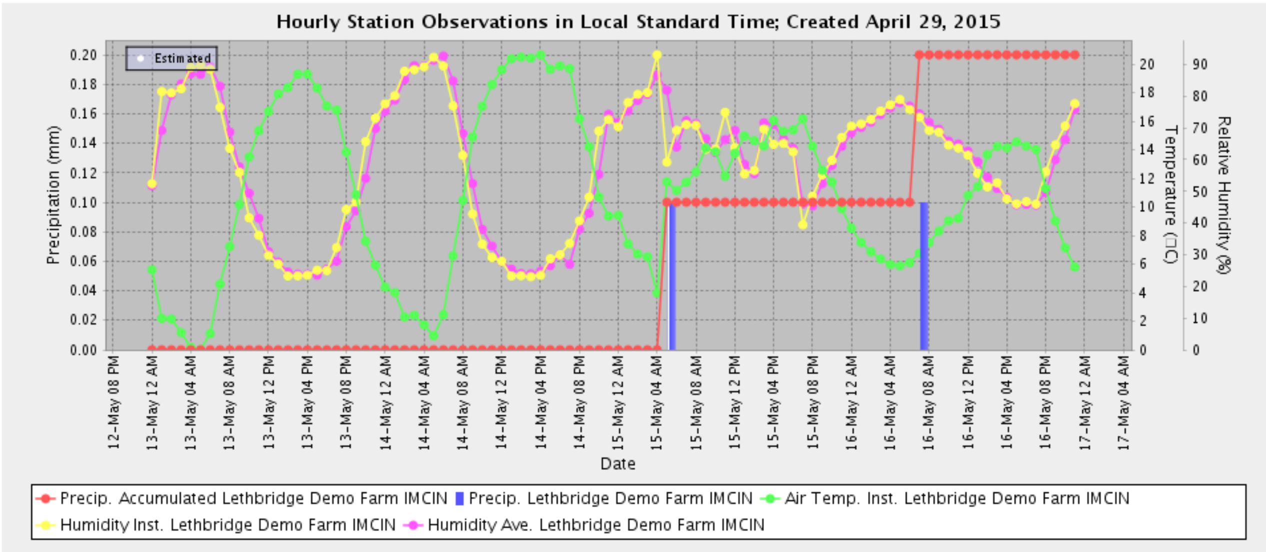

Figure 9. Hourly precipitation (mm), accumulated hourly precipitation (mm), average air temperature (degree C), relative humidity (%) from May 13 to 16, 2014 at the Lethbridge Demo Farm, Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on May 14 between 12-2 pm (Day time) and on May 15 between 12pm-1am (Night) and 4-5am (Dawn).

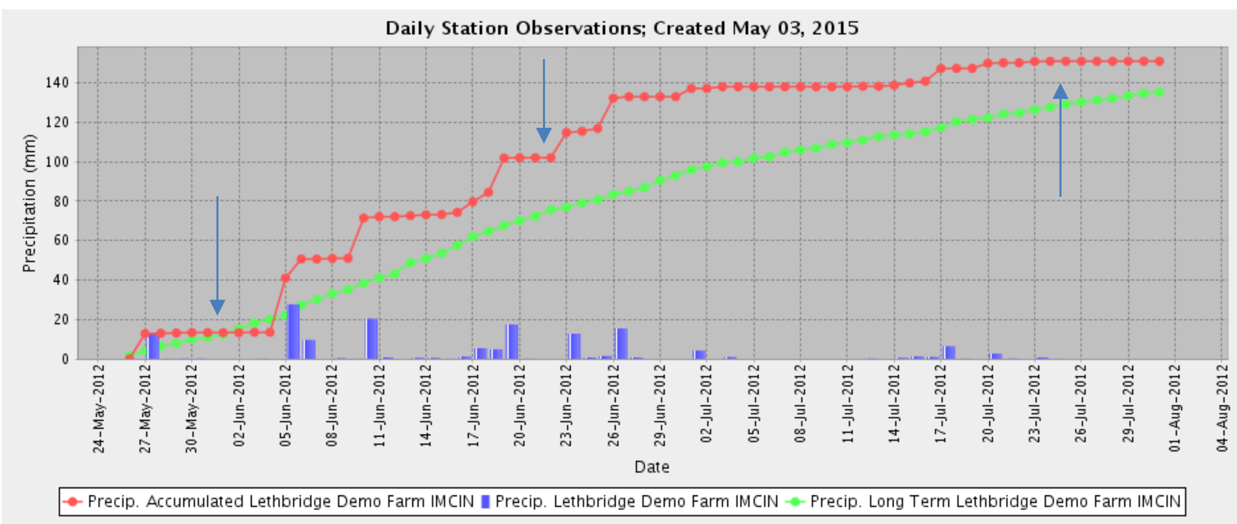

Figure 10. Daily instantaneous, accumulated and long term normal rainfall from May 25 to July 31, 2012, at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

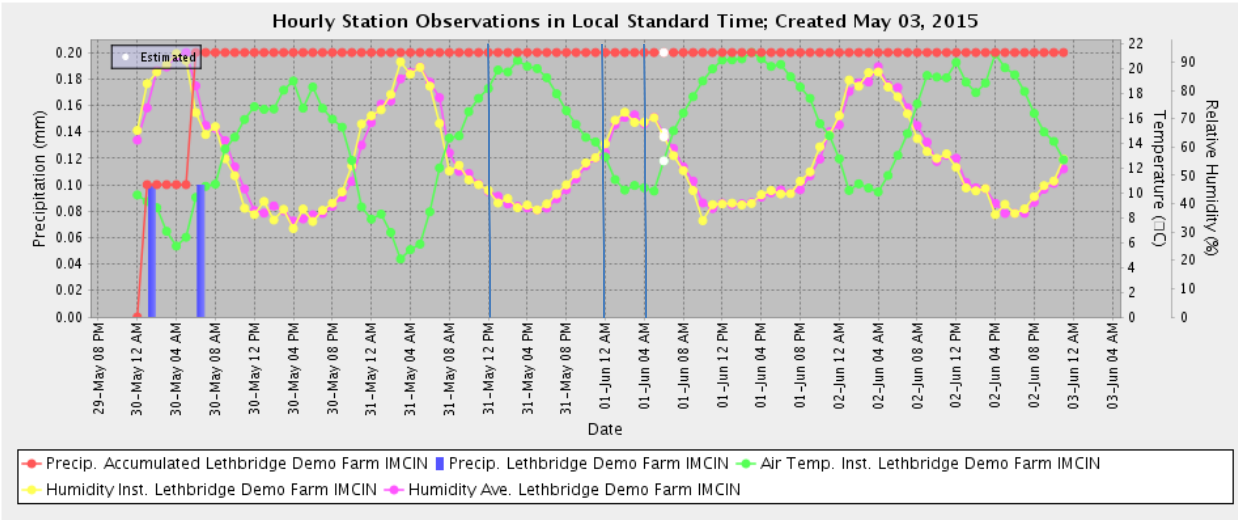

Figure 11. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from May 30 to June 2, 2012 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on May 31 between 12-2 pm (Day time) and on June 1 between 12pm-1am (Night) and 4-5am (Dawn).

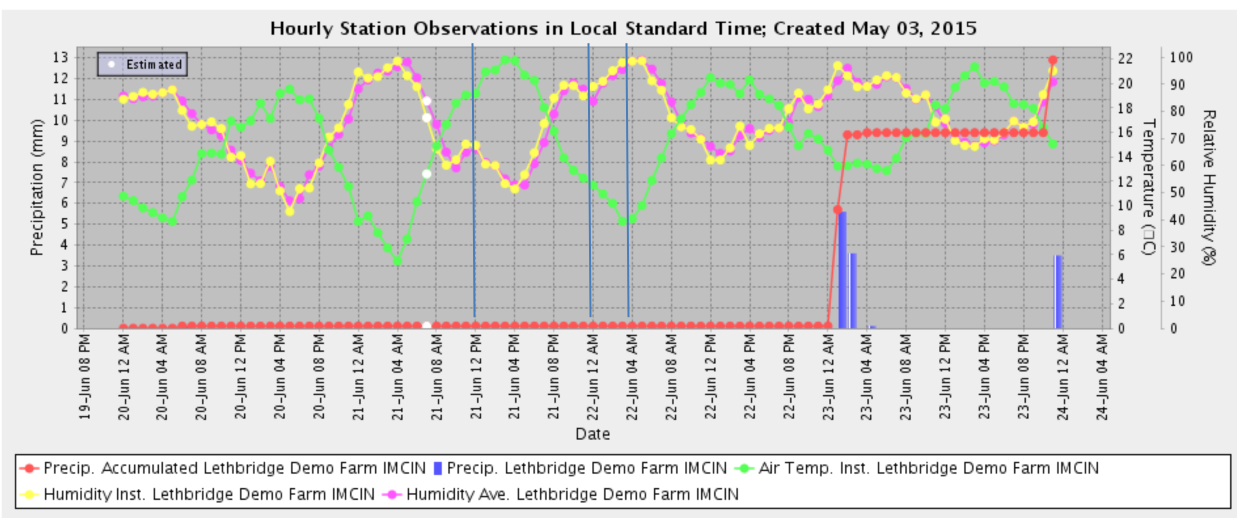

Figure 12. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 20 to 23, 2012 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied June 21 between 12-2 pm (Day time) and on June 22 between 12pm-1am (Night) and 4-5am (Dawn).

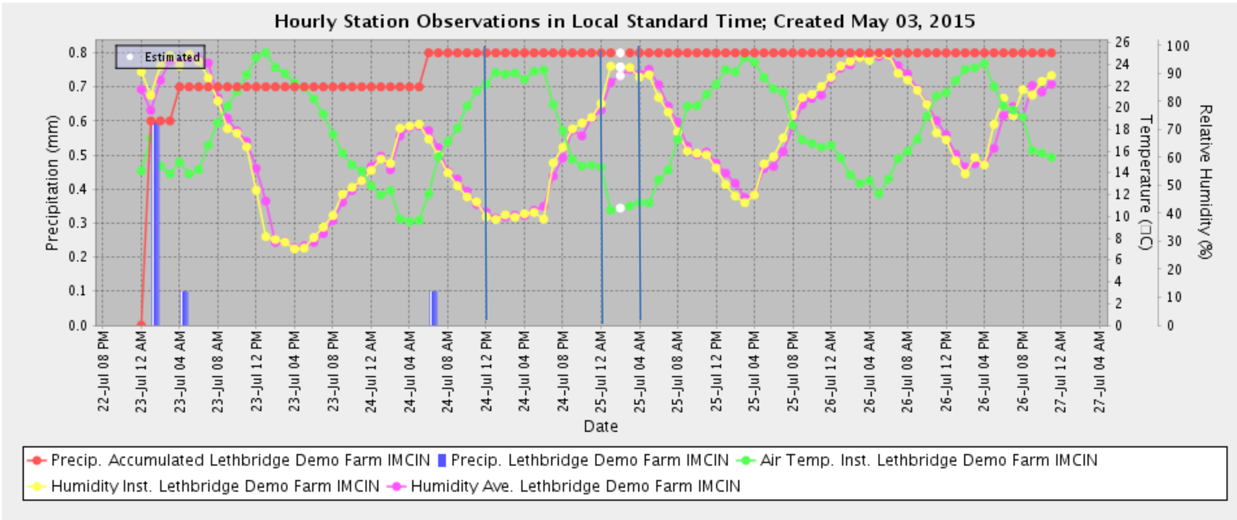

Figure 13. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from July 23 to 26, 2012 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-3, spray-applied on July 24 between 12-2 pm (Day time) and on July 25 between 12pm-1am (Night) and 4-5am (Dawn).

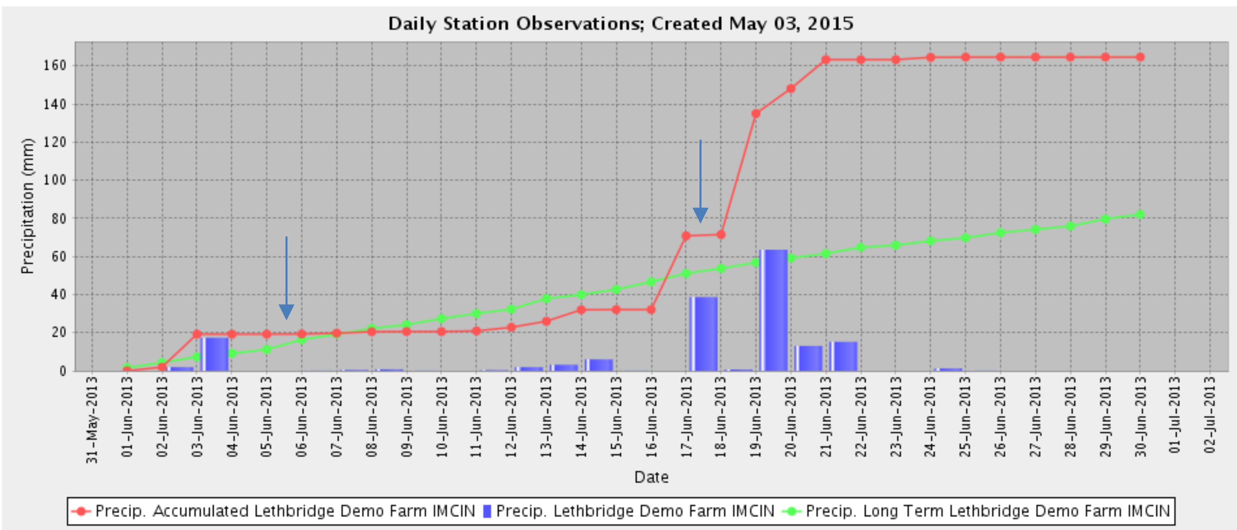

Figure 14. Daily instantaneous, accumulated and long term normal rainfall for June 2013, at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

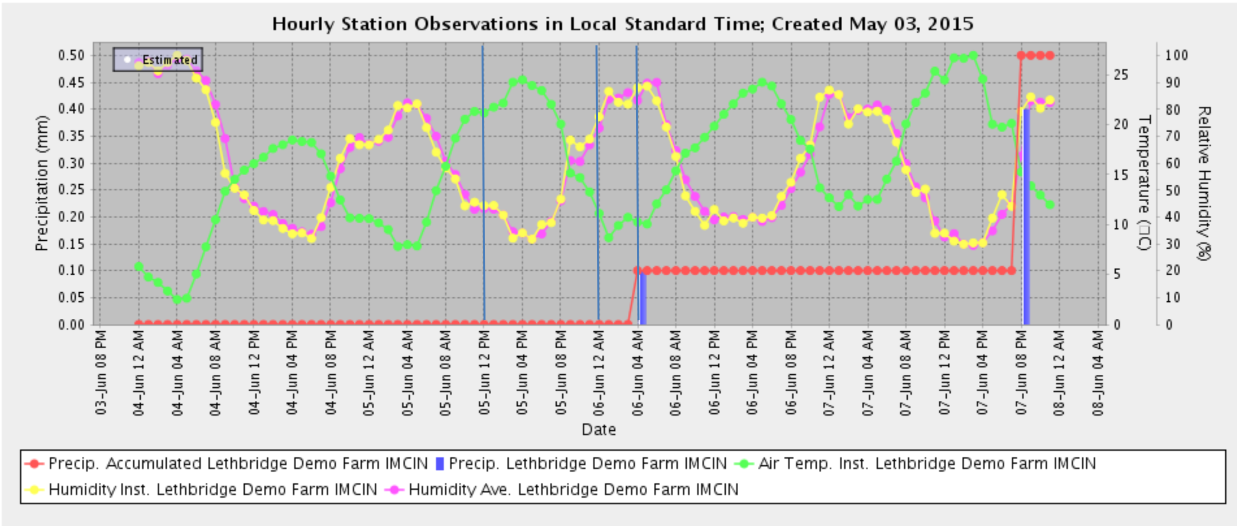

Figure 15. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 4 to 7, 2013 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 5 between 12-2 pm (Day time) and on June 6 between 12pm-1am (Night) and 4-5am (Dawn).

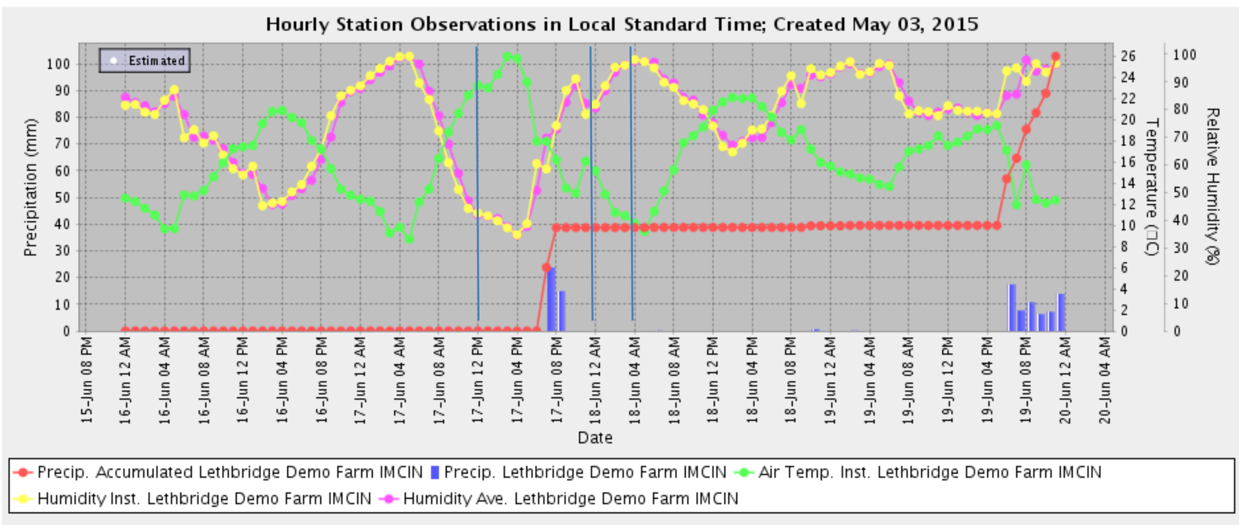

Figure 16. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 16 to 19, 2013 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on June 17 between 12-2 pm (Day time) and on June 18 between 12pm-1am (Night) and 4-5am (Dawn).

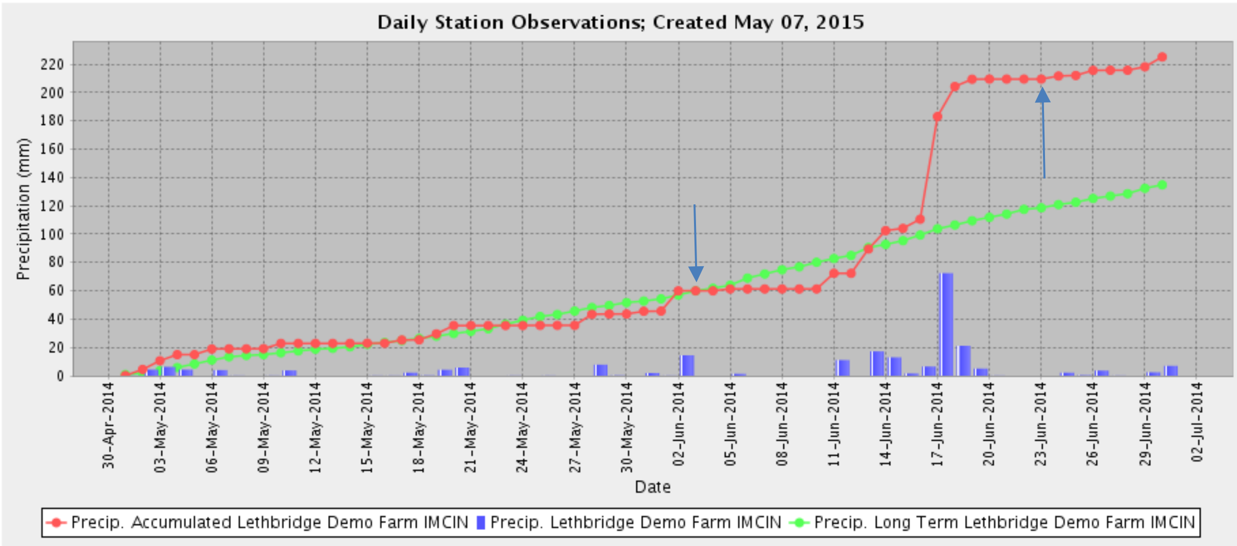

Figure 17. Daily instantaneous, accumulated and long term normal rainfall for May and June 2014, at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

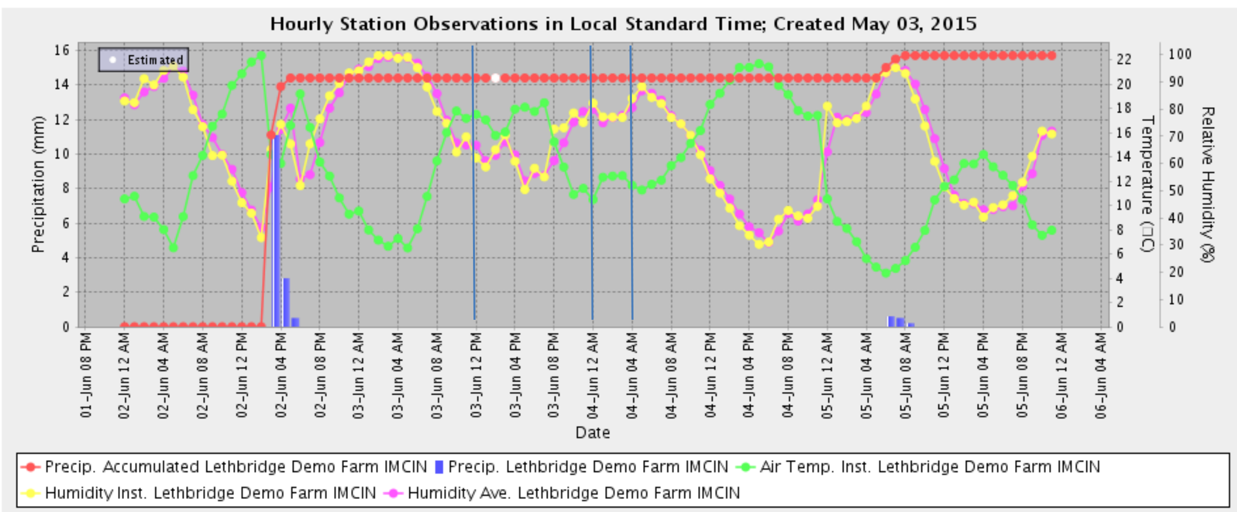

Figure 18. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 2 to 5, 2014 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 3 between 12-2 pm (Day time) and on June 4 between 12pm-1am (Night) and 4-5am (Dawn).

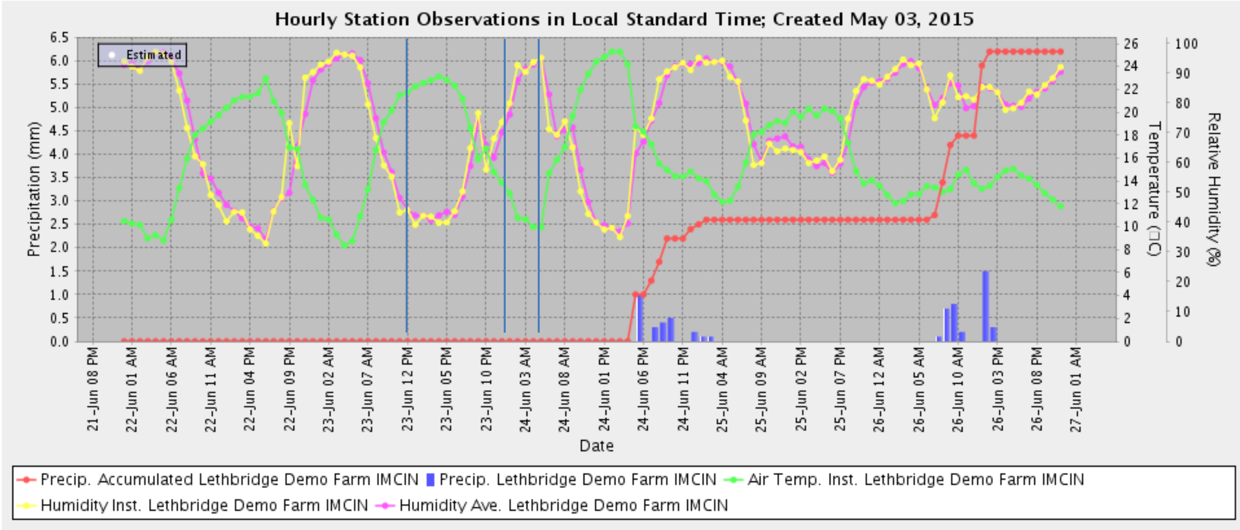

Figure 19. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 22 to 26, 2014 at the Farming Smarter project site (Lethbridge Demo Farm), Lethbridge, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on June 23 between 12-2 pm (Day time) and on June 24 between 12pm-1am (Night) and 4-5am (Dawn).

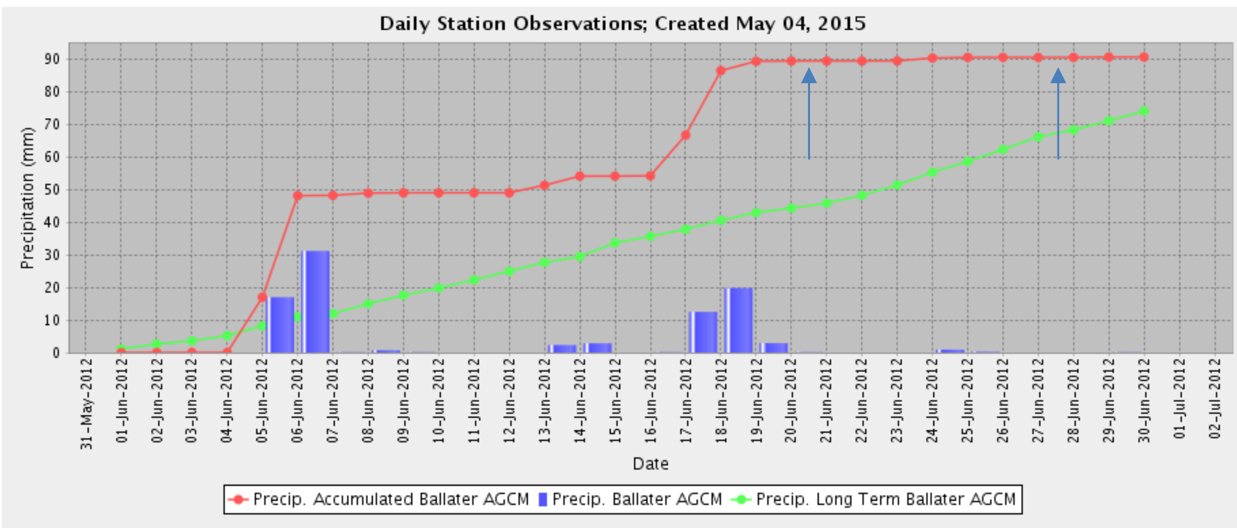

Figure 20. Daily instantaneous, accumulated and long term normal rainfall for June 2012, at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

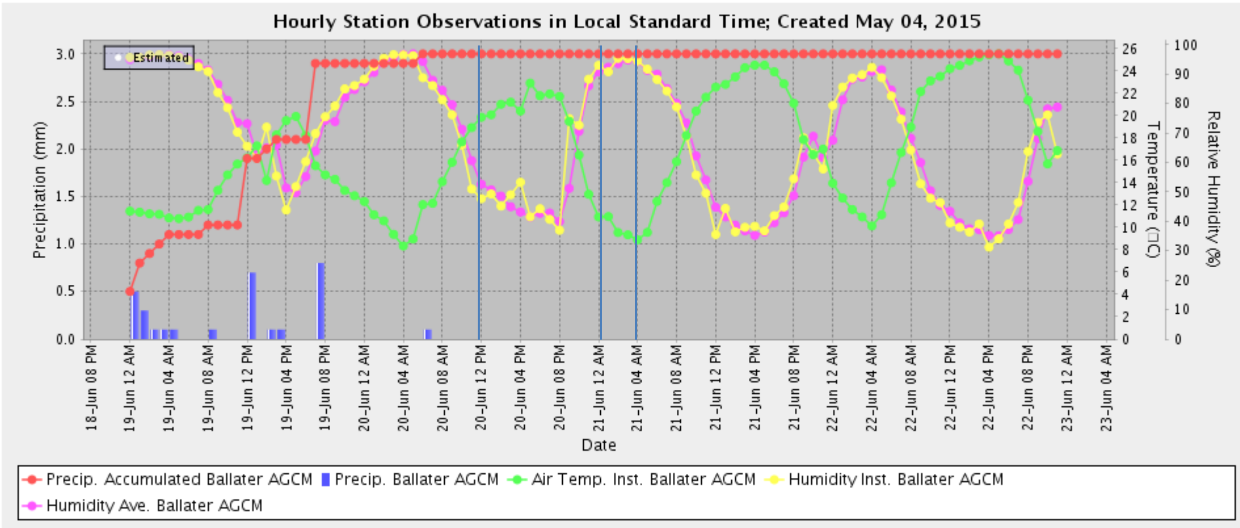

Figure 21. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 19 to 22, 2012 at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 20 between 12-2 pm (Day time) and on June 21 between 12pm-1am (Night) and 4-5am (Dawn).

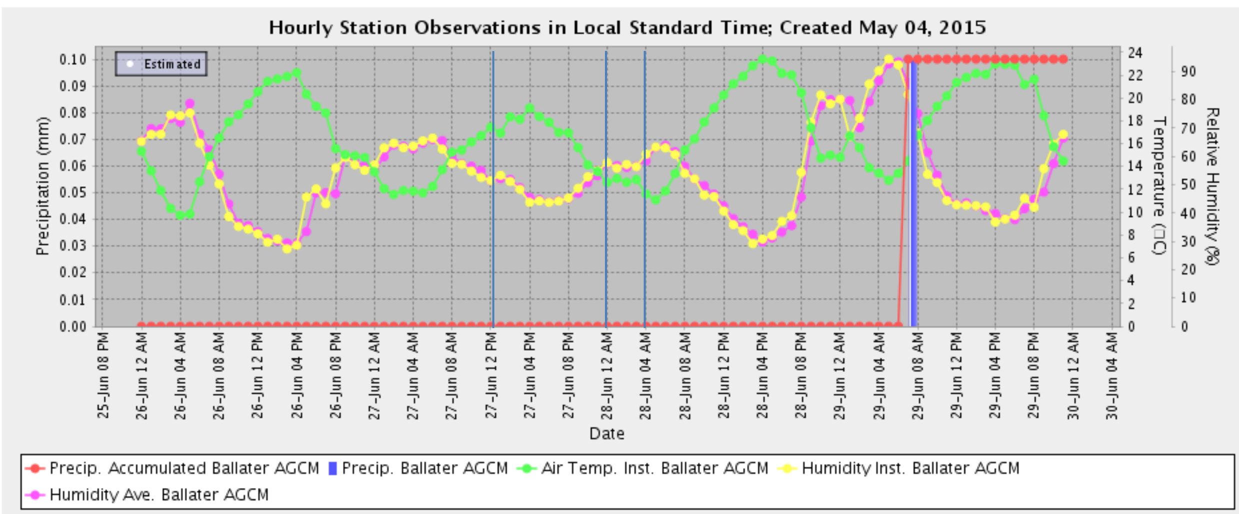

Figure 22. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 26 to 29, 2012 at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on June 27 between 12-2 pm (Day time) and on June 28 between 12pm-1am (Night) and 4-5am (Dawn).

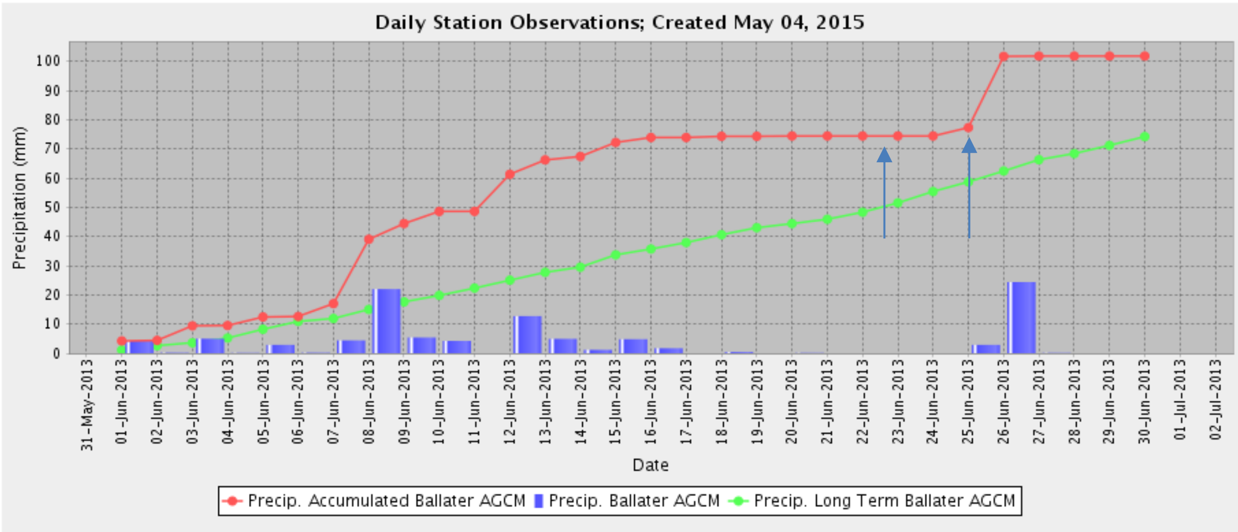

Figure 23. Daily instantaneous, accumulated and long term normal rainfall for June 2013, at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

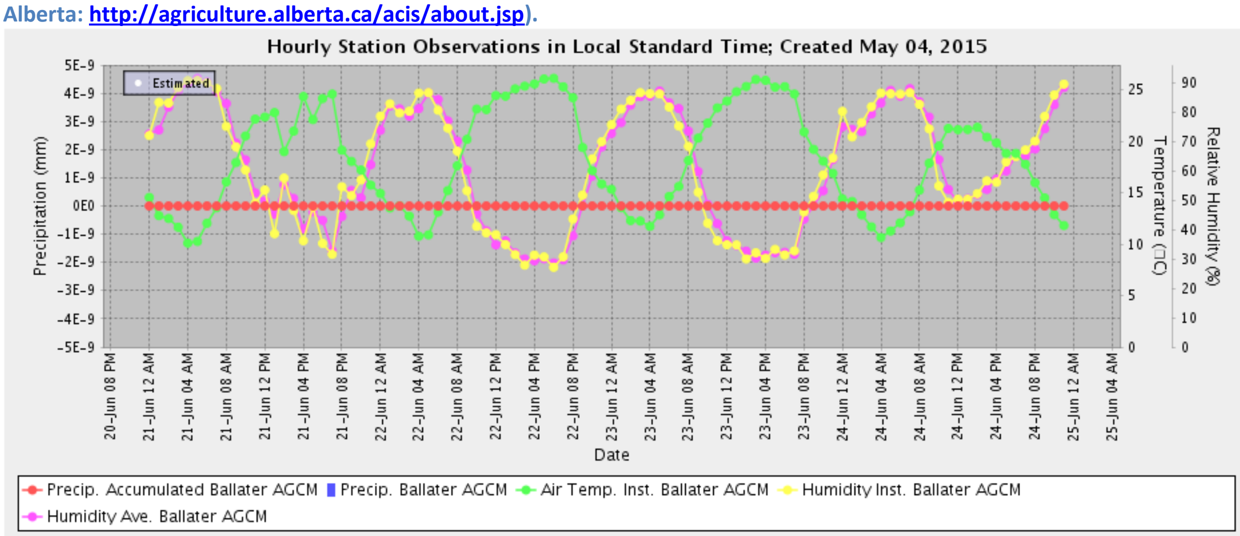

Figure 24. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 21 to 24, 2013 at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 22 between 12-2 pm (Day time) and on June 23 between 12pm-1am (Night) and 4-5am (Dawn).

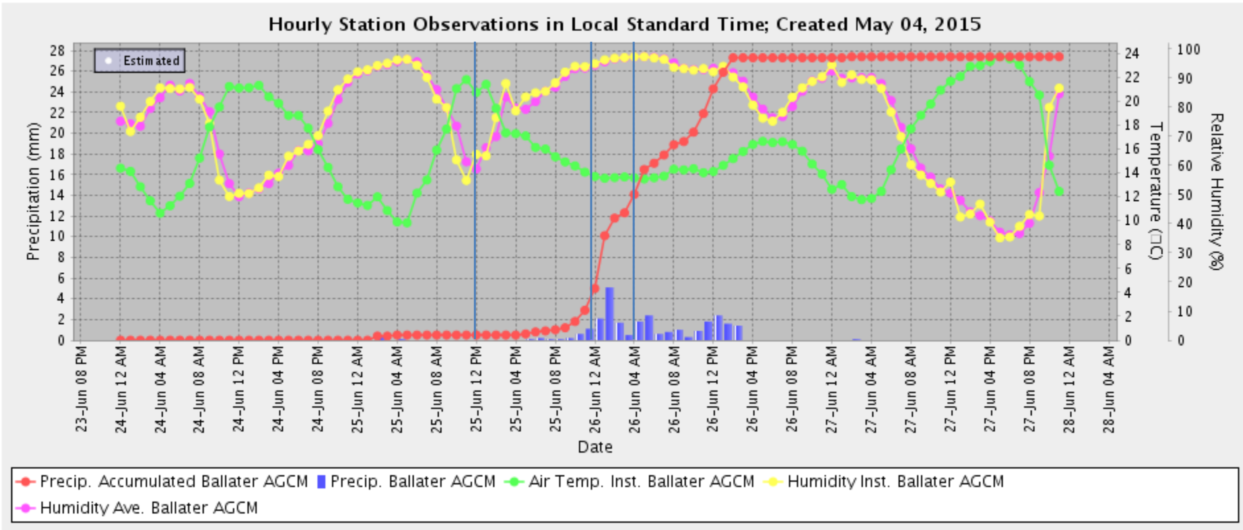

Figure 25. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 24 to 27, 2013 at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on June 25 between 12-2 pm (Day time) and on June 26 between 12pm-1am (Night) and 4-5am (Dawn).

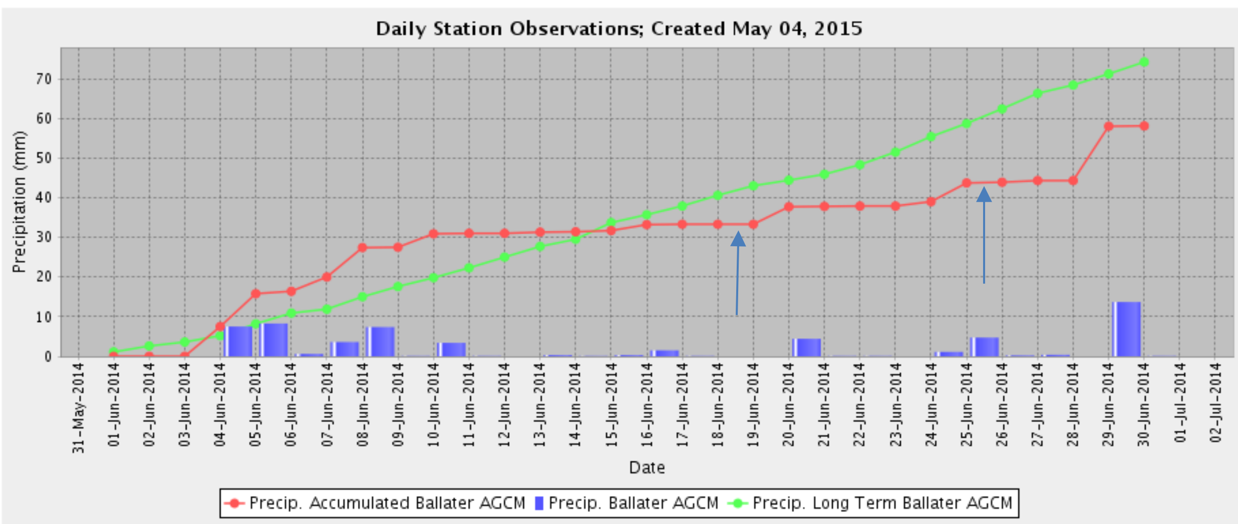

Figure 26. Daily instantaneous, accumulated and long term normal rainfall for June 2014, at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

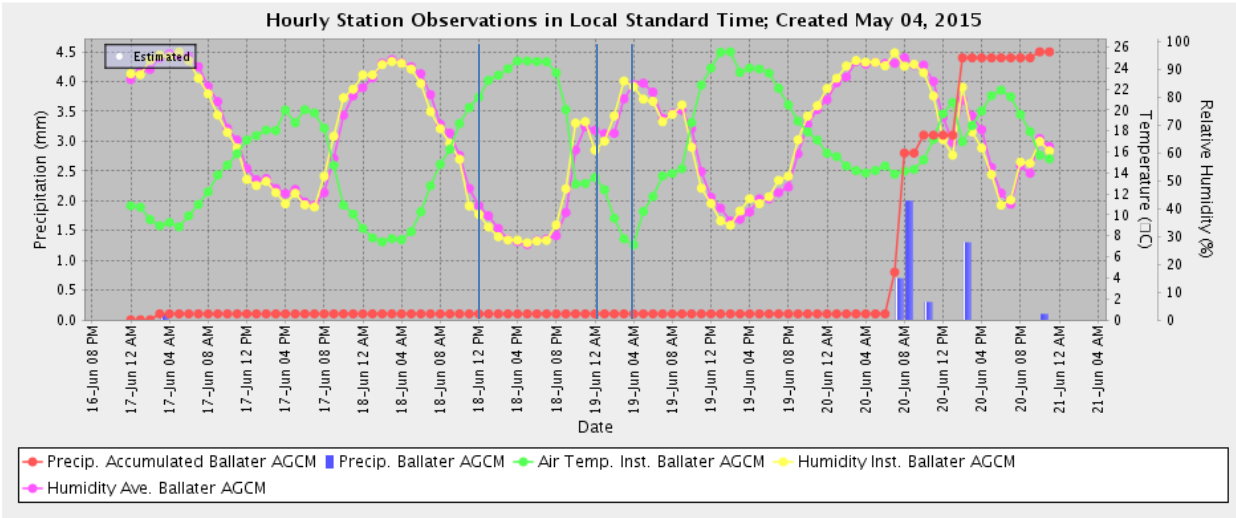

Figure 27. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 17 to 20, 2014 at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 18 between 12-2 pm (Day time) and on June 19 between 12pm-1am (Night) and 4-5am (Dawn).

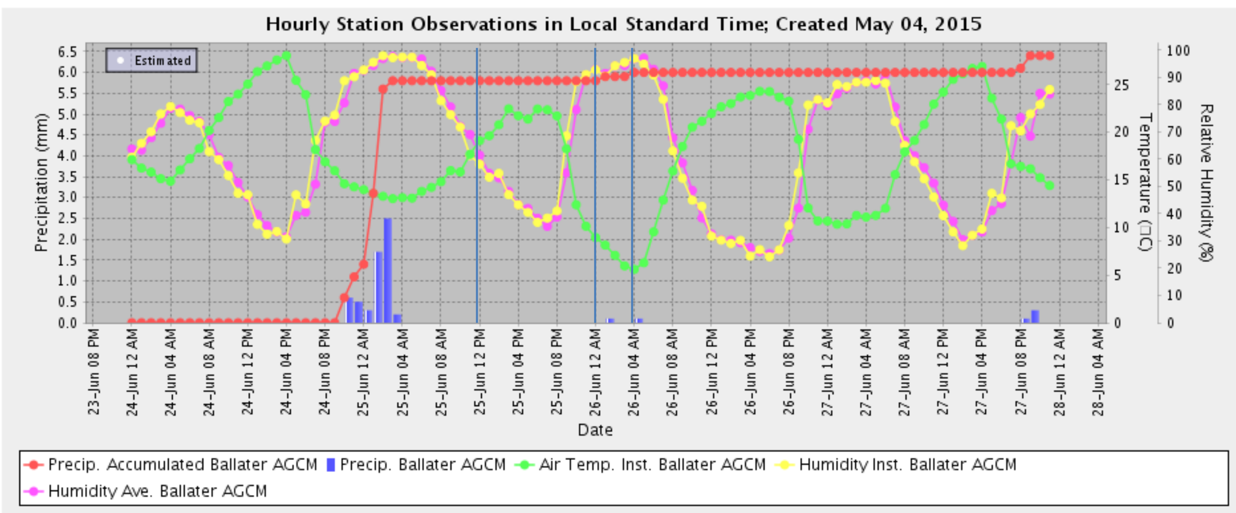

Figure 28. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 24 to 27, 2014 at the Ballater weather station about 25 km south of the SARDA project site, Falher, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on June 25 between 12-2 pm (Day time) and on June 26 between 12pm-1am (Night) and 4-5am (Dawn).

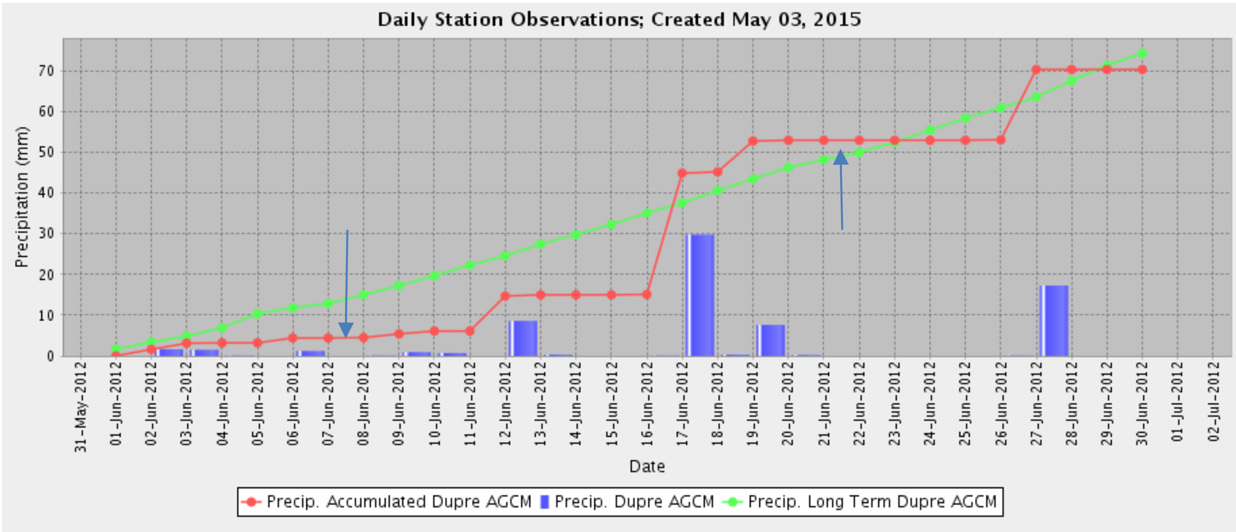

Figure 29. . Daily instantaneous, accumulated and long term normal rainfall for June 2012, at the Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

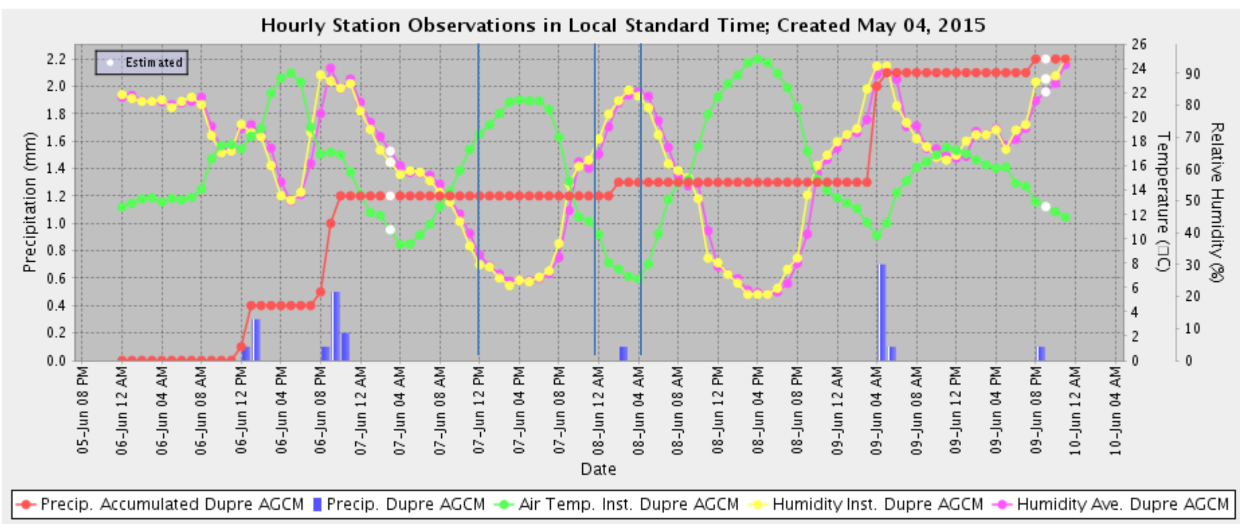

Figure 30. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 6 to 9, 2012 at Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 7 between 12-2 pm (Day time) and on June 8 between 12pm-1am (Night) and 4-5am (Dawn).

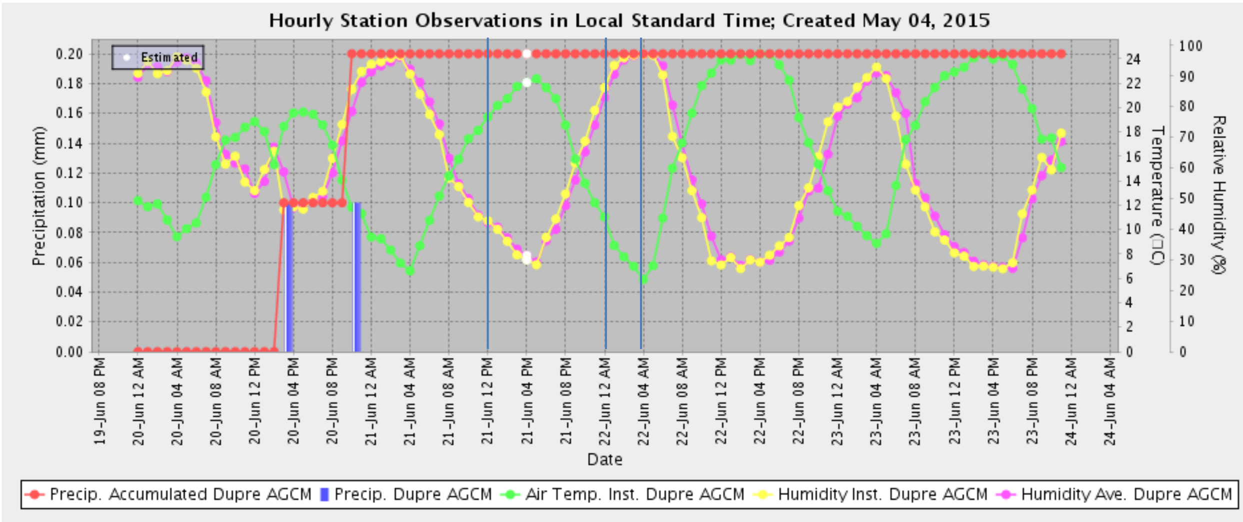

Figure 31. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 20 to 23, 2012 at Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on June 21 between 12-2 pm (Day time) and on June 22 between 12pm-1am (Night) and 4-5am (Dawn).

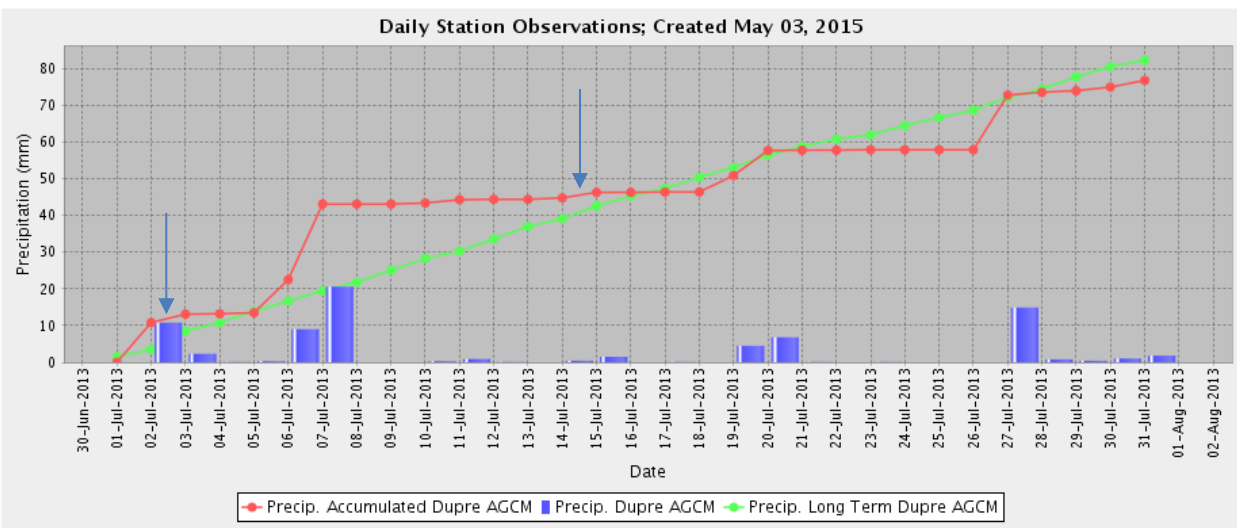

Figure 32. Daily instantaneous, accumulated and long term normal rainfall for July 2013, at the Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

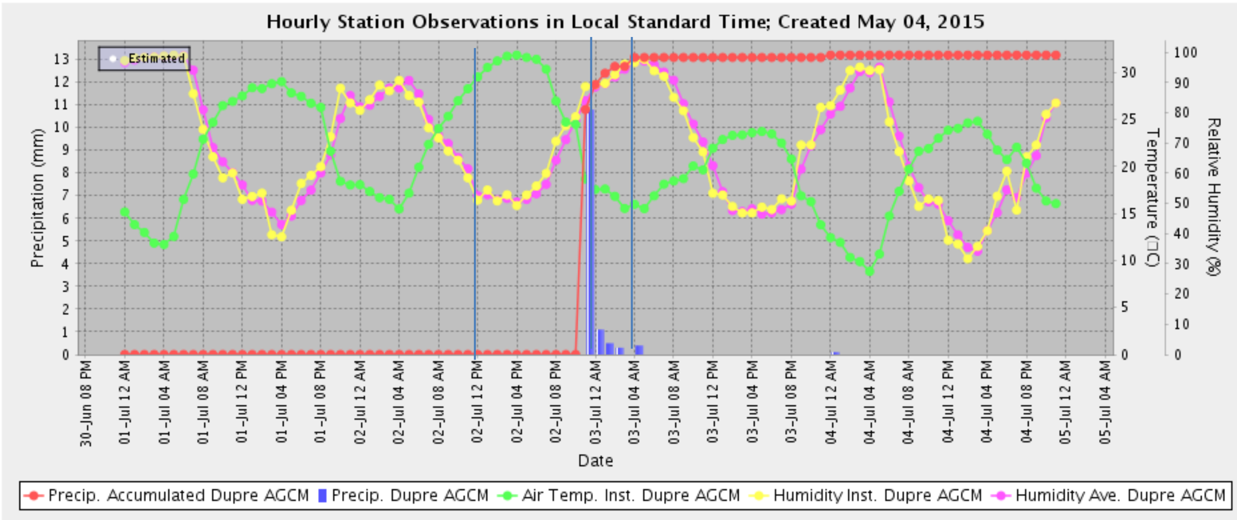

Figure 33. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from July 1 to 4, 2013 at Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on July 2 between 12-2 pm (Day time) and on July 3 between 12pm-1am (Night) and 4-5am (Dawn).

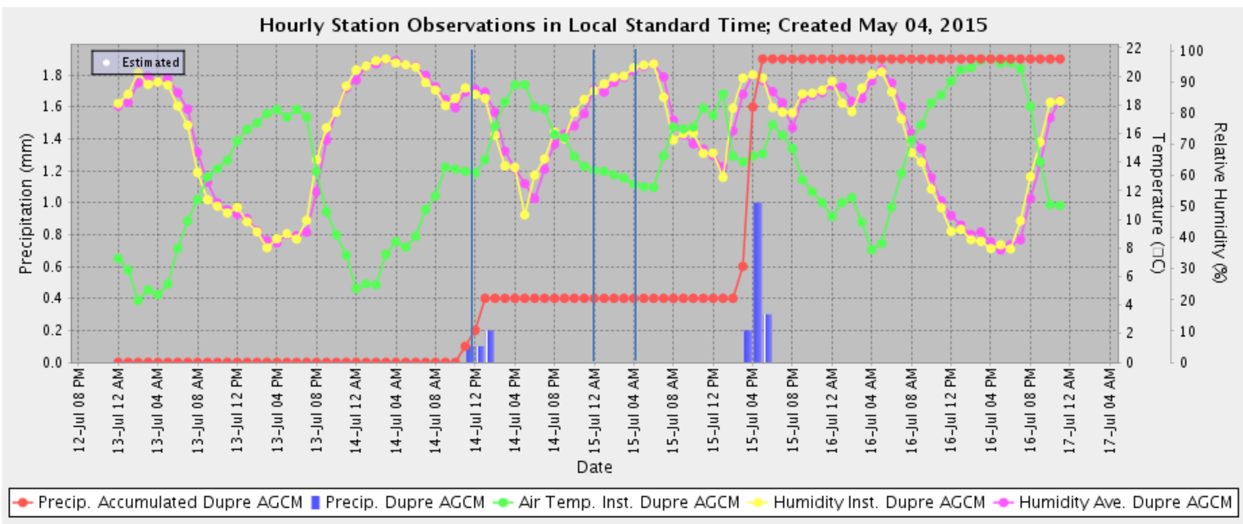

Figure 34. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from July 13 to 16, 2013 at Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on July 14 between 12-2 pm (Day time) and on July 15 between 12pm-1am (Night) and 4-5am (Dawn).

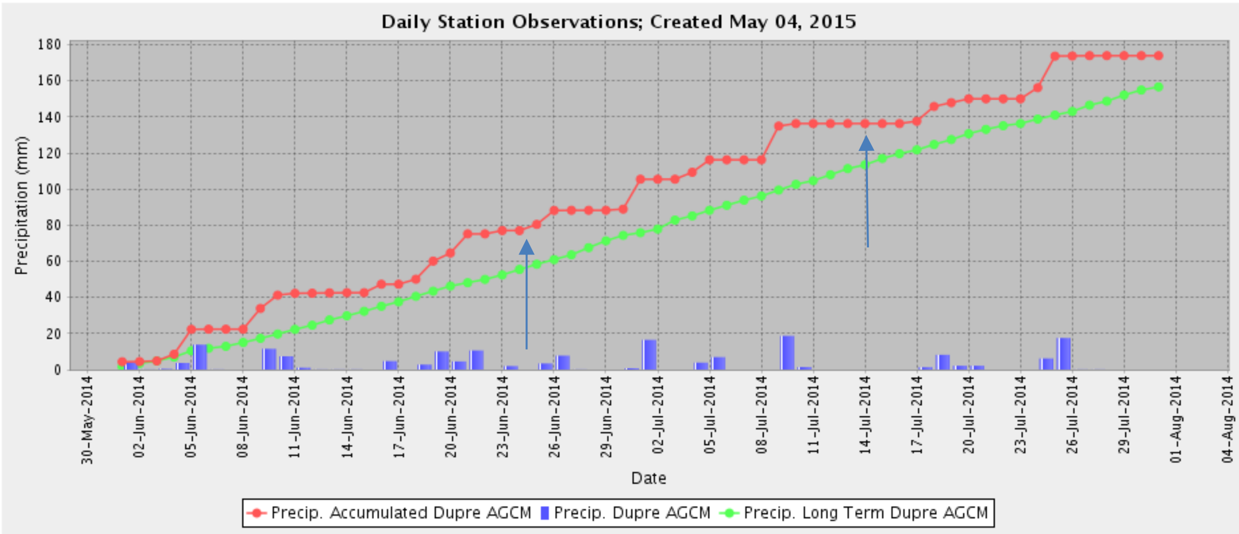

Figure 35. Daily instantaneous, accumulated and long term normal rainfall for June and July 2014, at the Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp).

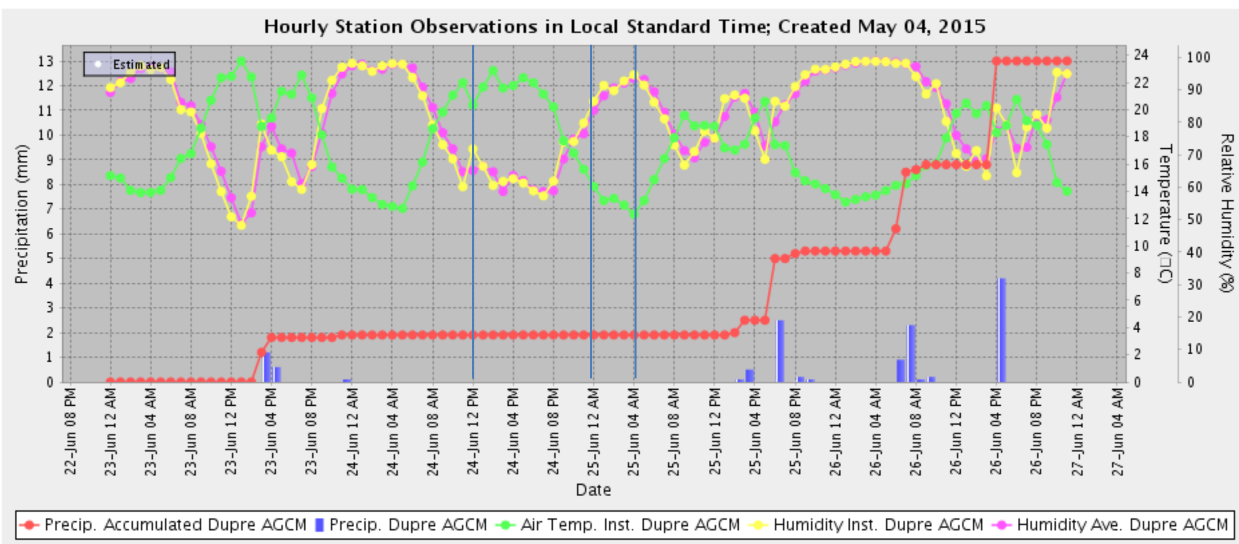

Figure 36. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from June 23 to 26, 2014 at Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-1, spray-applied on June 24 between 12-2 pm (Day time) and on June 25 between 12pm-1am (Night) and 4-5am (Dawn).

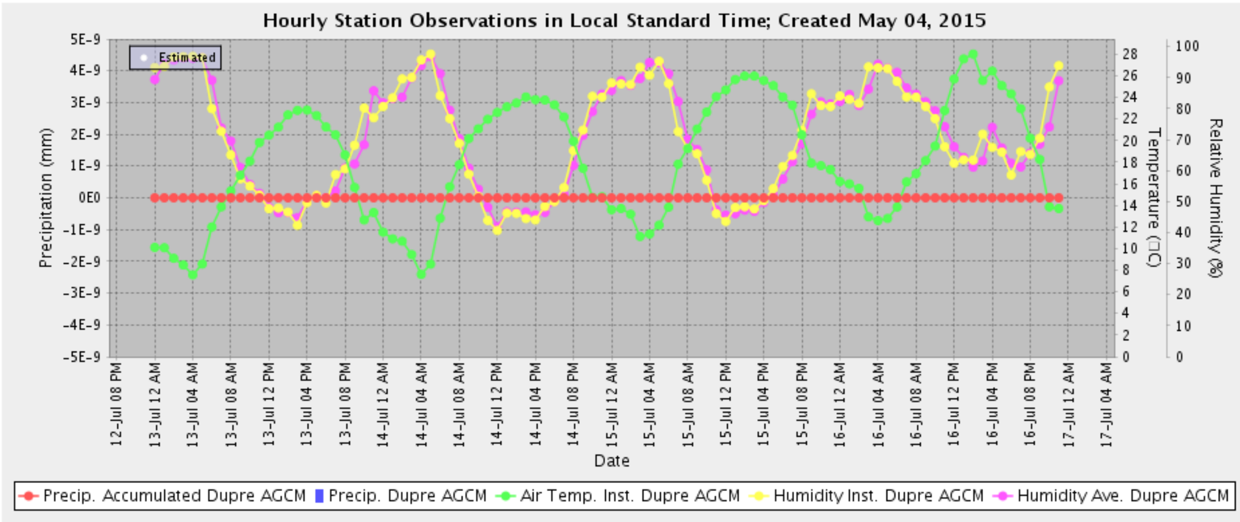

Figure 37. Hourly instantaneous and accumulated precipitation (mm), average air temperature (degree C) and relative humidity (%) from July 13 to 16, 2014 at Dupre AGCM weather station about 15 km north of the LARA project site, Bonnyville, Alberta (AgroClimatic Information Services (ACIS), Government of Alberta: http://agriculture.alberta.ca/acis/about.jsp). The weather data correspond to trial-2, spray-applied on July 14 between 12-2 pm (Day time) and on July 15 between 12pm-1am (Night) and 4-5am (Dawn).

Table 3. Performance comparison of the four herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the eradication of weeds before seeding a crop (pre-seeding burn-down) in two trials sprayed on the two different dates, May 7-8 and 16-17, 2012, in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2012 Herbicide ↓	**Application timing**	**Trial treated on May 7-8, 2012**				**Trial treated on May 16-17, 2012**			
		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)	
		Treat. means	Rank	Treat. means	Rank	Treat. means	Rank	Treat. means	Rank
Aim	Control	0 b	4	100 a	1	0 b	4	100 a	1
	Day	12 a	2	75 a	3	15 a	**1**	79 a	**4**
	Night	9 a	3	76 a	2	11 a	**2**	81 a	**3**
	Dawn	13 a	**1**	57 a	**4**	10 a	3	94 a	2
Heat	Control	0 c	4	100 a	1	0 b	4	100 a	1
	Day	18 a	**1**	59 bc	**3**	16 a	**1**	62 b	**3**
	Night	13 b	**2**	47 c	**4**	16 a	**2**	61 b	**4**
	Dawn	12 b	3	76 ab	2	12 a	3	86 ab	2
Prepass A	Control	0 b	4	100 a	1	0 b	4	100 a	1
	Day	35 a	**1**	62 a	**3**	25 a	**1**	49 b	**4**
	Night	28 a	**2**	57 a	**4**	17 a	**2**	52 b	**3**
	Dawn	25 a	3	63 a	2	16 a	3	73 ab	2
VPMII	Control	0 c	4	100 a	1	0 b	4	100 a	1
	Day	87 a	**1**	37 b	**3**	51 a	**1**	38 b	3
	Night	77 b	**2**	32 b	**4**	50 a	**2**	52 b	2
	Dawn	74 b	3	52 b	2	44 a	3	38 b	**4**
Summary (% of the total occurrences)									
Day time application more effective than Dawn time		75		75		100		75	
Night time application more effective than Dawn time		75		75		100		75	
Dawn time application more effective than Day and/or Night time applications		25		25		None		25	

Table 4. Performance comparison of the four herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the eradication of weeds before seeding a crop (pre-seeding burn-down) in two trials sprayed on the two different dates, May 9-10 and 27-28, 2013, in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2013 Herbicide ↓	**Application timing**	**Trial-1 treated on May 9-10, 2013**				**Trial-2 treated on May 27-28, 2013**			
		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)	
		Treat. means	Rank	Treat. means	Rank	Treat. means	Ran k	Treat. means	Rank
Aim	Control	0 b	4	100 a	1	1 b	4	100 a	1
	Day	15 a	1	86 a	3	16 a	3	56 b	3
	Night	11 a	3	92 a	2	17 a	2	57 b	2
	Dawn	11 a	2	85 a	4	18 a	1	56 b	4
Heat	Control	0 a	4	100 a	2	1 b	4	100 a	1
	Day	4 a	3	72 a	4	6 a	3	92 ab	3
	Night	5 a	2	81 a	3	9 a	1	64 b	4
	Dawn	6 a	1	102 a	1	8 a	2	96 ab	2
Prepass A	Control	0 b	4	100 a	2	1 c	4	100 a	1
	Day	22 a	2	111 a	1	15 a	1	89 a	3
	Night	10 b	3	95 a	3	10 b	3	79 a	4
	Dawn	25 a	1	76 a	4	13 ab	2	98 a	2
VPMII	Control	0 c	4	100 a	1	1 b	4	100 a	1
	Day	57 ab	2	43 b	3	89 a	1	7 b	4
	Night	46 b	3	48 b	2	82 a	3	7 b	2
	Dawn	63 a	1	24 b	4	83 a	2	7 b	3
Summary (% of the total occurrences)									
Day time application more effective than Dawn time		25		25		50		75	
Night time application more effective than Dawn time		None		25		25		50	
Dawn time application more effective than Day and/or Night time applications		75		75		25		25	

Table 5. Performance comparison of the four herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the eradication of weeds before seeding a crop (pre-seeding burn-down) in two trials sprayed on the two different dates, May 8-9 and 14-15, 2014, in Lethbridge. Treatment means with the same letter are not significantly different at $p<0.1$.

2014 Herbicide ↓	**Application timing**	**Trial-1 treated on May 8-9, 2014**				**Trial-2 treated on May 14-15, 2014**			
		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)	
		Treat. means	Rank	Treat. means	Rank	Treat. means	Rank	Treat. means	Rank
Aim	Control	0 c	4	100 a	2	0 b	4	100 a	1
	Day	51 a	1	47 a	4	30 a	1	29 b	4
	Night	24 b	3	100 a	1	22 a	2	32 b	3
	Dawn	36 ab	2	68 a	3	13 ab	3	39 b	2
Heat	Control	0 b	4	100 a	1	0 a	4	100 a	1
	Day	24 a	1	56 a	2	17 a	1	45 a	4
	Night	6 ab	3	48 a	3	17 a	2	46 a	3
	Dawn	12 ab	2	42 a	4	13 a	3	55 a	2
Prepass A	Control	0 b	4	100 a	1	0 b	4	100 a	1
	Day	42 a	1	13 a	4	31 a	1	17 b	3
	Night	36 a	3	19 a	3	10 b	3	32 b	2
	Dawn	37 a	2	24 a	2	29 a	2	17 b	4
VPMII	Control	0 c	4	100 a	1	0 b	4	100 a	1
	Day	94 a	1	21 a	4	86 a	1	3 b	3
	Night	84 b	3	41 a	2	81 a	2	2 b	4
	Dawn	90 ab	2	25 a	3	76 a	3	8 b	2
Summary (% of the total occurrences)									
Day time application more effective than Dawn time		100		75		100		75	
Night time application more effective than Dawn time		None		25		75		75	
Dawn time application more effective than Day and/or Night time applications		None		25		None		25	

Table 6. Summary of Tables 1, 2 and 3 showing the percent occurrences of the Day time application being more effective than the Dawn time application.

Application timing comparison	**Year**	**Trial-1 treated on an early data**		**Trial-2 treated on a later date**		**Average of Trial-1 and Trial-2**	
		Efficacy rating; lowest: 0 highest: 100	Weed biomass ratio (% of Control)	Efficacy rating; lowest: 0 highest: 100	Weed biomass ratio (% of Control)	Efficacy rating	Weed biomass ratio
Day time application more effective than Dawn time application (% of total number of occurrences)	2012	75	75	100	75	**88**	**75**
	2013	25	25	50	75	**38**	**50**
	2014	100	75	100	75	**100**	**75**
Average over all three years		**67**	**58**	**83**	**75**	**75**	**67**
Average over 2012 and 2014		**88**	**75**	**100**	**75**	**94**	**75**

Table 7. Performance comparison of the four herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the eradication of weeds before seeding a crop (pre-seeding burn-down) in two trials sprayed on the two different dates as shown in Tables 1, 2, and 3 in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

Year	Treatment		Trial treated on an early date				Trial treated on a later date			
			Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed biomass ratio (% of Control)	
			Treat. means	Rank	Treat. means	Rank	Treat. means	Rank	Treat. means	Rank
2012	Herbicide	Control	0 c	5	100 a	1	0 c	5	100 a	1
		Aim	11 c	4	69 ab	2	12 cb	4	85 ab	2
		Heat	14 c	3	61 ab	4	14 b	3	70 abc	3
		Prepass A	29 b	2	61 ab	3	19 b	2	58 bc	4
		VPMII	79 a	1	40 b	5	48 a	1	43 c	5
	Application timing	Control	0 c	4	100 a	1	0 c	4	100 a	1
		Day	38 a	1	58 b	3	27 a	1	57 c	4
		Night	32 b	3	53 b	4	23 ab	2	62 cb	3
		Dawn	32 b	2	62 b	2	20 b	3	73 b	2
2013	Herbicide	Control	0 c	5	100 a	1	1 d	5	100 a	1
		Aim	12 b	3	88 a	3	17 b	2	56 b	4
		Heat	5 c	4	85 a	4	8 c	4	84 ab	3
		Prepass A	19 b	2	94 a	2	13 cb	3	88 ab	2
		VPMII	55 a	1	38 a	5	85 a	1	7 c	5
	Application timing	Control	0 c	4	100 a	1	1 b	4	100 a	1
		Day	24 ab	2	78 a	3	31 a	1	61 b	3
		Night	18 b	3	79 a	2	30 a	3	52 b	4
		Dawn	26 a	1	71 a	4	30 a	2	64 b	2
2014	Herbicide	Control	0 c	5	100 a	1	0 c	5	100 a	1
		Aim	37 b	3	72 ab	2	22 b	3	33 b	3
		Heat	14 c	4	49 ab	3	15 b	4	48 b	2
		Prepass A	38 b	2	18 b	5	23 b	2	22 b	4
		VPMII	89 a	1	29 ab	4	81 a	1	5 b	5
	Application timing	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	53 a	1	34 b	4	41 a	1	23 b	4
		Night	38 b	3	52 b	2	32 a	3	28 b	3
		Dawn	44 ab	2	40 b	3	33 a	2	30 b	2
Summary (% of the total of 3 occurrences)										
Day time application more effective than Dawn time			66		66		100		100	
Night time application more effective than Dawn time			None		33		33		100	
Dawn time application more effective than Day and/or Night time applications			33		33		None		None	

Table 8. Performance comparison of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), applied in-crop for the eradication of the oats in three separate trials sprayed on May 31 – June 1, June 21 -22, and July 24 – 25 in 2012 at the FSA project site in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Herbicide	Application Timing	Trial-1 treated on May 31-June 1, 2012				Trial-2 treated on June 21-22, 2012				Trial-3 treated on July 24-25 2012			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 c	4	N/A	N/A	0 c	4	100 a	1
		Day	90.4 a	1	13 b	2	77.9 a	1	N/A	N/A	67.9 b	3	8 b	2
		Night	87.1 a	2	10 b	3	46.7 b	2	N/A	N/A	89.6 a	1	0 b	3
		Dawn	80.4 a	3	7 b	4	33.3 b	3	N/A	N/A	75.4 ab	2	0 b	3
	TM Muster + Select	Control	0 b	4	100 a	1	0 b	4	N/A	N/A	0 c	4	100 a	1
		Day	96.3 a	3	2 b	4	97.7 a	1	N/A	N/A	66.3 b	3	5 b	3
		Night	96.7 a	1	2 b	3	97.7 a	1	N/A	N/A	85.4 a	2	0 b	4
		Dawn	96.7 a	1	3 b	2	97.7 a	1	N/A	N/A	86.3 a	1	33 b	2
Canola (RR)	VPMII	Control	0 b	4	100 a	1	0 c	4	N/A	N/A	0 c	4	100 a	1
		Day	95.4 a	2	1 b	4	92.9 a	1	N/A	N/A	97.1 a	1	2 b	3
		Night	92.5 a	3	7 b	3	71.7 b	3	N/A	N/A	95.0 ab	2	31 b	2
		Dawn	95.8 a	1	30 ab	2	78.3 b	2	N/A	N/A	89.2 b	3	1 b	4
Peas	Odyssey	Control	0 b	4	100 a	1	11.3 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	75.0 a	2	19 a	3	81.3 a	1	18 b	3	N/A	N/A	N/A	N/A
		Night	75.8 a	1	18 a	4	77.9 a	2	22 b	2	N/A	N/A	N/A	N/A
		Dawn	73.8 a	3	20 a	2	75.0 a	3	17 b	4	N/A	N/A	N/A	N/A
	Select	Control	0 b	4	100 a	1	11.3 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	93.8 a	1	5 a	4	87.9 a	3	14 b	4	N/A	N/A	N/A	N/A
		Night	87.9 a	3	16 a	2	96.3 a	1	15 b	3	N/A	N/A	N/A	N/A
		Dawn	88.3 a	2	8 a	3	96.3 a	1	15 b	2	N/A	N/A	N/A	N/A
Wheat	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	91.7 a	1	11 b	4	97.9 a	1	4 b	3	N/A	N/A	N/A	N/A
		Night	90.8 a	3	12 b	2	97.1 a	3	3 b	4	N/A	N/A	N/A	N/A
		Dawn	91.7 a	1	12 b	3	97.5 a	2	5 b	2	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	95.4 a	1	7 b	3	96.3 a	2	2 b	4	N/A	N/A	N/A	N/A
		Night	94.6 a	2	8 b	2	97.1 a	1	3 b	2	N/A	N/A	N/A	N/A
		Dawn	94.2 a	3	7 b	4	95.8 a	3	3 b	3	N/A	N/A	N/A	N/A
Summary (% of the total occurrences)														
Day time application more effective than Dawn time			57		71		71		75		33		50	
Night time application more effective than Dawn time			43		43		43		50		67		50	
Dawn time application more effective than Day and/or Night time applications			43		29		29		25		33		50	

Table 9. Performance comparison of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), applied in-crop for the eradication of the mustard weed in three separate trials treated on May 31 – June 1, June 21 -22, and July 24 – 25 in 2012 at the FSA project site in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Herbicide	Application Timing	Trial-1 treated on May 31-June 1, 2012				Trial-2 treated on June 21-22, 2012				Trial-3 treated on July 24-25 2012			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	1	0 c	4	N/A	N/A	0 b	4	N/A	N/A
		Day	94.2 a	1	3 b	3	88.3 a	1	N/A	N/A	97.5 a	1	N/A	N/A
		Night	93.8 ab	2	4 b	2	33.3 b	2	N/A	N/A	97.1 a	2	N/A	N/A
		Dawn	90.0 b	3	2 b	4	15.0 bc	3	N/A	N/A	96.7 a	3	N/A	N/A
	TM Muster + Select	Control	N/A	N/A	100 a	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	169 a	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	102 a	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	140 a	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canola (RR)	VPMII	Control	0 b	4	100 a	1	0 c	4	N/A	N/A	0 b	4	N/A	N/A
		Day	96.3 a	2	1 b	4	92.5 a	1	N/A	N/A	97.5 a	1	N/A	N/A
		Night	96.7 a	1	2 b	2	51.7 b	3	N/A	N/A	96.1 a	3	N/A	N/A
		Dawn	96.3 a	2	1 b	3	62.9 b	2	N/A	N/A	96.7 a	2	N/A	N/A
Peas	Odyssey	Control	0 b	4	100 a	1	6.3 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	91.7 a	1	5 a	3	88.3 a	1	7 a	4	N/A	N/A	N/A	N/A
		Night	90 a	3	4 a	4	73.3 a	3	11 a	2	N/A	N/A	N/A	N/A
		Dawn	90 a	2	5 a	2	81.7 a	2	9 a	3	N/A	N/A	N/A	N/A
	Select	Control	N/A	N/A	N/A	N/A	6.3 b	4	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	45.6 a	2	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	46.3 a	1	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	44.4 a	3	N/A	N/A	N/A	N/A	N/A	N/A
Wheat	Barricade	Control	0 c	4	100 a	1	7.1 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	93.8 a	1	16 b	4	88.8 a	1	3 b	4	N/A	N/A	N/A	N/A
		Night	93.3ab	2	20 b	3	80.4 a	2	6 b	2	N/A	N/A	N/A	N/A
		Dawn	90.8 b	3	30 b	2	79.6 a	3	4 b	3	N/A	N/A	N/A	N/A
	Everest	Control	0 c	4	100 a	1	7.1 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	91.3 a	1	16 b	4	79.2 a	1	4 b	3	N/A	N/A	N/A	N/A
		Night	90 a	2	48 ab	3	73.3 a	2	4 b	2	N/A	N/A	N/A	N/A
		Dawn	83.3 b	3	53 ab	2	71.3 a	3	3 b	4	N/A	N/A	N/A	N/A
	OcTTain	Control	0 b	4	100 a	3	7.1 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	88.3 a	1	59 a	4	94.2 a	1	4 b	3	N/A	N/A	N/A	N/A
		Night	77.9 a	3	130 a	1	88.8 a	3	4 b	2	N/A	N/A	N/A	N/A
		Dawn	82.1 a	2	123 a	2	90.8 a	2	2 b	4	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	0 b	4	100 a	1	7.1 b	4	100 a	1	N/A	N/A	N/A	N/A
		Day	96.7 a	1	8 b	2	97.1 a	1	0 b	4	N/A	N/A	N/A	N/A
		Night	96.7 a	1	3 b	3	93.8 a	3	0 b	2	N/A	N/A	N/A	N/A
		Dawn	96.3 a	3	3 b	4	94.6 a	2	0 b	3	N/A	N/A	N/A	N/A
Summary (% of the total occurrences)														
Day time application more effective than Dawn time			100		63		100		60		100		N/A	
Night time application more effective than Dawn time			57		38		50		0		50		N/A	
Dawn time application more effective than Day and/or Night time applications			0		50		0		40		0		N/A	

Table 10. The ANOVA results for the three trials listed in Table 8 comparing the performance of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the in-crop eradication of the oats weed in 2012 at the FSA project site in Lethbridge, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	**Treatment type**	**Treatment**	**Efficacy rating (Scale: 0 – 100)**		**Oats biomass ratio (% of Control)**	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 c	3	100 a	1
		Liberty	72 b	2	6 b	3
		TM Muster + Select	91 a	1	7 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	83 a	**2**	7 b	**3**
		Night	84 a	**1**	3 b	**4**
		Dawn	78 a	3	11 b	2
Canola (RR)	Herbicide	Control	90 a	1	100 a	1
		VPMII	0 b	2	12 b	2
	Application timing	Control	0 c	4	100 a	1
		Day	95 a	**1**	1 b	**4**
		Night	87 b	3	19 b	2
		Dawn	88 ab	2	15 b	3
Peas	Herbicide	Control	6 c	3	100 a	1
		Odyssey	76 b	2	19 b	2
		Select	92 a	1	12 b	3
	Application timing	Control	6 b	4	100 a	1
		Day	85 a	**2**	14 b	**4**
		Night	85 a	**1**	18 b	2
		Dawn	83 a	3	15 b	3
Wheat	Herbicide	Control	0 c	3	100 a	1
		Everest	94 b	2	8 b	2
		TM Axial + Infinity	96 a	1	5 b	3
	Application timing	Control	0 b	4	100 a	1
		Day	95 a	**1**	6 b	**4**
		Night	95 a	**2**	7 b	**3**
		Dawn	95 a	3	7 b	2
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		100	
Night time application more effective than Dawn time			75		50	
Dawn time application more effective than Day and/or Night time applications			0		0	

Table 11. The ANOVA results for the three trials listed in Table 9 comparing the performance of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the in-crop eradication of the mustard weed in 2012 at the FSA project site in Lethbridge, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	**Treatment type**	**Treatment**	**Efficacy rating (Scale: 0 – 100)**			**Mustard biomass ratio (% of Control)**		
			Treatment means		Rank	Treatment means		Rank
Canola (LL)	Herbicide	Control	1	b	2	100	a	2
		Liberty	78	a	1	85	a	3
		TM Muster + Select	N/A		N/A	130	a	1
	Application timing	Control	1	b	4	100	a	3
		Day	93	a	1	120	a	1
		Night	75	a	2	96	a	4
		Dawn	67	a	3	106	a	2
Canola (RR)	Herbicide	Control	0	b	2	99	a	1
		VPMII	88	a	1	40	b	2
	Application timing	Control	0	b	4	100	a	1
		Day	96	a	1	33	b	3
		Night	83	a	3	59	ab	2
		Dawn	85	a	2	29	b	4
Peas	Herbicide	Control	3	b	2	100	a	1
		Odyssey	86	a	1	7	a	2
	Application timing	Control	3	b	4	100	a	1
		Day	90	a	1	6	b	4
		Night	82	a	3	7	b	3
		Dawn	86	a	2	7	b	2
Wheat	Herbicide	Control	4	c	5	100	a	1
		Barricade	88	b	2	13	c	4
		Everest	82	b	4	21	CB	3
		OcTTain	87	b	3	54	b	2
		TM Axial + Infinity	96	a	1	2	c	5
	Application timing	Control	4	b	4	100	a	1
		Day	91	a	1	14	b	4
		Night	87	a	2	27	b	3
		Dawn	86	a	3	27	b	2
Summary (% of the total occurrences)								
Day time application more effective than Dawn time			100			50		
Night time application more effective than Dawn time			50			75		
Dawn time application more effective than Day and/or Night time applications			0			25		

Table 12. Performance comparison of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), applied in-crop for the eradication of the oats weed in two separate trials sprayed on June 5-6 and June 17-18, 2013, at the FSA project site in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 5-6, 2013**				**Trial-2 treated on June 17-18, 2013**			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 d	4	100 a	2
		Day	88.1 a	**1**	10 b	3	35.8 c	3	106 a	1
		Night	87.1 a	**2**	15 b	2	77.5 b	2	28 b	3
		Dawn	86.3 a	3	9 b	4	93.8 a	1	7 b	4
	TM Muster + Select	Control	0 c	4	100 a	1	0 c	4	100 a	1
		Day	22.5 a	**2**	84 a	2	24.2 b	3	74 a	2
		Night	27.5 a	**1**	61 a	**4**	98.3 a	1	1 b	3
		Dawn	13.3 b	3	69 a	3	97.5 a	2	0 b	4
Canola (RR)	VPMII	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	97.5 a	**1**	0 b	2	75.4 b	3	16 b	2
		Night	95.8 a	3	0 b	2	96.3 a	2	2 b	3
		Dawn	97.1 a	2	0b	2	98.3 a	1	0 b	4
Peas	Odyssey	Control	0 c	4	100 ab	2	5.0 b	4	100 a	1
		Day	19.2 b	3	85 ab	**3**	13.8 b	3	98 a	2
		Night	39.6 a	**1**	76 b	**4**	75.6 a	2	25 b	3
		Dawn	21.3 b	2	102 a	1	92.1 a	1	2 b	4
	Select	Control	0 c	4	100 a	1	5.0 c	4	100 a	1
		Day	40 b	3	48 b	2	67.1 b	3	28 b	2
		Night	75.0 a	**1**	23 c	**4**	97.9 a	1	0 c	**4**
		Dawn	62.9 a	2	32 bc	3	91.7 a	2	0 c	3
Wheat	Everest	Control	0 b	4	100 a	1	0 c	4	100 a	2
		Day	79.2 a	**1**	0 b	2	42.9 b	3	112 a	1
		Night	79.2 a	**1**	0 b	2	87.9 a	2	38 a	**4**
		Dawn	77.1 a	3	0 b	2	88.8 a	1	39 a	3
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	88.3 a	**1**	0 b	2	98.3 a	1	0 b	2
		Night	86.7 a	**2**	0 b	2	98.3 a	1	0 b	2
		Dawn	85.8 a	3	0 b	2	98.3 a	1	0 b	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			71		25		0		0	
Night time application more effective than Dawn time			86		75		33		33	
Dawn time application more effective than Day and/or Night time applications			14		25		67		67	

Table 13. Performance comparison of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), applied in-crop for the eradication of the mustard weed in two separate trials sprayed on June 5-6 and June 17-18, 2013, at the FSA project site in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Herbicide	Application Timing	Trial-1 treated on June 5-6, 2013				Trial-2 treated on June 17-18, 2013			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 d	4	100 a	1	0 c	4	100 a	1
		Day	90.4 a	**1**	0 b	**4**	29.2 b	3	46 b	2
		Night	77.1 b	**2**	6 b	**3**	42.9 b	2	39bc	3
		Dawn	52.1 c	3	7 b	2	73.8 a	1	15 c	4
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canola (RR)	VPMII	Control	0 c	4	100 a	1	0 d	4	100 a	1
		Day	93.3 a	**1**	0 b	3	30 c	3	20 b	2
		Night	71.7 b	3	4 b	2	55.4 b	2	16 b	3
		Dawn	75.4 b	2	0 b	3	90.4 a	1	4 b	4
Peas	Odyssey	Control	0 b	4	100 a	1	5.0 c	4	100 a	1
		Day	63.8 a	3	2 b	**4**	50 b	3	19 b	2
		Night	71.3 a	**1**	4 b	2	79.2 a	2	10 b	3
		Dawn	66.3 a	2	4 b	3	89.6 a	1	4 b	4
	Select	Control	N/A	N/A	N/A	N/A	0 a	4	N/A	N/A
		Day	N/A	N/A	N/A	N/A	30 a	3	N/A	N/A
		Night	N/A	N/A	N/A	N/A	90 a	1	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	50 a	2	N/A	N/A
Wheat	Barricade	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	75.8 a	**2**	0 b	2	71.7 b	3	2 b	2
		Night	78.8 a	**1**	0 b	2	91.3 a	2	1 b	3
		Dawn	74.6 a	3	0 b	2	94.2 a	1	0 b	4
	Everest	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	61.7 a	**2**	0 b	2	17.5 b	3	44 b	2
		Night	60 a	3	0 b	2	81.3 a	2	2 b	3
		Dawn	67.1 a	1	0 b	2	81.7 a	1	0 b	4
	OcTTain	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	87.9 a	**1**	0 b	2	87.1 a	2	2 b	2
		Night	87.9 a	1	0 b	2	77.9 b	3	1 b	3
		Dawn	86.7 a	3	0 b	2	88.3 a	1	0 b	4
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	96.7 a	1	0 b	2	95.8 b	3	0 b	**4**
		Night	96.7 a	1	0 b	2	97.1 a	2	1 b	2
		Dawn	96.7 a	1	0 b	2	98.3 a	1	0 b	3
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			60		67		0		14	
Night time application more effective than Dawn time			60		33		13		0	
Dawn time application more effective than Day and/or Night time applications			40		33		88		86	

Table 14. The ANOVA results for trial-1 listed in Table 12 comparing the performance of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the in-crop eradication of the oats weed in 2013 at the FSA project site in Lethbridge, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Trial-1 Crop ↓	**Treatment type**	**Treatment**	**Efficacy rating (Scale: 0 – 100)**		**Oats biomass ratio (% of Control)**	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 c	3	100 a	1
		Liberty	87 a	1	11 b	3
		TM Muster + Select	21 b	2	71 a	2
	Application timing	Control	0 c	4	100 a	1
		Day	55 ab	2	47 b	2
		Night	57 a	1	38 b	4
		Dawn	50 b	3	39 b	3
Canola (RR)	Herbicide	Control	0 b	2	100 a	1
		VPMII	97 a	1	0 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	98 a	1	0 b	2
		Night	96 a	3	0 b	3
		Dawn	97 a	2	0 b	4
Peas	Herbicide	Control	0 c	3	100 a	1
		Odyssey	27 b	2	88 a	2
		Select	59 a	1	34 b	3
	Application timing	Control	0 d	4	100 a	1
		Day	30 c	3	67 b	3
		Night	57 a	1	50 c	4
		Dawn	42 b	2	67 b	2
Wheat	Herbicide	Control	0 c	3	100 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	79 b	2	0 b	2
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	87 a	1	0 b	3
	Application timing	Control	0 c	4	100 a	1
		Day	84 a	1	0 b	2
		Night	83 ab	2	0 b	3
		Dawn	82 b	3	0 b	4
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			75		50	
Night time application more effective than Dawn time			75		100	
Dawn time application more effective than Day and/or Night time applications			25		0	

Table 15. The ANOVA results for trial-1 listed in Table 13, comparing the performance of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the in-crop eradication of the mustard weed in 2013 at the FSA project site in Lethbridge, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Trial-1 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 a	1
		Liberty	73 a	1	4 b	2
		TM Muster + Select	N/A	N/A	N/A	N/A
	Application timing	Control	0 c	4	100 a	1
		Day	91 a	1	0 b	4
		Night	77 a	2	6 b	3
		Dawn	52 b	3	7 b	2
Canola (RR)	Herbicide	Control	0 b	2	100 a	1
		VPMII	80 a	1	1 b	2
	Application timing	Control	0 c	4	100 a	1
		Day	94 a	1	0 b	3
		Night	72 b	3	4 b	2
		Dawn	76 b	2	0 b	4
Peas	Herbicide	Control	0 b	2	100 a	1
		Odyssey	67 a	1	3 b	2
		Select	N/A	N/A	N/A	N/A
	Application timing	Control	0 b	4	100 a	1
		Day	64 a	3	2 b	4
		Night	71 a	1	4 b	2
		Dawn	67 a	2	4 b	3
Wheat	Herbicide	Control	0 e	5	N/A	N/A
		Barricade	76 c	3	N/A	N/A
		Everest	63 d	4	N/A	N/A
		OcTTain	88 b	2	N/A	N/A
		TM Axial + Infinity	97 a	1	N/A	N/A
	Application timing	Control	0 b	4	N/A	N/A
		Day	81 a	3	N/A	N/A
		Night	81 a	2	N/A	N/A
		Dawn	81 a	1	N/A	N/A
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			75		67	
Night time application more effective than Dawn time			75		33	
Dawn time application more effective than Day and/or Night time applications			25		33	

Table 16. Performance comparison of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), applied in-crop for the eradication of the oats weed in two separate trials sprayed on June 3-4 and June 23-24, 2014, at the FSA project site in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 3-4, 2014**				**Trial-2 treated on June 23-24, 2014**			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	1	0 c	4	100 a	1
		Day	64.2 b	3	23 b	2	71.3 a	**1**	44 b	**4**
		Night	89.2 a	2	7 b	3	55.0 b	**2**	47 b	**3**
		Dawn	90.8 a	1	7 b	4	48.8 b	3	49 b	2
	TM Muster + Select	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	86.7 a	3	0 b	2	70 a	**1**	46 b	**4**
		Night	88.3 a	1	0 b	2	63.1ab	**2**	60 b	2
		Dawn	87.9 a	2	0 b	2	50.6 b	3	55 b	3
Canola (RR)	VPMII	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	90.4 b	3	0 b	4	93.8 a	**1**	0 b	2
		Night	93.3 a	2	0 b	2	93.1 a	**2**	0 b	2
		Dawn	94.2 a	1	0 b	3	92.5 a	3	0 b	2
Peas	Odyssey	Control	0 b	4	100 a	1	11.9 b	4	100 a	1
		Day	58.8 a	3	10 b	2	71.3 a	**1**	23 b	**3**
		Night	70.4 a	1	0 b	4	71.3 a	**1**	17 b	**4**
		Dawn	67.9 a	2	3 b	3	51.3 a	3	40 b	2
	Select	Control	0 b	4	100 a	1	11.9 b	4	100 a	1
		Day	92.1 a	3	0 b	2	85.6 a	**1**	0 b	3
		Night	94.6 a	**1**	0 b	3	73.8 a	3	0 b	3
		Dawn	94.6 a	1	0 b	3	83.1 a	2	2 b	2
Wheat	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	85.4 a	**1**	5 b	2	82.5 a	1	15 b	**4**
		Night	85.4 a	**2**	0 b	4	82.5 a	1	16 b	**3**
		Dawn	83.8 a	3	5 b	3	82.5 a	1	17 b	2
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	89.2 a	**1**	0 b	2	90.3 a	**1**	15 b	2
		Night	89.2 a	**1**	0 b	2	88.1 a	**2**	3 b	3
		Dawn	88.8 a	3	0 b	2	88.1 a	2	1 b	4
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			29		14		100		57	
Night time application more effective than Dawn time			71		29		57		43	
Dawn time application more effective than Day and/or Night time applications			29		71		29		43	

Table 17. Performance comparison of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), applied in-crop for the eradication of the mustard weed in two separate trials sprayed on June 3-4 and June 23-24, 2014, at the FSA project site in Lethbridge. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 3-4, 2014**				**Trial-2 treated on June 23-24, 2014**			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	76.4 a	**2**	5 b	2	80.6 a	**1**	32 b	**4**
		Night	84.2 a	**1**	2 b	4	46.3 b	**2**	40 b	**3**
		Dawn	73.8 a	3	5 b	3	35.0 b	3	57 b	2
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canola (RR)	VPMII	Control	0 b	4	100 a	1	0 d	4	100 a	1
		Day	62.5 a	2	4 b	**4**	85.0 a	**1**	1 b	**4**
		Night	61.3 a	3	5 b	**3**	63.8 b	**2**	5 b	**3**
		Dawn	63.3 a	1	6 b	2	53.8 c	3	17 b	2
Peas	Odyssey	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	56.7 a	3	8 b	2	63.8 a	**2**	39 a	**4**
		Night	65.4 a	1	0 b	**4**	65.6 a	**1**	54 a	**3**
		Dawn	59.6 a	2	3 b	3	30.6 b	3	56 a	2
	Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wheat	Barricade	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	65.8 a	**1**	0 b	3	54.4 a	**1**	8 b	**4**
		Night	64.6 a	3	0 b	3	46.3 ab	**2**	16 b	**3**
		Dawn	65.4 a	2	3 b	2	44.4 b	3	17 b	2
	Everest	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	42.1 a	**1**	2 b	**4**	43.1 a	**1**	19 b	**4**
		Night	37.9 b	3	34 ab	2	38.1 a	**2**	24 b	**3**
		Dawn	41.7 a	2	27 b	3	35.0 a	3	30 b	2
	OcTTain	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	57.1 a	2	8 b	2	78.1 a	**1**	5 b	**4**
		Night	54.6 a	3	1 b	**4**	74.4 ab	**2**	23 b	2
		Dawn	60 a	1	5 b	3	68.1 b	3	17 b	3
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	91.3 a	**1**	0 b	3	90.6 a	**1**	2 b	**4**
		Night	88.8 a	3	0 b	3	84.4 a	**2**	4 b	**3**
		Dawn	88.8 a	2	0 b	2	73.1 b	3	6 b	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			57		43		88		100	
Night time application more effective than Dawn time			14		71		88		86	
Dawn time application more effective than Day and/or Night time applications			43		29		0		0	

Table 18. The ANOVA results for trial-2 listed in Table 16 comparing the performance of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the in-crop eradication of the oats weed in 2013 at the FSA project site in Lethbridge, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Trial-2 Crop ↓	**Treatment type**	**Treatment**	**Efficacy rating (Scale: 0 – 100)**		**Oats biomass ratio (% of Control)**	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	3	100 a	1
		Liberty	58 a	2	47 b	3
		TM Muster + Select	62 a	1	54 b	2
	Application timing	Control	0 c	4	100 a	1
		Day	71 a	1	45 b	4
		Night	59 ab	2	54 b	2
		Dawn	50 b	3	52 b	3
Canola (RR)	Herbicide	Control	0 b	2	100 a	1
		VPMII	93 a	1	0 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	94 a	1	0 b	2
		Night	94 a	2	0 b	3
		Dawn	93 a	3	0 b	4
Peas	Herbicide	Control	12 b	3	100 a	1
		Odyssey	65 a	2	27 b	2
		Select	81 a	1	1 c	3
	Application timing	Control	12 b	4	100 a	1
		Day	79 a	1	12 bc	3
		Night	73 a	2	8 c	4
		Dawn	68 a	3	21 b	2
Wheat	Herbicide	Control	0 c	3	100 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	83 b	2	16 b	2
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	89 a	1	1 c	3
	Application timing	Control	0 b	4	100 a	1
		Day	87 a	1	8 b	4
		Night	86 a	2	10 b	2
		Dawn	86 a	3	9 b	3
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		75	
Night time application more effective than Dawn time			100		50	
Dawn time application more effective than Day and/or Night time applications			0		25	

Table 19. The ANOVA results for trial-2 listed in Table 17 comparing the performance of the selected post-emergence herbicides with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), for the in-crop eradication of the mustard weed in 2013 at the FSA project site in Lethbridge, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Trial-2 Crop ↓	**Treatment type**	**Treatment**	**Efficacy rating (Scale: 0 – 100)**		**Mustard biomass ratio (% of Control)**	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 a	1
		Liberty	54 a	1	43 b	2
		TM Muster + Select	N/A	N/A	N/A	N/A
	Application timing	Control	0 c	4	100 a	1
		Day	81 a	1	32 b	4
		Night	46 b	2	40 b	3
		Dawn	35 b	3	57 b	2
Canola (RR)	Herbicide	Control	0 b	2	100 a	1
		VPMII	68 a	1	8 b	2
	Application timing	Control	0 d	4	100 a	1
		Day	85 a	1	1 c	4
		Night	64 b	2	5 c	3
		Dawn	54 c	3	17 b	2
Peas	Herbicide	Control	0 b	2	100 a	1
		Odyssey	54 a	1	50 b	2
		Select	N/A	N/A	N/A	N/A
	Application timing	Control	0 c	4	100 a	1
		Day	64 a	2	39 a	4
		Night	66 a	1	54 a	3
		Dawn	31 b	3	56 a	2
Wheat	Herbicide	Control	0 e	5	100 a	1
		Barricade	49 c	3	14 b	4
		Everest	39 d	4	24 b	2
		OcTTain	74 b	2	15 b	3
		TM Axial + Infinity	83 a	1	4 b	5
	Application timing	Control	0 c	4	100 a	1
		Day	67 a	1	8 b	4
		Night	61 ab	2	17 b	3
		Dawn	55 b	3	18 b	2
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		100	
Night time application more effective than Dawn time			100		100	
Dawn time application more effective than Day and/or Night time applications			0		0	

Table 20. Performance comparison of the selected post-emergence herbicides on eradicating oats when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 20-21, and 27-28 in 2012 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Herbicide	Application Timing	Trial-1 treated on June 20-21, 2012				Trial-2 treated on June 27-28, 2012			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	1	0 d	4	100 a	1
		Day	78 a	1	17 b	4	89 a	1	92 a	2
		Night	62 b	3	29 b	2	61 b	2	77 a	4
		Dawn	64ab	2	21 b	3	38 c	3	87 a	3
	TM Muster + Select	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	90 a	3	38 b	2	92 a	2	100 a	2
		Night	93 a	1	37 b	3	93 a	1	88 a	4
		Dawn	90 a	2	33 b	4	85 a	3	91 a	3
Wheat	Barricade	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	82 a	1	15 b	4	75 a	1	44 b	4
		Night	75 a	3	18 b	3	71 a	3	53 b	2
		Dawn	78 a	2	21 b	2	73 a	2	53 b	3
	OcTTain	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	94 a	2	18 b	4	88 a	2	46 b	4
		Night	87 b	3	28 b	2	88 a	3	53 b	3
		Dawn	95 a	1	21 b	3	93 a	1	58ab	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			50		75		75		50	
Night time application more effective than Dawn time			25		25		25		75	
Dawn time application more effective than Day and/or Night time applications			25		25		25		25	

Table 21. Performance comparison of the selected post-emergence herbicides on eradicating mustard when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 20-21, and 27-28 in 2012 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 20-21, 2012**				**Trial-2 treated on June 27-28, 2012**			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	3	100 a	1	0 b	4	100 a	2
		Day	55 a	1	5 b	4	74 a	1	96 a	4
		Night	10 b	2	78 a	3	73 a	2	98 a	3
		Dawn	0 b	3	90 a	2	68 a	3	104 a	1
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wheat	Barricade	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	89 a	1	1 b	4	93 a	1	11 b	4
		Night	68 a	3	15 b	2	85 a	3	16 b	3
		Dawn	73 a	2	10 b	3	89 a	2	25 b	2
	Everest	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	93 a	1	11 b	4	93 a	1	16 b	4
		Night	67 b	2	19 b	3	89 a	2	27ab	2
		Dawn	62 b	3	23 b	2	88 a	3	20 b	3
	OcTTain	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	97 a	1	15 b	2	96 a	2	41 a	2
		Night	91 a	3	13 b	3	94 a	3	24 a	4
		Dawn	93 a	2	7 b	4	97 a	1	26 a	3
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	96 a	2	3 b	3	100 a	1	11 b	2
		Night	94 a	3	2 b	4	98 a	3	5 b	3
		Dawn	99 a	1	4 b	2	100 a	1	4 b	4
Summary (% of the total occurrences)										
Day time application more effective than Dawn time				80		80		60		60
Night time application more effective than Dawn time				40		40		40		60
Dawn time application more effective than Day and/or Night time applications				20		20		40		40

Table 22. The ANOVA results for the two trials listed in Table 20 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop for the performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2012 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Oats biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 c	3	100 a	1
		Liberty	66 b	2	55 b	3
		TM Muster + Select	90 a	1	65 b	2
	Application timing	Control	0 c	4	100 a	1
		Day	87 a	1	65 b	2
		Night	77 b	2	58 b	3
		Dawn	69 b	3	58 b	4
Wheat	Herbicide	Control	0 c	3	100 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	76 b	2	36 b	3
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	91 a	1	39 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	85 a	1	33 b	4
		Night	80 a	3	40 b	3
		Dawn	84 a	2	40 b	2
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		50	
Night time application more effective than Dawn time			50		50	
Dawn time application more effective than Day and/or Night time applications			0		50	

Table 23. The ANOVA results for the two trials listed in Table 21 comparing the treatment means of the selected post-emergence herbicides on eradicating mustard when applied in-crop for the performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2012 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 ab	2
		Liberty	47 a	1	82 b	3
		TM Muster + Select	N/A	N/A	115 a	1
	Application timing	Control	0 b	4	100 a	2
		Day	65 a	1	84 a	4
		Night	41 a	2	99 a	3
		Dawn	34 ab	3	113 a	1
Wheat	Herbicide	Control	0 c	5	99 a	1
		Barricade	83 b	3	14 b	4
		Everest	82 b	4	20 b	3
		OcTTain	95 a	2	22 b	2
		TM Axial + Infinity	98 a	1	5 b	5
	Application timing	Control	0 c	4	99 a	1
		Day	95 a	1	15 b	4
		Night	86 b	3	15 b	2
		Dawn	88 ab	2	15 b	3
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		100	
Night time application more effective than Dawn time			50		50	
Dawn time application more effective than Day and/or Night time applications			0		0	

Table 24. Performance comparison of the selected post-emergence herbicides on eradicating oats when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 22-23, and 25-26 in 2013 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 22-23, 2013**				**Trial-2 treated on June 25-26, 2013**			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 c	4	100 a	2
		Day	92 a	1	5 b	4	22 b	3	144 b	1
		Night	73 a	2	6 b	3	76 a	2	74 c	3
		Dawn	60 a	3	9 b	2	92 a	1	51 c	4
	TM Muster + Select	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	100 a	1	5 b	2	93 a	1	46 b	4
		Night	98 a	2	3 b	3	88ab	2	66 b	3
		Dawn	98 a	3	1 b	4	79 b	3	71 b	2
Wheat	Barricade	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Everest	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	OcTTain	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	N/A	N/A	100 a	1	0 b	4	100 a	1
		Day	N/A	N/A	13 b	4	83 a	2	21 b	3
		Night	N/A	N/A	29 b	2	83 a	3	23 b	2
		Dawn	N/A	N/A	29 b	3	85 a	1	20 b	4
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			100		67		33		33	
Night time application more effective than Dawn time			100		33		33		33	
Dawn time application more effective than Day and/or Night time applications			0		33		67		67	

Table 25. Performance comparison of the selected post-emergence herbicides on eradicating mustard when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 22-23, and 25-26 in 2013 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Herbicide	Application Timing	Trial-1 treated on June 22-23, 2013				Trial-2 treated on June 25-26, 2013			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	N/A	N/A	N/A	N/A	N/A	N/A
		Day	93 a	1	N/A	N/A	N/A	N/A	N/A	N/A
		Night	68 a	2	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	67 a	3	N/A	N/A	N/A	N/A	N/A	N/A
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	100 a	1
		Day	N/A	N/A	N/A	N/A	N/A	N/A	10 c	4
		Night	N/A	N/A	N/A	N/A	N/A	N/A	12bc	3
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	20 b	2
Wheat	Barricade	Control	N/A	N/A	100 a	1	0 c	4	100 a	1
		Day	N/A	N/A	3 a	4	98 a	1	6 b	4
		Night	N/A	N/A	7 a	3	97ab	2	7 b	3
		Dawn	N/A	N/A	7 a	2	93 b	3	14 b	2
	Everest	Control	N/A	N/A	100 a	1	0 b	4	100 a	1
		Day	N/A	N/A	17 a	4	76 a	1	44 a	4
		Night	N/A	N/A	39 a	3	74 a	2	51 a	2
		Dawn	N/A	N/A	53 a	2	72 a	3	49 a	3
	OcTTain	Control	N/A	N/A	100 a	1	0 b	4	100 a	1
		Day	N/A	N/A	48 a	2	81 a	1	33 b	4
		Night	N/A	N/A	23 a	4	76 a	3	46ab	2
		Dawn	N/A	N/A	40 a	3	79 a	2	41ab	3
	TM Axial + Infinity	Control	N/A	N/A	100 a	1	0 b	4	100 a	1
		Day	N/A	N/A	30 a	4	73 a	1	44 b	4
		Night	N/A	N/A	42 a	3	72 a	2	51 b	3
		Dawn	N/A	N/A	46 a	2	71 a	3	52ab	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			100		75		100		100	
Night time application more effective than Dawn time			100		100		75		60	
Dawn time application more effective than Day and/or Night time applications			0		25		0		0	

Table 26. The ANOVA results for the two trials listed in Table 24 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop for the performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2013 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Oats biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 c	3	133 a	1
		Liberty	71 b	2	54 b	2
		TM Muster + Select	92 a	1	36 b	3
	Application timing	Control	0 b	4	133 a	1
		Day	78 a	3	57 b	2
		Night	83 a	1	42 b	3
		Dawn	83 a	2	37 b	4
Wheat	Herbicide	Control	0 c	3	100 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	50 b	2	N/A	N/A
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	84 a	1	22 b	2
	Application timing	Control	0 c	4	100 a	1
		Day	84 a	1	17 b	4
		Night	76 b	3	26 b	2
		Dawn	78 b	2	24 b	3
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			50		50	
Night time application more effective than Dawn time			50		0	
Dawn time application more effective than Day and/or Night time applications			50		50	

Table 27. The ANOVA results for the two trials listed in Table 25 comparing the treatment means of the selected post-emergence herbicides on eradicating mustard when applied in-crop for the performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2013 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 b	2
		Liberty	76 a	1	202 a	1
		TM Muster + Select	N/A	N/A	69 b	3
	Application timing	Control	0 b	4	100 a	4
		Day	93 a	1	105 a	3
		Night	68 ab	2	105 a	2
		Dawn	67 ab	3	117 a	1
Wheat	Herbicide	Control	0 c	5	100 a	1
		Barricade	96 a	1	7 c	5
		Everest	74 b	3	42 bc	3
		OcTTain	79 ab	2	38 bc	4
		TM Axial + Infinity	72 b	4	44 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	82 a	1	28 b	4
		Night	80 a	2	33 b	3
		Dawn	79 a	3	38 b	2
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		50	
Night time application more effective than Dawn time			100		50	
Dawn time application more effective than Day and/or Night time applications			0		50	

Table 28. Performance comparison of the selected post-emergence herbicides on eradicating oats when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 18-19, and 25-26 in 2014 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 18-19, 2014**				**Trial-2 treated on June 25-26**			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	87 a	1	9 b	3	92 a	1	7 b	4
		Night	86 a	3	3 b	4	91 a	2	21 b	2
		Dawn	87 a	2	10 b	2	90 a	3	17 b	3
	TM Muster + Select	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	53 a	3	72ab	2	93 a	3	13 b	2
		Night	54 a	2	66ab	3	94 a	2	1 b	4
		Dawn	77 a	1	36 b	4	96 a	1	3 b	3
Wheat	Barricade	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Everest	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	93 a	1	2 b	3	91 a	1	13 b	3
		Night	90 a	3	1 b	4	86 a	2	11 b	4
		Dawn	91 a	2	4 b	2	75 b	3	17 b	2
	OcTTain	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	97 a	1	0 b	3	91 a	1	2 b	4
		Night	94ab	2	0 b	3	82 a	3	3 b	3
		Dawn	91 b	3	0 b	2	87 a	2	4 b	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			75		75		75		75	
Night time application more effective than Dawn time			25		75		50		75	
Dawn time application more effective than Day and/or Night time applications			25		25		25		25	

Table 29. Performance comparison of the selected post-emergence herbicides on eradicating mustard when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 18-19, and 25-26 in 2014 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 18-19, 2014**				**Trial-2 treated on June 25-26**			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	1	0 c	4	100 a	1
		Day	84 a	1	10 b	4	85 a	1	7 a	4
		Night	42 b	3	60ab	2	48 b	3	43 a	2
		Dawn	52 b	2	25 b	3	57ab	2	31 a	3
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wheat	Barricade	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	98 a	1	0 a	2	84 a	1	1 b	4
		Night	97 a	2	0 a	2	77 a	3	5 b	3
		Dawn	95 a	3	0 a	2	79 a	2	7 b	2
	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	96 a	1	1 a	3	77 a	2	18ab	2
		Night	94 a	2	1 a	2	80 a	1	13ab	3
		Dawn	92 a	3	1 a	4	72 a	3	9 b	4
	OcTTain	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	98 a	2	0 a	2	89 a	2	12 b	2
		Night	99 a	1	0 a	2	86 a	3	7 b	3
		Dawn	97 a	3	0 a	2	92 a	1	5 b	4
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	99 a	3	0 a	2	99 a	1	0 b	3
		Night	100 a	1	0 a	2	96 a	3	0 b	4
		Dawn	100 a	1	0 a	2	98 a	2	2 b	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			80		50		80		60	
Night time application more effective than Dawn time			60		0		20		40	
Dawn time application more effective than Day and/or Night time applications			20		50		20		40	

Table 30. The ANOVA results for the two trials listed in Table 28 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop for the performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2014 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Oats biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 c	3	100 a	1
		Liberty	89 a	1	11 c	3
		TM Muster + Select	78 b	2	32 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	81 a	3	25 b	2
		Night	81 a	2	23 b	3
		Dawn	87 a	1	16 b	4
Wheat	Herbicide	Control	0 b	3	100 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	88 a	2	8 b	2
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	91 a	1	2 b	3
	Application timing	Control	0 c	4	100 a	1
		Day	93 a	1	4 b	3
		Night	88 ab	2	4 b	4
		Dawn	86 b	3	6 b	2
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			50		50	
Night time application more effective than Dawn time			50		50	
Dawn time application more effective than Day and/or Night time applications			50		50	

Table 31. The ANOVA results for the two trials listed in Table 29 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop for the performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2014 at the SARDA project site in Falher, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 a	1
		Liberty	61 a	1	29 b	2
		TM Muster + Select	N/A	N/A	N/A	N/A
	Application timing	Control	0 c	4	100 a	1
		Day	85 a	1	8 b	4
		Night	45 b	3	52 b	2
		Dawn	54 b	2	28 b	3
Wheat	Herbicide	Control	11 b	5	100 a	1
		Barricade	88 a	3	2 b	4
		Everest	85 a	4	7 b	2
		OcTTain	94 a	2	4 b	3
		TM Axial + Infinity	98 a	1	0 b	5
	Application timing	Control	11 b	4	100 a	1
		Day	92 a	1	4 b	2
		Night	91 a	2	3 b	3
		Dawn	91 a	3	3 b	4
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		50	
Night time application more effective than Dawn time			50		0	
Dawn time application more effective than Day and/or Night time applications			0		50	

Table 32. Treatment means comparison of the selected post-emergence herbicides on eradicating oats when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 7-8, and 21-22 in 2012 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 7-8, 2012**				**Trial-2 treated on June 21-22, 2012**			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	95 a	1	10 b	3	80 a	3	10 b	2
		Night	93 a	2	3 b	4	88 a	2	4 b	3
		Dawn	87 a	3	16 b	2	98 a	1	1 b	4
	TM Muster + Select	Control	0 b	4	100 a	1	0 b	4	N/A	N/A
		Day	79 a	3	37 a	2	90 a	3	N/A	N/A
		Night	86 a	2	31 a	3	100 a	1	N/A	N/A
		Dawn	99 a	1	4 a	4	100 a	1	N/A	N/A
Wheat	Barricade	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	65 a	3	35 a	3	80 a	1	32ab	3
		Night	73 a	2	48 a	2	75 a	2	36ab	2
		Dawn	91 a	1	0 a	4	75 a	2	1 b	4
	OcTTain	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	82 a	1	1 b	4	100 a	1	0 b	2
		Night	81 a	2	2 b	3	100 a	1	0 b	3
		Dawn	59 a	3	32ab	2	100 a	1	0 b	3
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			50		50		33		0	
Night time application more effective than Dawn time			50		50		0		0	
Dawn time application more effective than Day and/or Night time applications			50		50		67		100	

Table 33. Treatment means comparison of the selected post-emergence herbicides on eradicating mustard when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 7-8, and 21-22 in 2012 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 7-8, 2012**				**Trial-2 treated on June 21-22, 2012**			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	3	0 c	4	100 a	1
		Day	84 a	1	30 a	4	91 a	1	14 b	4
		Night	53 b	2	116 a	1	25bc	3	65 a	3
		Dawn	45 b	3	114 a	2	35 b	2	83 a	2
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	100 a	2
		Day	N/A	N/A	N/A	N/A	N/A	N/A	78 a	4
		Night	N/A	N/A	N/A	N/A	N/A	N/A	93 a	3
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	110 a	1
Wheat	Barricade	Control	0 b	4	N/A	N/A	0 a	4	100 a	3
		Day	86 a	2	N/A	N/A	100 a	1	1891 a	1
		Night	84 a	3	N/A	N/A	100 a	1	122 a	2
		Dawn	100 a	1	N/A	N/A	67 a	3	53 a	4
	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	93 a	2	1 b	3	75 a	3	14 a	3
		Night	91 a	3	6ab	2	98 a	2	19 a	2
		Dawn	100 a	1	0 b	4	100 a	1	6 a	4
	OcTTain	Control	0 b	4	100 a	1	0 b	4	100 a	2
		Day	85 a	2	10 a	2	63 a	3	498 a	1
		Night	66 a	3	5 a	3	68 a	2	0 a	3
		Dawn	96 a	1	0 a	4	88 a	1	0 a	3
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	98 a	1	0 b	3	100 a	1	0 a	3
		Night	91 a	2	0 b	2	93 a	2	0 a	3
		Dawn	81 a	3	0 b	3	83 a	3	1 a	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			40		20		60		50	
Night time application more effective than Dawn time			40		0		40		50	
Dawn time application more effective than Day and/or Night time applications			60		80		40		50	

Table 34. The ANOVA results for the two trials listed in Table 32 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop showing the herbicides' performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2012 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Oats biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	3	100 a	1
		Liberty	90 a	2	8 b	3
		TM Muster + Select	92 a	1	25 b	2
	Application timing	Control	0 b	4	100 a	1
		Day	86 a	3	19 b	2
		Night	92 a	2	10 b	3
		Dawn	96 a	1	8 b	4
Wheat	Herbicide	Control	0 b	3	100 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	76 a	2	26 b	2
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	87 a	1	6 b	3
	Application timing	Control	0 b	4	100 a	1
		Day	82 a	2	17 b	3
		Night	82 a	1	23 b	2
		Dawn	81 a	3	9 b	4
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			50		0	
Night time application more effective than Dawn time			50		0	
Dawn time application more effective than Day and/or Night time applications			50		100	

Table 35. The ANOVA results for the two trials listed in Table 33 comparing the treatment means of the selected post-emergence herbicides on eradicating mustard when applied in-crop showing the herbicides' performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2012 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2012 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 a	2
		Liberty	55 a	1	70 a	3
		TM Muster + Select	N/A	N/A	126 a	1
	Application timing	Control	0 c	4	100 a	3
		Day	87 a	1	68 a	4
		Night	39 b	3	107 a	2
		Dawn	40 b	2	119 a	1
Wheat	Herbicide	Control	0 b	5	100 a	2
		Barricade	88 a	3	277 a	1
		Everest	93 a	1	7 a	4
		OcTTain	78 a	4	86 a	3
		TM Axial + Infinity	91 a	2	0 a	5
	Application timing	Control	0 b	4	52 a	2
		Day	86 a	2	258 a	1
		Night	86 a	3	19 a	3
		Dawn	90 a	1	8 a	4
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			50		50	
Night time application more effective than Dawn time			0		0	
Dawn time application more effective than Day and/or Night time applications			50		50	

Table 36. Treatment means comparison of the selected post-emergence herbicides on eradicating oats when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on July 2-3, and 14-15 in 2013 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Herbicide	Application Timing	Trial-1 treated on July 2-3, 2013				Trial-2 treated on July 14-15, 2013			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	89 a	1	14 b	3	86 a	3	0 b	4
		Night	89 a	1	9 b	4	89 a	1	6 b	2
		Dawn	70 a	3	59ab	2	88 a	2	5 b	3
	TM Muster + Select	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	68 b	3	22 b	2	83 a	2	0 b	3
		Night	75ab	2	9 b	3	83 a	3	0 b	3
		Dawn	84 a	1	6 b	4	85 a	1	7 b	2
Wheat	Barricade	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Everest	Control	0 b	N/A	100 a	1	0 b	N/A	100 a	1
		Day	70 a	N/A	24 a	2	70 a	N/A	44 a	3
		Night	70 a	N/A	20 a	3	70 a	N/A	78 a	2
		Dawn	70 a	N/A	18 a	4	70 a	N/A	33 a	4
	OcTTain	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	80 b	1	55 a	4	0 b	N/A	100 a	1
		Day	78 a	2	12 b	3	75 a	N/A	31 b	3
		Night	78 a	2	15 b	2	75 a	N/A	32 b	2
		Dawn	73 a	4	50 b	1	75 a	N/A	28 b	4
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			67		50		0		50	
Night time application more effective than Dawn time			67		50		50		25	
Dawn time application more effective than Day and/or Night time applications			33		50		50		50	

Table 37. Treatment means comparison of the selected post-emergence herbicides on eradicating mustard when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on July 2-3, and 14-15 in 2013 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on July 2-3, 2013**				**Trial-2 treated on July 14-15, 2013**			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	1	0 c	4	100 a	1
		Day	76 a	1	31 a	4	90 a	1	59 a	2
		Night	70 a	2	58 a	3	43 b	3	57 a	3
		Dawn	45 b	3	96 a	2	45 b	2	44 a	4
	TM Muster + Select	Control	N/A	N/A	100 a	2	N/A	N/A	100 a	2
		Day	N/A	N/A	107 a	1	N/A	N/A	91 a	4
		Night	N/A	N/A	96 a	3	N/A	N/A	101 a	1
		Dawn	N/A	N/A	96 a	4	N/A	N/A	98 a	3
Wheat	Barricade	Control	0 b	4	100 a	1	0 c	4	100 a	1
		Day	66 a	3	16 b	3	76 a	1	23ab	3
		Night	69 a	2	33ab	2	68 b	3	17 b	4
		Dawn	71 a	1	14 b	4	74ab	2	54ab	2
	Everest	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	70 a	2	16 b	4	66 a	1	21 a	4
		Night	73 a	1	18 b	3	65 a	2	36 a	2
		Dawn	70 a	2	36ab	2	59 a	3	35 a	3
	OcTTain	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	59 a	3	35ab	2	78 a	3	51 a	2
		Night	66 a	1	14 b	4	80 a	2	7 a	4
		Dawn	66 a	1	19 b	3	84 a	1	9 a	3
	TM Axial + Infinity	Control	0 b	4	100 a	1	0 b	4	100 a	1
		Day	83 a	1	9 b	4	88 a	1	1 b	4
		Night	80 a	2	11 b	3	80 a	2	5 b	3
		Dawn	78 a	3	13 b	2	80 a	3	12 b	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			67		50		80		67	
Night time application more effective than Dawn time			67		67		40		50	
Dawn time application more effective than Day and/or Night time applications			40		33		20		33	

Table 38. The ANOVA results for the two trials listed in Table 36 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop showing the herbicides' performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2013 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Oats biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	3	100 a	1
		Liberty	85 a	1	17 b	2
		TM Muster + Select	80 a	2	7 b	3
	Application timing	Control	0 b	4	100 a	1
		Day	82 a	3	10 b	3
		Night	84 a	1	6 b	4
		Dawn	82 a	2	19 b	2
Wheat	Herbicide	Control	0 c	3	78 a	1
		Barricade	N/A	N/A	N/A	N/A
		Everest	70 b	2	37 ab	2
		OcTTain	N/A	N/A	N/A	N/A
		TM Axial + Infinity	77 a	1	21 b	3
	Application timing	Control	0 b	4	78 a	1
		Day	74 a	1	27 b	3
		Night	73 a	2	36 b	2
		Dawn	73 a	3	24 b	4
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			50		50	
Night time application more effective than Dawn time			100		50	
Dawn time application more effective than Day and/or Night time applications			0		50	

Table 39. The ANOVA results for the two trials listed in Table 37 comparing the treatment means of the selected post-emergence herbicides on eradicating mustard when applied in-crop showing the herbicides' performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2013 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2013 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 a	1
		Liberty	62 a	1	58 b	3
		TM Muster + Select	N/A	N/A	98 a	2
	Application timing	Control	0 c	4	100 a	1
		Day	83 a	1	72 a	4
		Night	56 b	2	78 a	3
		Dawn	45 b	3	84 a	2
Wheat	Herbicide	Control	0 c	5	100 a	1
		Barricade	71 b	3	26 b	3
		Everest	67 b	4	27 b	2
		OcTTain	72 b	2	23 b	4
		TM Axial + Infinity	81 a	1	9 b	5
	Application timing	Control	0 b	4	100 a	1
		Day	73 a	1	22 b	3
		Night	73 a	3	18 b	4
		Dawn	73 a	2	24 b	2
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		100	
Night time application more effective than Dawn time			50		100	
Dawn time application more effective than Day and/or Night time applications			0		0	

Table 40. Treatment means comparison of the selected post-emergence herbicides on eradicating oats when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 24-25, and July 14-15 in 2014 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	**Herbicide**	**Application Timing**	**Trial-1 treated on June 24-25, 2014**				**Trial-2 treated on July 14-15, 2014**			
			Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	1	0 b	4	100 a	1
		Day	74 b	3	32 b	2	93 a	1	4 b	4
		Night	93 a	2	4 b	4	93 a	2	21 b	3
		Dawn	94 a	1	11 b	3	93 a	3	21 b	2
	TM Muster + Select	Control	0 c	4	100 a	1	0 b	N/A	100 a	1
		Day	89 a	1	11 b	2	76 a	N/A	4 b	3
		Night	76 b	3	4 b	4	76 a	N/A	3 b	4
		Dawn	79ab	2	11 b	3	76 a	N/A	6 b	2
Wheat	Barricade	Control	N/A	N/A	N/A	N/A	N/A	N/A	100 a	3
		Day	N/A	N/A	N/A	N/A	N/A	N/A	106 a	2
		Night	N/A	N/A	N/A	N/A	N/A	N/A	88 a	4
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	110 a	1
	Everest	Control	0 b	N/A	N/A	N/A	0 b	N/A	100 a	1
		Day	58 a	N/A	N/A	N/A	68 a	N/A	38 b	4
		Night	58 a	N/A	N/A	N/A	68 a	N/A	46 b	3
		Dawn	58 a	N/A	N/A	N/A	68 a	N/A	65 b	2
	OcTTain	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TM Axial + Infinity	Control	0 b	4	N/A	4	0 c	4	100 a	1
		Day	63 a	1	N/A	2	86 a	1	6 b	4
		Night	63 a	1	N/A	3	82 b	3	14 b	2
		Dawn	60 a	3	N/A	1	83 b	2	13 b	3
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			67		0		100		80	
Night time application more effective than Dawn time			33		100		0		80	
Dawn time application more effective than Day and/or Night time applications			33		0		0		20	

Table 41. Treatment means comparison of the selected post-emergence herbicides on eradicating mustard when applied in-crop with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in two separate trials sprayed on June 24-25, and July 14-15 in 2014 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	Herbicide	Application Timing	Trial-1 treated on June 24-25, 2014				Trial-2 treated on July 14-15, 2014			
			Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)		Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
			Trt. means	Rank	Trt. means	Rank	Trt. means	Rank	Trt. means	Rank
Canola (LL)	Liberty	Control	0 c	4	100 a	3	0 b	4	100 a	1
		Day	95 a	1	31 a	4	95 a	1	2 b	4
		Night	40 b	3	133 a	2	91 a	3	5 b	3
		Dawn	43 b	2	173 a	1	92 a	2	8 b	2
	TM Muster + Select	Control	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Day	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Night	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Dawn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wheat	Barricade	Control	0 b	N/A	N/A	N/A	0 b	4	100 a	1
		Day	55 a	N/A	N/A	N/A	80 a	2	6 b	4
		Night	55 a	N/A	N/A	N/A	83 a	1	10 b	3
		Dawn	55 a	N/A	N/A	N/A	78 a	3	23 b	2
	Everest	Control	0 c	4	100 b	3	0 b	4	100 a	2
		Day	53 a	1	88 b	4	78 a	1	4 a	4
		Night	45ab	2	308ab	2	76 a	2	20 a	3
		Dawn	40 b	3	606 a	1	75 a	3	147 a	1
	OcTTain	Control	0 b	4	N/A	N/A	0 b	4	100 a	1
		Day	56 a	1	N/A	N/A	87 a	3	3 b	4
		Night	51 a	3	N/A	N/A	88 a	1	8 b	3
		Dawn	53 a	2	N/A	N/A	88 a	2	14 b	2
	TM Axial + Infinity	Control	0 b	4	N/A	N/A	0 b	4	100 a	1
		Day	83 a	1	N/A	N/A	94 a	1	5 b	4
		Night	81 a	2	N/A	N/A	94 a	1	7 b	3
		Dawn	79 a	3	N/A	N/A	93 a	3	10 b	2
Summary (% of the total occurrences)										
Day time application more effective than Dawn time			100		100		80		100	
Night time application more effective than Dawn time			50		0		60		100	
Dawn time application more effective than Day and/or Night time applications			0		0		20		0	

Table 42. The ANOVA results for the two trials listed in Table 40 comparing the treatment means of the selected post-emergence herbicides on eradicating oats when applied in-crop showing the herbicides' performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2014 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Oats biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 c	3	100 a	1
		Liberty	90 a	1	16 b	2
		TM Muster + Select	79 b	2	6 b	3
	Application timing	Control	0 b	4	100 a	1
		Day	83 a	3	13 b	2
		Night	84 a	2	8 b	4
		Dawn	86 a	1	12 b	3
Wheat	Herbicide	Control	0 c	3	100 ab	4
		Barricade	N/A	N/A	137 a	1
		Everest	63 b	2	110 ab	3
		OcTTain	N/A	N/A	133 a	2
		TM Axial + Infinity	72 a	1	75 b	5
	Application timing	Control	0 b	4	100 a	4
		Day	68 a	1	108 a	3
		Night	67 a	2	115 a	2
		Dawn	67 a	3	119 a	1
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			50		50	
Night time application more effective than Dawn time			50		50	
Dawn time application more effective than Day and/or Night time applications			50		50	

Table 43. The ANOVA results for the two trials listed in Table 41 comparing the treatment means of the selected post-emergence herbicides on eradicating mustard when applied in-crop showing the herbicides' performance with respect to the three distinct application timings, Day (12-2pm), Night (12-1am) and Dawn (4-5am), in 2014 at the LARA project site in Bonnyville, Alberta. Treatment means with the same letter are not significantly different at p<0.1.

2014 Crop ↓	Treatment type	Treatment	Efficacy rating (Scale: 0 – 100)		Mustard biomass ratio (% of Control)	
			Treatment means	Rank	Treatment means	Rank
Canola (LL)	Herbicide	Control	0 b	2	100 a	2
		Liberty	76 a	1	59 a	3
		TM Muster + Select	N/A	N/A	141 a	1
	Application timing	Control	0 c	4	100 a	3
		Day	95 a	1	76 a	4
		Night	65 b	3	101 a	2
		Dawn	67 b	2	122 a	1
Wheat	Herbicide	Control	0 d	5	N/A	N/A
		Barricade	68 bc	3	N/A	N/A
		Everest	61 c	4	N/A	N/A
		OcTTain	70 b	2	N/A	N/A
		TM Axial + Infinity	87 a	1	N/A	N/A
	Application timing	Control	0 b	4	N/A	N/A
		Day	73 a	1	N/A	N/A
		Night	72 a	2	N/A	N/A
		Dawn	70 a	3	N/A	N/A
Summary (% of the total occurrences)						
Day time application more effective than Dawn time			100		100	
Night time application more effective than Dawn time			50		0	
Dawn time application more effective than Day and/or Night time applications			0		0	

Table 44. Treatment means comparison averaged over all herbicides and crops for mustard at the FSA site in Lethbridge.

Year	Trial	Site year	Application Timing	Efficacy rating (Scale: 0 – 100)		Weed (Mustard) biomass ratio (% of Control)	
				Treatment means	Rank	Treatment means	Rank
2012	Trial site 2	1	Control	0	4	100	1
			Day	90	**1**	4	**4**
			Night	71	2	5	2
			Dawn	71	2	4	3
	Trial site 3	2	Control	0	4	100	1
			Day	98	**1**	124	3
			Night	97	2	132	2
			Dawn	97	2	112	4
2013	Trial site 1	3	Control	0	4	100	1
			Day	81	**1**	0	**4**
			Night	78	2	2	2
			Dawn	74	3	2	3
2014	Trial site 2	4	Control	0	4	100	1
			Day	71	**1**	15	**4**
			Night	60	2	24	3
			Dawn	49	3	29	2
Summary (% of the total occurrences)							
Day time application more effective than Night and/or Dawn time				100		75	

Table 45. Treatment means comparison averaged over all herbicides and crops for oats at the FSA site in Lethbridge.

Year	Trial	Site year	Application Timing	Efficacy rating (Scale: 0 – 100)		Weed (Oats) biomass ratio (% of Control)	
				Treatment means	Rank	Treatment means	Rank
2012	Trial site 2	1	Control	0	4	100	1
			Day	90	**1**	9	**4**
			Night	84	2	11	3
			Dawn	82	3	10	2
	Trial site 3	2	Control	0	4	100	1
			Day	77	3	5	**4**
			Night	90	1	10	3
			Dawn	84	2	11	2
2013	Trial site 1	3	Control	0	4	100	1
			Day	62	3	32	2
			Night	70	1	25	4
			Dawn	63	2	30	3
2014	Trial site 2	4	Control	0	4	100	1
			Day	81	**1**	18	**4**
			Night	75	2	21	3
			Dawn	71	3	24	2
Summary (% of the total occurrences)							
Day time application more effective than Night and/or Dawn time				50		75	

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Appendices

Appendix A: Original full proposal, Project 2012F083R, “Name Night Spraying: Pesticide Efficacy with Night Time Applications”

Appendix B: Night Spraying Presentation – Ken Coles

Appendix C: Popular Press Articles

Appendix A

Original full proposal, Project 2012F083R, "Name Night Spraying: Pesticide Efficacy with Night Time Applications"

Proposal Number	2012F083R
Name	Night Spraying: Pesticide Efficacy with Night Time Applications
Abstract	Producers rely heavily on pesticides, especially under zero-tillage systems. Growers try to farm more acres using the same equipment, and sometimes stretch the boundaries of recommended application conditions. Timing is critical for optimal herbicide performance. Night spraying may provide a feasible alternative to poor daytime conditions and could potentially improve efficacy due to greater absorption. Night spraying might provide farmers with the option to cover the same acres in a shorter time frame or to cover more acres with the same equipment. This project will evaluate day (12-2pm), night (12pm-1am) and early morning (4-5am) spray timings for preseed burn down and in crop herbicide applications. The preseed burn down trials will be near Lethbridge, AB and will evaluate 4 herbicides at label and half rates. Two trials will be conducted with different spray dates to ensure differing spray conditions. The in crop trials will be in Lethbridge, Bonnyville and Falher, and will evaluate approximately 12 herbicides for efficacy (weed control) and crop tolerance (phytotoxicity) in wheat, peas, Liberty Link (LL) -canola and Roundup Ready (RR)-canola. If night spraying proves to be a valuable option to farmers, it has the potential to increase profits for farmers and decrease irresponsible application of pesticides.
Keywords	night spraying, wind, drift, herbicides, pesticides, application timing, efficacy, phytotoxicity, pesticide safety, precision agriculture, optimum application weather, zero-tillage, plant physiology, water volumes, herbicide absorption, inversion
Team Leader Name:	Ken Coles
Team Leader Organization:	Southern Applied Research Association (Farming Smarter in 2012)
Project Duration (Yrs)	3
Project Start Date	04/01/2012
Project End Date	03/31/2015
Stand-Alone Project	Yes
Background	Producers rely heavily on pesticides, especially under zero-tillage systems. Growers try to farm more acres using the same equipment, and sometimes stretch the boundaries of recommended application conditions. Timing is critical for optimal herbicide performance (Ramsey et al., 2005). Night spraying may provide a feasible alternative to poor daytime conditions and could potentially improve efficacy due to greater absorption. Growing seasons are short and most crops are seeded and sprayed in a very short time frame. Weather conditions including temperature and wind speed can further limit ability to apply pesticides at the correct time. Applying pesticides in hot and windy conditions with low humidity causes spray droplets to evaporate quickly on the leaf surface decreasing absorption time and potentially affecting efficacy (Ramsey et al., 2005). Volatilization and photodegradation is also at its highest under these conditions (McInnes et al., 2000). At night, evaporation potential is lower because of cooler temperatures, less wind and higher humidity. Dew on the leaf cuticle may increase absorption of the pesticides through better cuticle hydration

(Fausey & Renner, 2001; Ramsey et al., 2005). Plant metabolism continues at night and it is often the time when plants are growing most actively.

Scientific research is limited in this area. Ramesy et al. (2005) noted that among environmental factors, temperature and relative humidity have the biggest effect on herbicide uptake; however, broad conclusions about the exact mechanisms for herbicide/species/humidity/temperature interactions are difficult because of the scope required. While a study showed that paraquat was more effective at controlling one weed species at 8pm than 2pm, another study showed it was more effective at controlling different weed species at 9am and 3pm than 9pm or 3am (Fausey & Renner, 2001).
The main hazard is the potential for a temperature inversion. Inversions are most likely to happen at night when a layer of cooler air is trapped near the earth's surface. Under these conditions it is possible for fine mists (such as spray drift), pollutants and other particles to be suspended in a layer above the ground and later deposited in a non-intended location. Inversions may be less of a concern in windy regions and in the early spring compared to later summer and fall.

Demonstration plots were established at the Farming Smarter Field School in 2011. Liberty, Glyphosate, Solo and Gramoxone herbicides were sprayed on pea, barley and camelina (as weeds) during the day and at night. Night spraying did not reduce efficacy and some plots showed slightly better visual control. Dr. Bob Blackshaw (weed specialist with AAFC) and Don Boles (farmer in Three Hills, AB) lead the module and discussed how the development of new technology like GPS and autosteer has aided implementation. Boles noted he has been spraying at night for a number of years with little to no adverse effects on his crops and at times saw improved efficacy. He also noted that in some situations night spraying has allowed him to lower his water volumes.

Objectives and Deliverables

Objectives

This project will provide detailed scientific information on the effects of night spraying using herbicides currently registered in Alberta on common weeds and crops for the area. Objectives are to:
(a) Determine if applying herbicides at night is a practical option for producers.
(b) Generate unbiased data on the efficacy and tolerance of night applications of herbicides.
(c) Uncover possible issues/complications associated with night spraying

Deliverables

This project will be designed and delivered with producers, industry and other stakeholders in mind to:
(a) Evaluate phytotoxicity (crop tolerance) and efficacy (weed control) of herbicides with differing modes of action applied at various times of day (12-2pm, 12pm-1am and 4am-5am).
(b) Utilize long-term weather records to determine average and annual variability in daytime and nighttime hours suitable for spraying each week at different locations in Alberta.
(c) Calculate the increase in acres that could be sprayed in "optimum" spray conditions per sprayer.
(d) Distribute information to growers via farming smarter magazine, newsletters, crop walks, tours, workshops/conferences, media, websites (www.farmingsmarter.com, ropintheweb, www.areca.ab.ca) social media etc. which will give them the tools necessary to make an informed choice.

This trial is designed to determine if there is real potential for night spraying. Should positive results be found, a more comprehensive research program may be devised that includes multiple herbicide rates, reduced water volumes and field scale testing.

Project Design and Methodology

Small plot research trials (approx. 2 X 6m plots) will be established in three locations: Lethbridge, (SARA), Bonnyville (LARA) and Falher, Alberta (SARDA). All trials will be designed as randomized split-plots with four replicates. Two preseed burn down (PSBD) trials and eight in crop trials (432 plots) will be conduct at the SARA site per year. Four in crop trials (216 plots) will be conducted with SARDA and LARA. Trial locations are summarized below:

SARA
2 Preseed burn down trials, (96 plots)

8 In Crop trials: 2 LL-canola (72 plots), 2 RR-canola (72 plots), 2 pea (48 plots), 2 wheat (144 plots)

LARA
4 In Crop trials: 2 LL-canola (72 plots), 2 wheat (144 plots)

SARDA
4 In Crop trials: 2 LL-canola (72 plots), 2 wheat (144 plots)

Plots will be sprayed using hand held sprayers equipped with two meter booms and C02 propellant. Low drift nozzles will be used at all locations to minimize drift. Herbicide labels will be consulted for rates and application timing and other considerations. Nozzles will be spaced 50cm apart and held 50cm above the canopy. Plot dimensions, number or rows, row spacing etc. may be adjusted as necessary to accommodate different seeding and spraying equipment.

Preseed Burndown (PSBD) trials

The PSBD trial will be sprayed in Lethbridge, AB (SARA) only. It will be a randomized split-plot design with 4 replicates. The main plots will be herbicides (label rate and half rate) and the subplots are spray application times: day (12-2pm), night (12pm-1am), early morning (4-5am). In order to ensure an appropriate range of spray conditions, two trials will be conducted with early and normal spray application dates (April, May). The herbicides treatments will include:

Trade Name, Chemical Name, Group, Activity
(1) Prepass TM, Florasulam, group 4/9, systemic
(2) Rounndup, Glyphosate, group 9, systemic
(3) Heat, Saflufenacil, group 14, contact
(4) Aim, Carfentrazone, group 14, contact

Site selection will include known weedy areas including both broad leaf and grassy weeds. Should these sites not be readily available, weeds will be seeded to ensure an effective study.

Environmental data will be recorded before and after spray applications including air temperature, soil temperature, wind speed and direction, relative humidity, cloud cover, and precipitation. Dew period and evapotranspiration will also be measured. Weed control ratings will be conducted at 7 DAS (days after spraying), 14 DAS and 21+ DAS. Weed biomass will be taken as fresh weights from natural weed infestations using four 1/4m2 quadrats at 7 DAS and 14 DAS. The top 5 most prevalent weeds will be noted for each plot. Other data collected will include growth stage, weeds present and pictures.

In Crop Trials

In crop trial locations will include Lethbridge, AB (SARA), Falher, AB (SARDA) and Bonnyville, AB (LARA). These trials will be randomized split plots with herbicide as the main plot and spray timing as the sub plot. The three spray timings will be day (12-2pm), night (12pm-1am) and early morning (4-5am). Four trials will be seeded to barley/wheat, peas, LL-Canola and RR-Canola as early as possible and four additional trials will be seeded at a later date to ensure variations in spray conditions. Seeding rates will be 300 seeds/m2 for barley/wheat, 100 seeds/m2 for peas and 5lbs/ha for canola. Tame oats (150seeds/m^2) and wild mustard (50seeds/m^2) will be seeded across the plots in all trials to simulate weeds.

Herbicides were selected based on mode of action, activity, selectivity and use in Alberta. The tentative herbicides to be tested in each trial are as follows (some herbicides are used in multiple crops):

Canola (LL)
Liberty (group 10, contact)
Select (group 1, systemic)

Lontrel (group 4, systemic)

Canola (RR)
Glyphosate (group 9, systemic)
Select (group 1, systemic)
Lontrel (group 4, systemic)

Peas
Odyssey (group 2, partially systemic*)
Select (group 1, systemic)

Wheat
Attain (group 4, partially systemic)
Axial (group 1, systemic)
Everest (group 2, partially systemic)
Infinity (group 6/27, partially systemic)
Refine SG (group 2, partially systemic)
Lontrel (group 4, systemic)
*partially systemic refers to herbicides with limited mobility within the plant, where the herbicide generally is not translocated into the root system

Environmental data will be recorded before and after spray applications including air temperature, soil temperature, wind speed and direction, relative humidity, cloud cover, and precipitation. Dew period and evapotranspiration will also be measured. Crop tolerance and weed control ratings will be conducted at 7-14 DAS, 21-27 DAS and 35+ DAS.
weed biomass will be taken as fresh weights using four 1/4m2 quadrats at 7-14 DAS and 14-21 DAS. Crop biomass will be taken at physiological maturity. Other data collected will include growth stage, weeds present, pictures and yield when possible.

Data will be analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC).

Time Opportunities with Night Spraying

SARA will utilize long-term weather records from appropriate criteria (wind speed, day length, trafficability, etc.) to determine average and annual variability in daytime and night time hours suitable for spraying each week at different locations in Alberta. This data will be collected from the AgroClimatic Information Service (ACIS). For May and June the previous 5 years of data will be assessed for "optimum" spraying conditions which will be defined as periods with wind speeds between 2 Km/h and 15 Km/h, temperatures between 2 and 20 degrees C and no precipitation. Wind speeds below 2Km/h will not be included as "optimum" because of the risk of inversion. Methods to estimate the risk of inversion will be explored.

Annual work plan

Year 1
Spring 2012
(1) Start-up meeting: review contracts, review equipment, chemicals needed, deliver randomizations, review protocols, review budget
(2) Pre-seeding meeting: ensure signed contracts are delivered, funding is in place, ship chemicals/equipment as necessary
(3) Begin plot work: groups will begin staking/mapping plots, setup/calibrate instruments
(4) Plot work begins on PSBD trials (SARA, April and May)
a) spray trials
b) data collection 7 DAS, 14 DAS
c) weed biomass

	(5) Plot work begins on in crop trials (April and May) a) seed early date and seed normal dates b) spray early date and normal date at 3-4 leaf of the weeds c) data collection 7-14 DAS, 21-27 DAS, 35+ DAS d) weed biomass e) crop biomass f) yield (6) Trial update: ensure seeding and spraying went as per protocol, note any revisions to procedure (7) Site visit: SARA to view trials in LARA and SARDA locations before the final evaluation date, compare results with Lethbridge site Fall 2012 (1) obtain all data including pictures and video (2) Begin data analysis: SARA will review preliminary results, process data for statistical analysis, review findings (3) Review long term weather records (4) Create a progress report (5) Preliminary extension work: a) Post pictures, video and relevant content to the web b) Present progress at conferences, workshops and events c) Share progress report on website and through social media d) Write articles about night spraying for the Magazine Year 2 and Year 3 Research in year 2 and year 3 will follow the same as year 1 Year 3 Year three will focus more heavily on extension work: a) Creating a full report with 3 years data and statistical analysis b) Sharing final results on the web c) Presenting overall findings at conferences
Contributions to Alberta's Agriculture and Agri-Food Knowledge	Until recently, spraying pesticides at night was simply not an option. However, GPS guidance, automatic steering, and live video feeds to the cab of tractor has made this a real option. While there is scientific data on certain weed/herbicide spray timings, there is little data about the general efficacy (weed control) and crop tolerance (phytotoxicity) of herbicides sprayed at night. This project will: (a) provide efficacy and tolerance data for common herbicides sprayed on common crops in Alberta (b) provide background research and knowledge on plant physiology, herbicide mode-of-action, sprayer technology to farmers (c) add further knowledge to best management practices in terms of determining application rates, selecting a herbicide and reducing spray drift as they pertain to night spraying. There is limited research in the area of night spraying. What research has been done tends to focus on a single criterion such as a specific herbicide, weed or environmental condition. Current knowledge about how herbicides are affected by environmental conditions note that temperature and humidity are the most important criteria for increasing cuticle hydration and that any means that would extending the drying time (i.e. conditions with night spraying) should increase herbicide absorption. This project is unique as a new opportunity caused by the widespread adoption of precision agriculture.
Benefits to Alberta's Agriculture and Agri-Food Industry	Waiting for ideal conditions before spraying pesticides is a key problem facing producers and can often cause significant economic and environmental consequences. Environmental conditions such as wind, temperature and humidity as well as the characteristics of plant physiology and droplet drying improve at night. Providing data on night spraying could greatly improve the options producers have when faced with difficult choices about which pesticides to spray, how to spray them and when to spray (e.g. a producer

	may select a more effective herbicide if the danger of spray drift to adjacent crops is lower). Perception towards pesticide use is a contentious issue. Forward thinking research that addresses public concerns and has the possibility to reduce the environmental impact of herbicides (through improved efficacy, lower application rates, lower water volumes, improved herbicide options, lowered drift, less residual herbicide) will be seen in a good light. If efficacy is found to be greater with night applications, it may also help reduce pesticide risk, rates and perhaps water volumes saving producers money and time. There are over 9,621,606 ha of land farmed for crops in Alberta of which 6,623,945 ha are maintained with commercial herbicides (Stats Canada 2006). At a cost of \$10 - \$20/ac (AAFC, 1997) depending on rates, farmers in Alberta collectively spend between \$72-138 each year on herbicides. Our funding request for \$60,000/year is less than 0.1% of this total yearly value and represents a strong investment for continued research on optimizing herbicide use in Alberta.
Knowledge Transfer Plan	Should this concept be proven a viable option it is likely that many producers and custom applicators may adopt this practice. It is likely that very large farms would be the first to adopt. This project also has a possibility to influence many parts of the agricultural industry. For example, chemical manufacturers may sell different herbicides if the possibility for drift is reduced, or manufactures may adjust rates, water volumes and application timings on labels for night application. The Government of Alberta Crop Protection guide may also include a section with guidelines for night spraying. As SARA, LARA and SARDA continue to gain trust in the industry as providers of unbiased and innovative information, we have the ability to connect with producers and industry. Modern communication tools provide us with a great opportunity to expand our influence with which we hope to raise the profile of issues while promoting sustainable agricultural practices. Not only can we connect with those in the agriculture industry but with interested individuals from the public. We have an opportunity to promote the adoption of improved farming practices by sharing information collaboratively and to communicate the many good stories with the public. SARA is on the edge of launching the new www.farmingsmarter.com website, with the goal of showcasing key information in an easily understandable and accessible format. We are currently taking advantage of social media such as YouTube, Facebook and Twitter. These media devices when coupled with wireless technology and smart phones have the ability to deliver timely information to a widespread audience. This use of technology also provides an opportunity to connect with younger individuals who are currently the main users of this technology. All three groups regularly present research to farmers though workshops, crop walks, field schools and conferences. Each year, hundreds of people attend to learn valuable information for their farming operation. These events offer a wide range of hands on opportunities, captivating presentations, live demonstrations and dialogue for moving agriculture forward
Project Team Qualifications	The research team will be made up of SARA (Southern Applied Research Association), SARDA (Smoky Applied Research and Demonstration Association) and LARA (Lakeland Agricultural Research Association), applied research organizations within the ARECA (Agricultural Research and Extension Council of Alberta) group. Together the three collaborators have joint operating budgets of over \$2,000,000. These groups of research professionals have a proven track record of managing large agricultural research projects and sharing important data with producers in practical way. The project will be led by Ken Coles , B.Sc, M.Sc, P.Ag (SARA) who has 15+ years of experience in agricultural research. SARA currently has 5 other staff members of various education including Diplomas in Agricultural Technologies and GIS and degrees in Biochemistry, Environmental Science and Management. SARA has successfully coordinated many previous projects involving chemical trials (including contracts with DuPont, Becker Underwood and Agrotain) as well as the night spraying demo at

	the 2011 Diagnostic Field School. SARA will provide randomizations, written protocols and will be responsible for data analysis, reports and extension. Collaborators will be supplied with seed and chemical if needed, but will be responsible for supplying/maintaining equipment and for data collection. Communication will take place by telephone, email and GoToMeeting. Once data collection is completed all the information will be sent to SARA for organization, analysis and extension. Keith Kornelsen, B.Sc., P.Ag. will manage the LARA trial in Bonnyville, AB. LARA is a producer run, nonprofit, agricultural research and extension association with its headquarters in Fort Kent, AB. Keith is Vice Chairman of a provincial cropping team with ARECA and contributing editor of "Grow With Us" a bi-monthly LARA Newsletter (circulation 2200) and of LARA's annual report (circulation 300). JP Pettyjohn will manage the SARDA trial in Falher, AB. SARDA is a producer run, nonprofit, agricultural research and extension association with its headquarters in Falher, AB. JP is actively involved in ARECA teams and contributes to SARDA's bimonthly newsletter the "Back Forty" which is distributed to 3500 producers in the Peace region. SARA, LARA and SARDA have a well-established network of producers and industry members to communicate results with (See attached representation of SARA's partners, sponsors and funders). We are invested in social media as extension tools (Webpage, Facebook, Twitter etc). SARA, LARA and SARDA will distribute information to growers via farming smarter magazine, newsletters, crop walks, tours, workshops/conferences, websites (www.farmingsmarter.com, www.areca.ab.ca, Ropin' The Web), social media (Facebook, Twitter) etc. SARA has already shared and identified potential benefits/drawbacks and interest for night spraying from DFS module.
Ability to Complete	Resources One of the most important strengths of SARA, LARA and SARDA is their capacity to work with a diverse network of growers, producers, industry members and research professionals. SARA has countless partners that provide funding to projects, sponsor events and work within our mandate to provide extension to producers in the region. SARA: Facilities The Farming Smarter Research and Demonstration Site is on 50+ acres of irrigated research land under 4 year rotation. On site are a heated shop (for tools, equipment storage, work area for maintenance and repair), chemical storage shed and quonset for events and additional workspace. The Farming Smarter office is located a few minutes from the farm in the Government of Alberta building, connected to the Lethbridge Research Center (Agriculture and Agri-Food Canada). Equipment - 2m handsprayer (two, CO2) - 4m bicycle push sprayer (CO2) - 20m truck mounted sprayer with Omnistar XP GPS and EZ Steer - Full safety equipment (respirators, goggles, gloves, spray suits, boots etc) - Electronic pipettors accurate to 0.005mL - Analytical balance to 1000th of a decimal place - John Deere 5325 tractor with Omnistar XP GPS and EZ Steer - Custom plot air seeder with cone, 8 rows, Barton Disc/Hoe openers - HEGE plot combine (1989) LARA: Facilities LARA's main farm in Fort Kent, AB consists of 50 acres of research land with a shop, large storage shed,

	and an office house. LARA also has an office in the town of St. Paul at the St. Paul Municipal Seed Cleaning Plant. Equipment - Fabro minimum till seeder, dual shoot openers, 5 rows, 9" spacing - John Deere 3320 (2011) tractor with StarFire system - hand held sprayer and bicycle sprayer - rainfall sensors and HOBO soil/air temperature sensors - seed counter, seed moisture meter, test weight tools, seed cleaners, and scales for harvest data. - Wintersteiger Elite Combine (1991) SARDA: Facilities SARDA shares office space in the municipal building in Falher and has a heated shop/storage area in an adjacent lot. SARDA does not have a dedicated farm site, but prefers to work with a variety of farmers and selects land based on specific trial test parameters. SARDA will guarantee land selected will not have flooded in the past five years and will be flat. Equipment - 2007 JD Tractor 5470 equipped with a 2010 RTK guidance system - 2011 Wintersteiger Delta Plot Combine - 2000 ConservaPak Plot Seeder (CP1212A) - 2008 Fabro Plot Seeder with dual cone system and atom jet openers - Fabricated truck mounted high clearance sprayer with Raven controller - 3pt hitch sprayer - 2 m hand held spray booms (two) - 3 m hand held spray boom (one) - Gooseneck high-boy trailer
Literature Cited	Fausey, J.C., and Karen A. Renner. Environmental effects on CGA-248757 and flumiclorac efficacy/soybean tolerance. Weed Science, 49: 668-64, 2001 McInnes, D., Harker, K. Neil, Blackshaw, Robert E., and William H. Vanden Born. The influence of ultraviolet light on the phytotoxicity of sethoxydim tank mixtures with various adjuvants. Adjuvants for Agrichemicals, Chap. 17: 205-213, 2000 Ramsey, R.J.L., Stephenson G.R., and J.C. Hall. A review of the effects of humidity, humectants, and surfactantscomposition on the absorption and efficacy of highly water-woluble herbicides. Pesticide biochemistry & Physiology, 82: 162-175, 2005 Statstics Canada, 2006. statcan.gc.ca Agriculture and Agri-Food Canada. Estimated 1997 Herbicide Application Costs. 2007
Budget Commentary	We anticipate no withholding of government funds and, thus with a certain level of assuredness, expect funds to be in place. Each of the partnering groups (SARA, SARDA, LARA), expects to use government funds to cover all costs pertaining to overhead, CDL and supplies. Agricultural Opportunity Fund (AOF) is applied for on a three year basis and is being reviewed for funding for the upcoming 2012-2015 period. The level of funding may be adjusted slightly but historically there has rarely been a greater than 15% change in funding levels. Municipal funding is slightly more secure, as it is considered a line budget item. All government funds are used to support projects in the municipal mandate areas. We will be approaching our producer groups to help support this project. Our working relationship with these groups is strong and we anticipate that since the LOI was accepted by them that we can count on their support. We will contact them collectively so that they can determine the amount each can contribute

such that we can cover the needed $15,000 over three years.

Profits from industry trial work, each group conducts for various companies, such as DuPont, Bayer, or Monsanto, will be used as industry in-kind portions. For example, in 2011 SARDA collected approximately $20,000 in surplus attributed to industry dollars. All Associations have a yearly audit and this profit can be determined.

The cost of doing these trials is based on $425 per treatment, a fair value factoring in the early morning and late night spray times. Given that there are tentatively around 200 treatments our costs for doing the trial over three years will be $260,000. Labor is the single largest cost in performing trials. One needs to consider that labor costs for planning, funding applications, data analysis, reporting and extension are as much as, and in many cases more than, the actual trial work. Also, we include in our costs of production, capital replacement, and depreciation on equipment, insurance and accounting

AARD will be utilized in assessing trial protocols and in giving general advice in determining how to assess the data most effectively. AARD staff will also be used to present related information to producer groups in conjunction with our information to give well-rounded information to all producers. AARD will also be contacted for related articles to be used in promoting our research.

Anticipated Budget By Year

Year 1

Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Total/Year
Funding Consortium	Cash	$60,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$60,000.00
Gov't	Cash	$0.00	$500.00	$0.00	$1,500.00	$3,000.00	$10,000.00	$15,000.00
Gov't	In-Kind	$1,667.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,667.00
Industry	Cash	$3,050.00	$0.00	$0.00	$100.00	$350.00	$1,500.00	$5,000.00
Industry	In-Kind	$0.00	$0.00	$0.00	$0.00	$0.00	$5,000.00	$5,000.00
	Total:	$64,717.00	$500.00	$0.00	$1,600.00	$3,350.00	$16,500.00	$86,667.00
*Communication, Dissemination, and Linkage								

Year 2

Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Total/Year
Funding Consortium	Cash	$60,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$60,000.00
Gov't	Cash	$0.00	$500.00	$0.00	$1,500.00	$3,000.00	$10,000.00	$15,000.00
Gov't	In-Kind	$1,667.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,667.00
Industry	Cash	$3,050.00	$0.00	$0.00	$100.00	$350.00	$1,500.00	$5,000.00
Industry	In-Kind	$0.00	$0.00	$0.00	$0.00	$0.00	$5,000.00	$5,000.00
	Total:	$64,717.00	$500.00	$0.00	$1,600.00	$3,350.00	$16,500.00	$86,667.00
*Communication, Dissemination, and Linkage								

Year 3

Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Total/Year
Funding Consortium	Cash	$60,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$60,000.00
Gov't	Cash	$0.00	$500.00	$0.00	$1,500.00	$3,000.00	$10,000.00	$15,000.00
Gov't	In-Kind	$1,667.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,667.00
Industry	Cash	$3,050.00	$0.00	$0.00	$100.00	$350.00	$1,500.00	$5,000.00
Industry	In-Kind	$0.00	$0.00	$0.00	$0.00	$0.00	$5,000.00	$5,000.00
	Total:	$64,717.00	$500.00	$0.00	$1,600.00	$3,350.00	$16,500.00	$86,667.00
*Communication, Dissemination, and Linkage								

Budget Grand Total

Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Grand Total
$194,151.00	$1,500.00	$0.00	$4,800.00	$10,050.00	$49,500.00	$260,001.00

*Communication, Dissemination, and Linkage

LOI Funding Request

Funding Consortium	Gov't Cash	Gov't In-kind	Industry Cash	Industry In-kind	Total Project Cost
$180,000.00	$45,000.00	$5,000.00	$15,000.00	$15,000.00	$260,000.00

Total Amount Requested from Members of the FC

Year	Amt Requested From FC
Year 1	$60,000.00
Year 2	$60,000.00
Year 3	$60,000.00
Year 4	$0.00
Year 5	$0.00
Total Amount Requested From FC:	$180,000.00

Funding Contribution and Sources

Source	Amount	Percentage of Total
Funding Consortium Cash	$180,000.00	69.23%
Gov't Cash	$45,000.00	17.31%
Gov't In-Kind	$5,001.00	1.92%
Industry Cash	$15,000.00	5.77%
Industry In-Kind	$15,000.00	5.77%
Total Project Cost:	$260,001.00	100%

Government Sources

Name	Amount Cash	Amount In-Kind	Confirmed
Municipalities (various)	$13,500.00	$0.00	Yes
Agricultural Opportunity Fund	$31,500.00	$0.00	Yes
Alberta Agriculture and Rural Development	$0.00	$5,000.00	Yes

Industry Sources

Name	Amount Cash	Amount In-Kind	Confirmed
Alberta Pulse Growers	$2,700.00	$0.00	No
Chemical Companies	$0.00	$600.00	Yes
Industry Contract Profits	$0.00	$14,400.00	Yes
Alberta Barley Commission	$2,700.00	$0.00	No
Alberta Canola Producers Commission	$9,000.00	$0.00	No

Approvals and Permits

Approval/Permit	Status
Canadian Environmental Assessment Act	N/A
Alberta Environment Act	N/A
Human Ethics Approval	N/A
Animal Care Approval	N/A
Other	N/A
Transgenic Crop Permit	N/A

Suggested Reviewers

Name	Tom Wolf
Position	Research Scientist
Institution	Agriculture and Agri-food Canada
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Phone Number	306-956-7635
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Name	Eric Johnson
Position	Weed biologist
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Country	Canada
Phone Number	306-247-2011 ext. 23
Fax Number	Fax: 306-247-2022
Email Address	eric.johnson@agr.gc.ca

Name	Chris Neeser
Position	Weed Science Research Scientist
Institution	Government of Alberta, Agriculture and Rural Development; Pest Surveillance Branch
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Phone Number	403-362-1331
Fax Number	403 362-1326
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Project Team Leader

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ken@farmingsmarter.com

Degrees Certificates/Diplomas:
M.Sc. Royal Roads University, Victoria, BC, 2005
B.Sc. University of Lethbridge, Lethbridge, AB, 1999

Publications and Patents:
Farming Smarter Magazine (www.farmingsmarter.com)
Thesis Project: Modeling the Sustainability of Organic Agriculture vs. Integrated Cropping Systems
Various speaking engagements including, Agronomy Update, Advanced Agronomy Conference, Saskatchewan Soil Science Association Annual meeting, SACA Conference and AGM, SARA AGM

Other Evidence of Productivity:
Registered Professional Agrologist -Alberta Institute of Agrologists
2009 ARECA Service Excellence Award
General Manager of SARA and SACA managing 32 research projects with funding from various sources with a combined budget of approximately $800,000
Strong Extension skills and outreach through various outlets
Agriculture Opportunity Fund
Alberta Environmentally Sustainable Agriculture
Pest Management Center, AAFC,
Funding from AAFC for four research programs
Industry contracts with Dupont, Agrotain, BeckerUnderwood, Agrium

Project Team JP Pettyjohn Smokey

Members		Applied Research and Demonstration Association
	Keith Kornelson	Lakeland Agricultural Research Association
	Robert Blackshaw	Agriculture and Agri-Food Canada
	Eric Bremer	Symbio Ag Consulting
	Don Boles	Producer

Detailed Info:

Mr. JP Pettyjohn
Smokey Applied Research and Demonstration Association Manager
Box 90 Falher
AB T0H 1M0
780-837-2900
sarda@serbernet.com
Publications and Patents:
2 reports in SARDA's 2010 Annual Report
3 Articles in SARDA's Back Forty bimonthly newsletter
Other Evidence of Productivity:
Agricultural Opportunity Funds 2010-2012 funding received
ASB environmental stream 2011-2013 funding received

Mr. Keith Kornelson
Lakeland Agricultural Research Association
Box 7068 Bonnyville
AB T9N 2H4
780-826-7260
manager.lara@mcsnet.ca
Degrees Certificates/Diplomas:
B.Sc., Agriculture, University of Alberta, 2001
P.Ag., Alberta Institure of Agrologists, 2009
Other Evidence of Productivity:
5 Years managing an agricultural research association with an annual budget of $500,000.
Vice Chairman of a provincial cropping team with ARECA.
Contributing editor of 'Grow With Us' a bi-monthly LARA Newsletter (circulation 2200)and of LARA's annual report (circulation 300).
Speaker at various events such as LARA's AGM, Seeding for Success, and Producer Group Meetings.

Dr. Robert Blackshaw
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403-317-2268 403-382-3156
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Degrees Certificates/Diplomas:
Ph.D.,Weed Science, University of Guelph,1986
M.Sc., Weed Science, University of Manitoba, 1979
B.Sc., Botany/Chemistry, Brandon University, 1976
Publications and Patents:

58 refereed scientific papers
4 book chapters
63 conference and workshop proceedings
Other Evidence of Productivity:
Editor-in-Chief of the international journal 'Weed Science' from 2003-2008
Received the Outstanding Research Award form the Weed Science Society of America in 2006
Adjunct Professor, University of Lethbridge, 2005-present
Project Leader of a 12-scientist team for a four-year project entitled 'Sustainable expansion of canola for food and biodiesel markets'

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Degrees Certificates/Diplomas:
Ph.D. University of Saskatchewan, 1991
M.Sc., University of Saskatchewan, 1987
B.Sc., University of British Columbia, 1984
Publications and Patents:
61 refereed journal articles
Other Evidence of Productivity:
Head of R&D at Western Ag Innovations

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Producer
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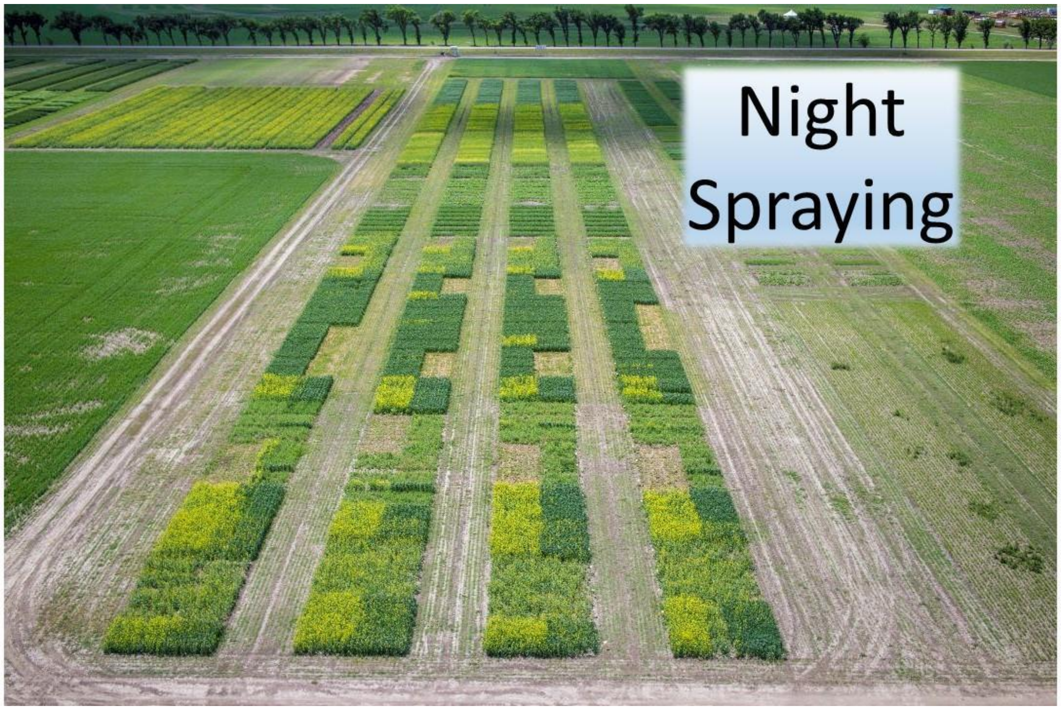
Other Evidence of Productivity:
Director on Farm Tech Conference Board
Director at Three Hills Seed Cleaning Plant
President Kneehill Rural Electrification Association

Comments No comments to load for this proposal.

Appendix B

Night Spraying Presentation – Ken Coles

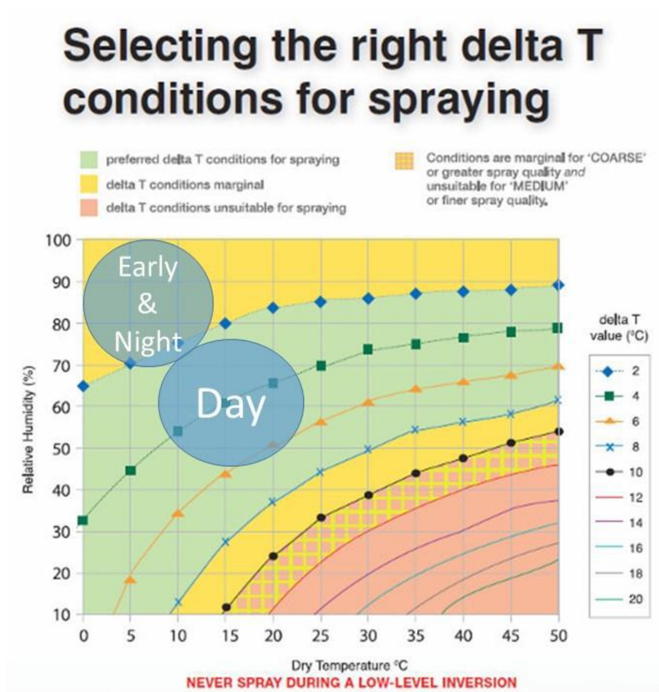


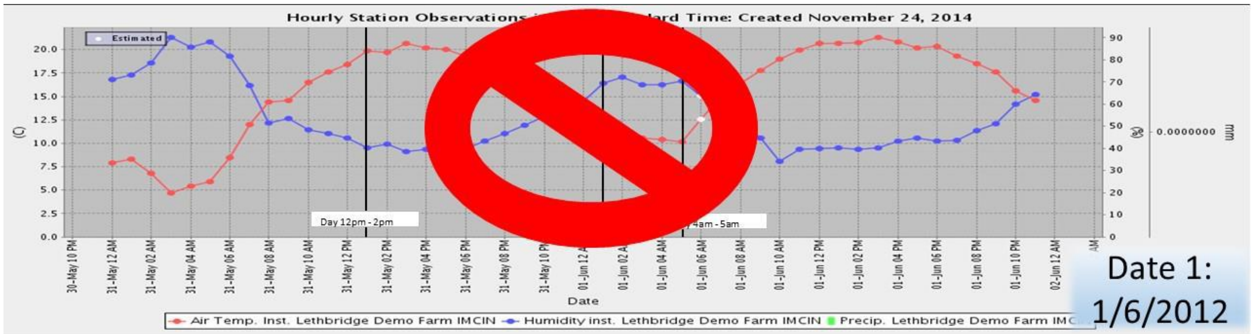
delta T =

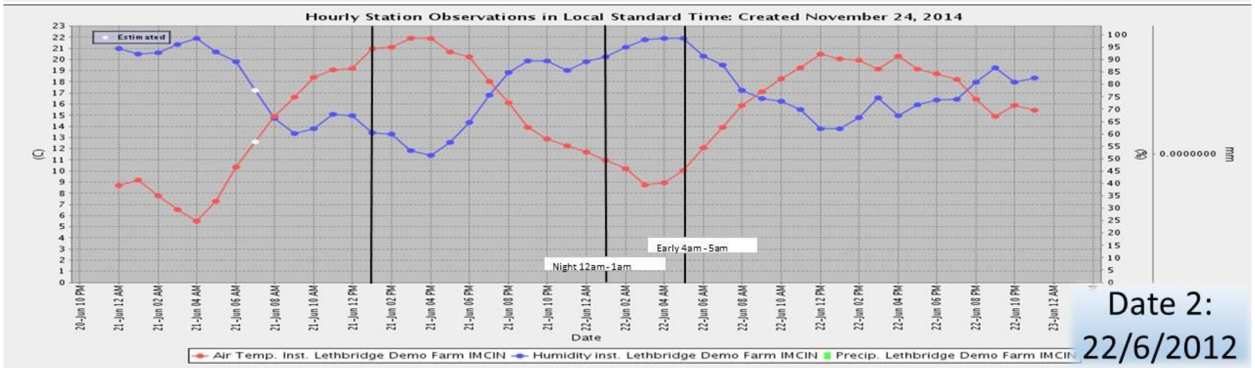
Wet bulb temperature
minus
Dry bulb temperature

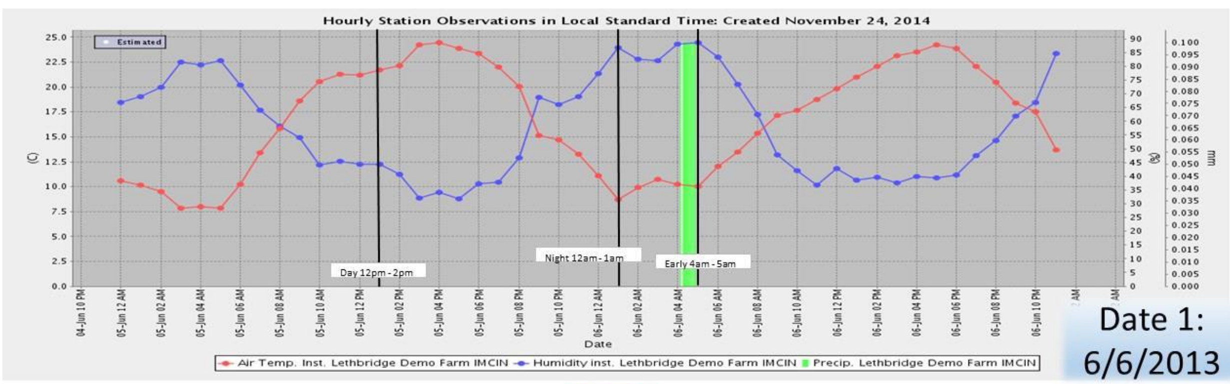
A wet bulb thermometer measures evaporative cooling.

Relative humidity is the amount of water in the air in relation to full saturation (dew/rain)

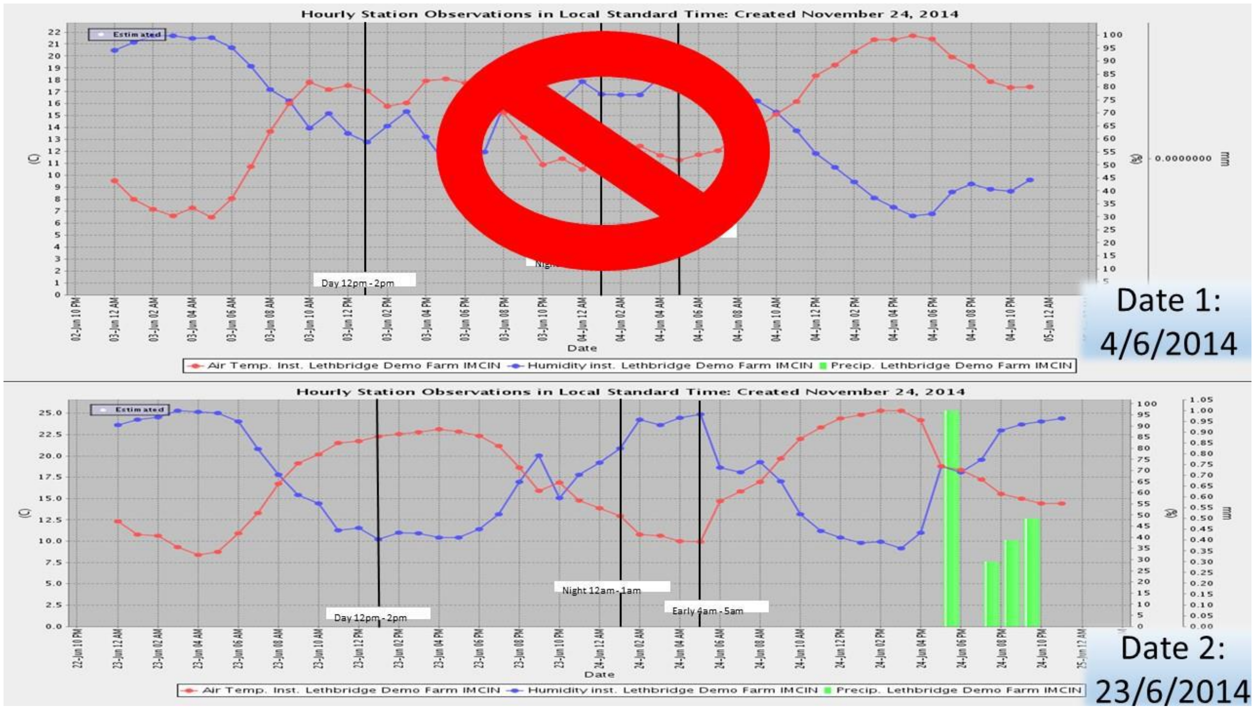


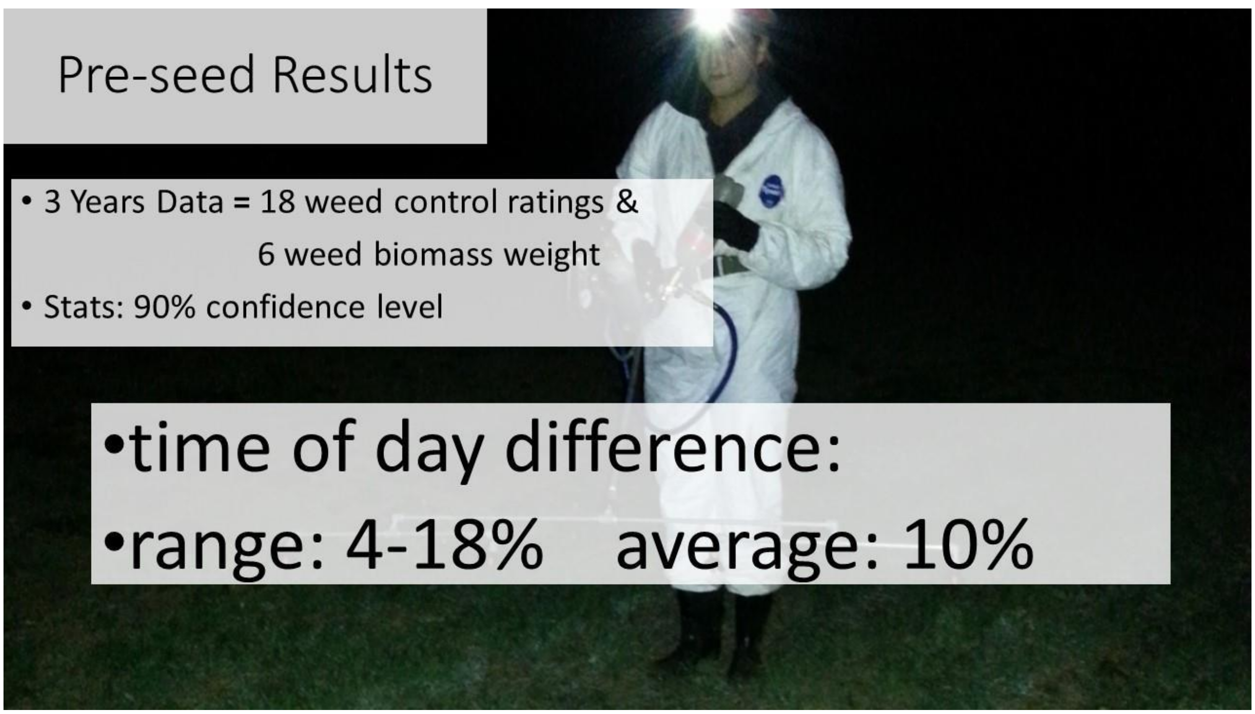

Hourly Station Observations
ard Time: Created November 24, 2014
Estimated
Day 12pm - 2pm
4am - 5am
Date
Air Temp. Inst. Lethbridge Demo Farm IMCIN
Humidity inst. Lethbridge Demo Farm IMCIN
Precip. Lethbridge Demo Farm IMC
Date 1: 1/6/2012


Hourly Station Observations in Local Standard Time: Created November 24, 2014
Estimated
Night 12am - 1am
Early 4am - 5am
Date
Air Temp. Inst. Lethbridge Demo Farm IMCIN
Humidity inst. Lethbridge Demo Farm IMCIN
Precip. Lethbridge Demo Farm IMCIN
Date 2: 22/6/2012

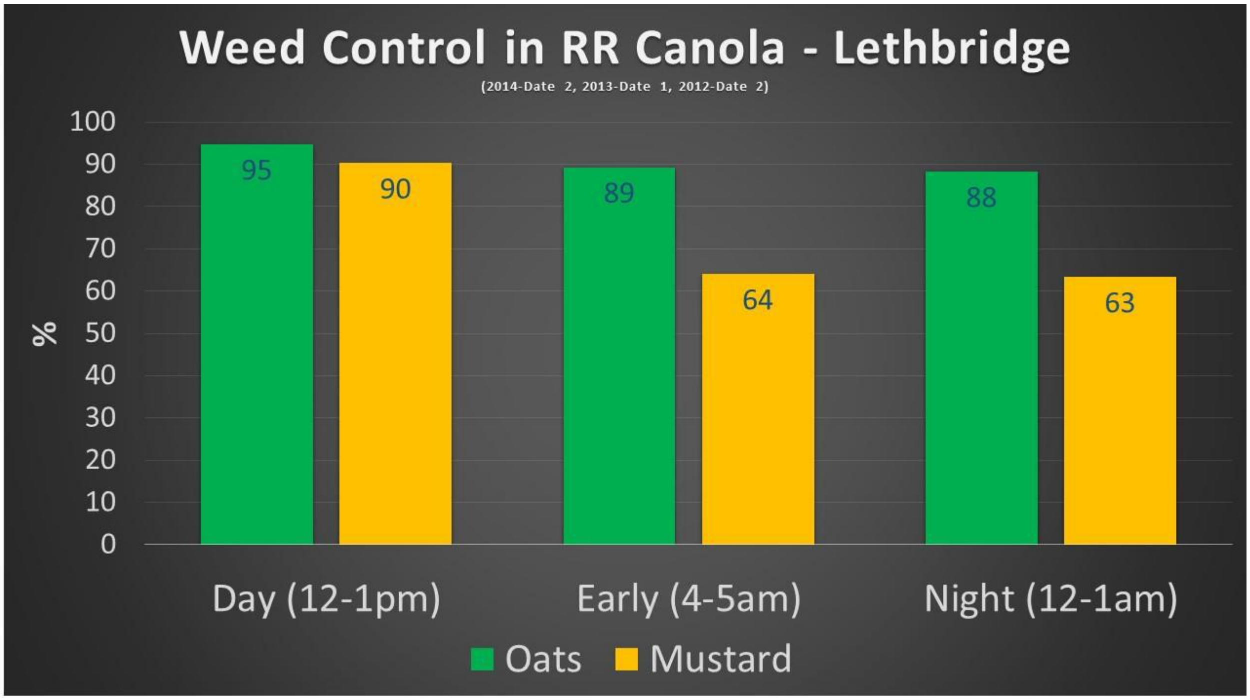

Hourly Station Observations in Local Standard Time: Created November 24, 2014
Estimated
Day 12pm - 2pm
Night 12am - 1am
Early 4am - 5am
Date
Air Temp. Inst. Lethbridge Demo Farm IMCIN
Humidity inst. Lethbridge Demo Farm IMCIN
Precip. Lethbridge Demo Farm IMCIN
Date 1: 6/6/2013

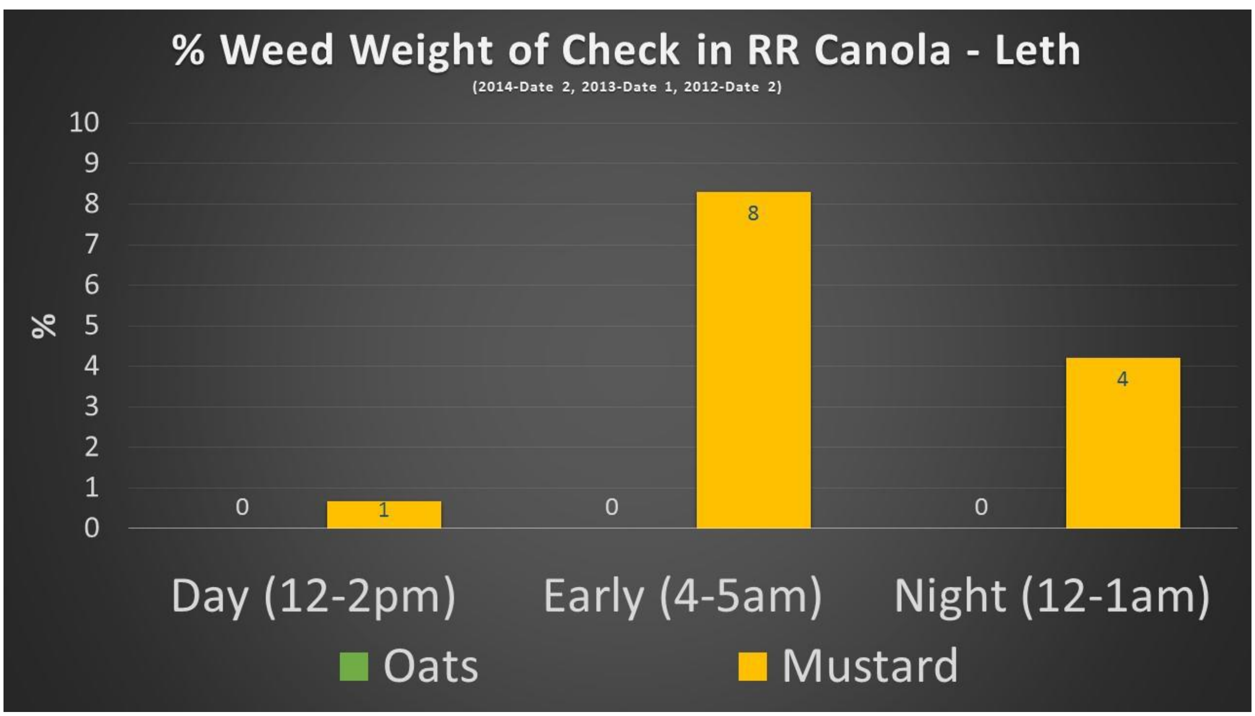

Hourly Station Observations in Loc
ard Time: Created November 24, 2014
Estimated
Day 12pm - 2pm
Date
Air Temp. Inst. Lethbridge Demo Farm IMCIN
Humidity inst. Lethbridge Demo Farm IMCIN
Precip. Lethbridge Demo Farm IMCIN
Date 2: 18/6/2013


Hourly Station Observations in Local Standard Time: Created November 24, 2014
Estimated
Day 12pm - 2pm
Date
Air Temp. Inst. Lethbridge Demo Farm IMCIN
Humidity inst. Lethbridge Demo Farm IMCIN
Precip. Lethbridge Demo Farm IMCIN
Date 1:
4/6/2014
Hourly Station Observations in Local Standard Time: Created November 24, 2014
Estimated
Day 12pm - 2pm
Night 12am - 1am
Early 4am - 5am
Date
Air Temp. Inst. Lethbridge Demo Farm IMCIN
Humidity inst. Lethbridge Demo Farm IMCIN
Precip. Lethbridge Demo Farm IMCIN
Date 2:
23/6/2014

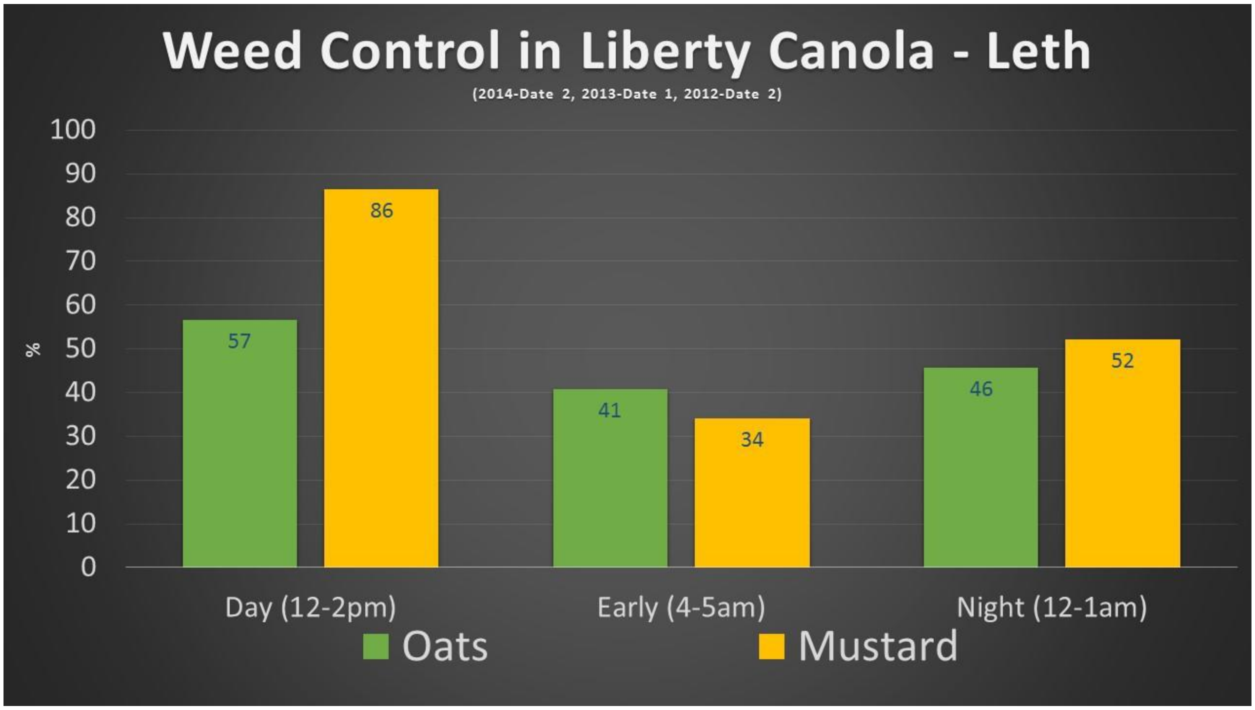

Pre-seed Results
• 3 Years Data = 18 weed control ratings &
6 weed biomass weight
• Stats: 90% confidence level
•time of day difference:
•range: 4-18% average: 10%

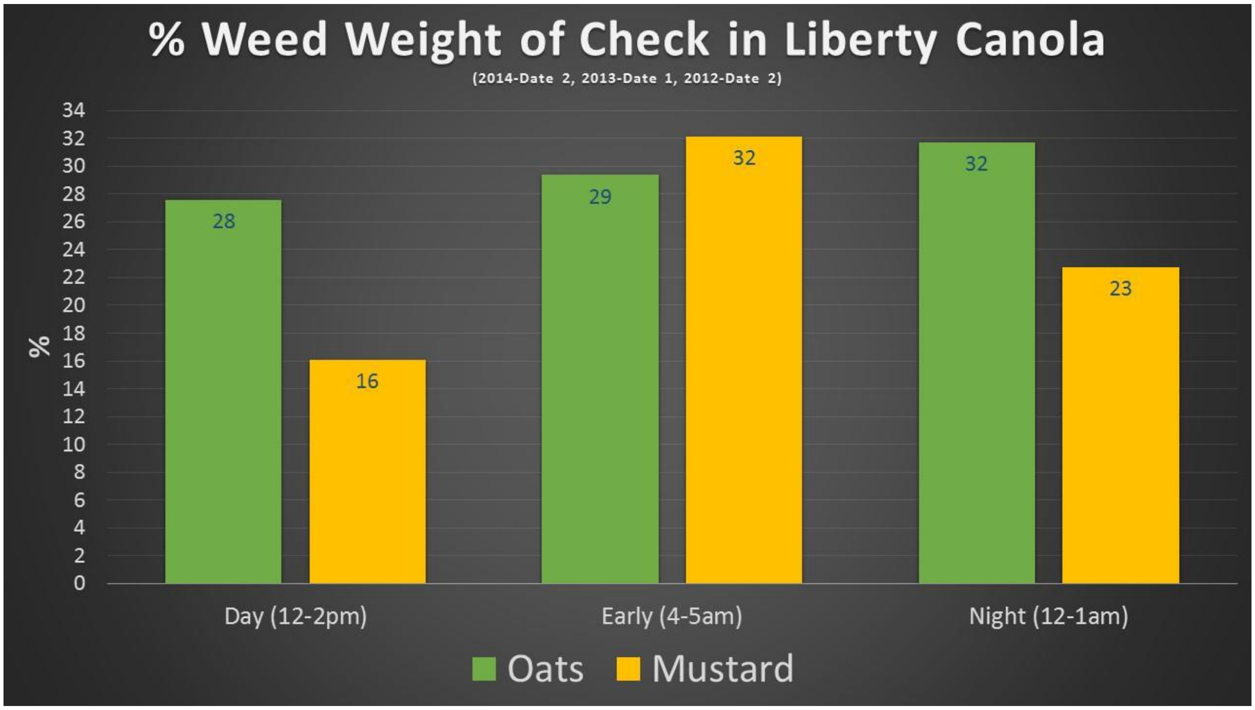
Timing	Best or Tied 4 Best	%
Day	14 / 18	78
Early	6 / 18	33
Night	4 / 18	22

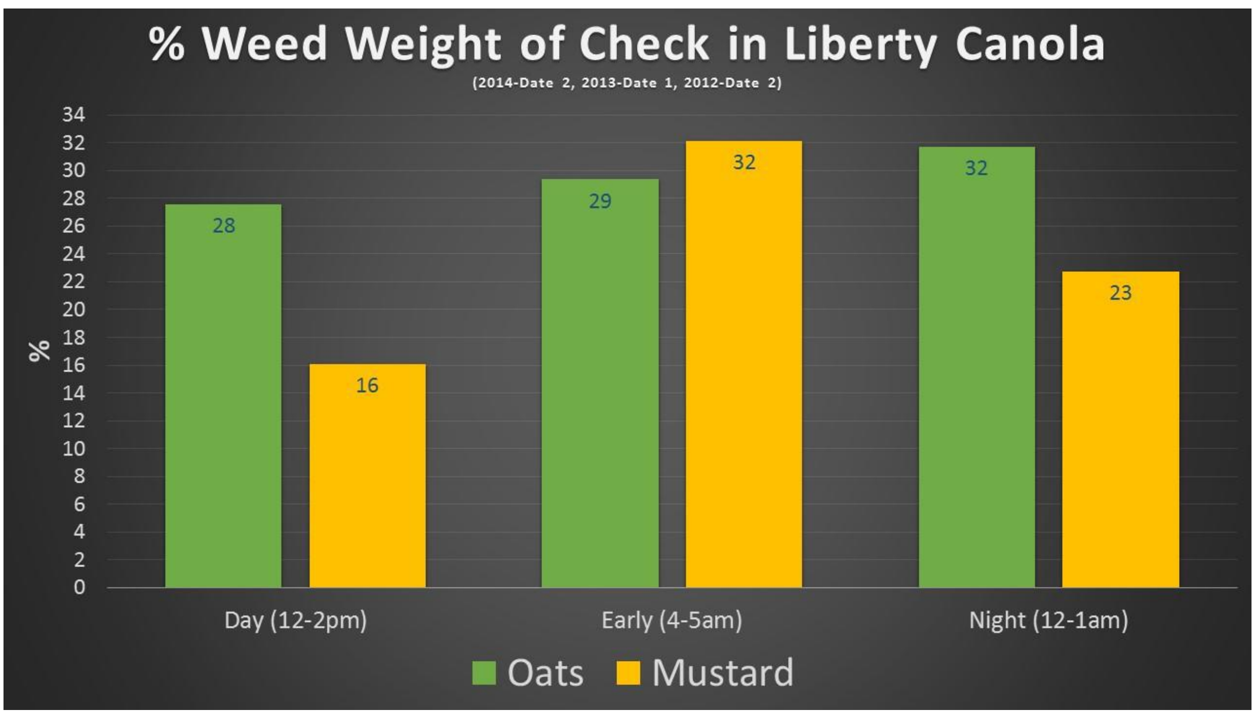

Weed Control in RR Canola - Lethbridge
(2014-Date 2, 2013-Date 1, 2012-Date 2)
100
90
80
70
60
50
40
30
20
10
0
%
95
90
89
64
88
63
Day (12-1pm)
Early (4-5am)
Night (12-1am)
Oats
Mustard

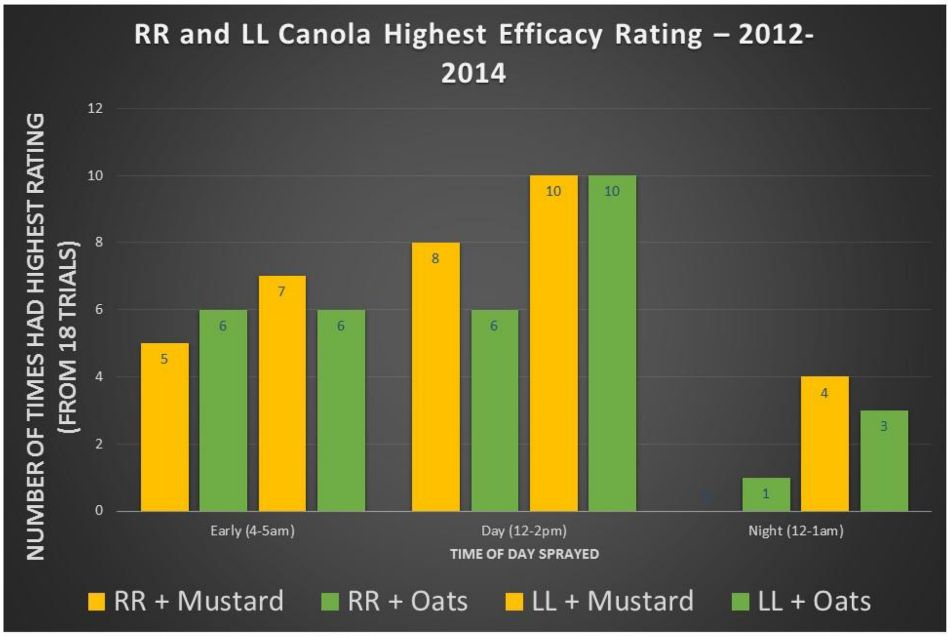

% Weed Weight of Check in RR Canola - Leth
(2014-Date 2, 2013-Date 1, 2012-Date 2)
10
9
8
7
6
5
4
3
2
1
0
%
0
1
0
8
0
4
Day (12-2pm)
Early (4-5am)
Night (12-1am)
Oats
Mustard


LIBERTY
DAY
NIGHT
EARLY

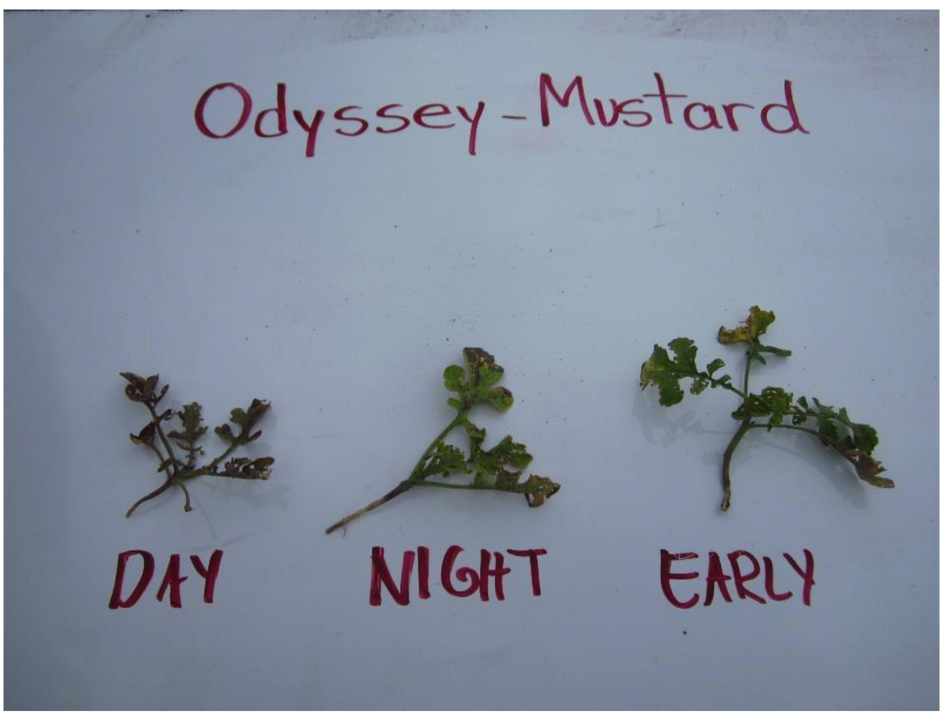

Weed Control in Liberty Canola - Leth
(2014-Date 2, 2013-Date 1, 2012-Date 2)
100
90
80
70
60
50
40
30
20
10
0
%
57
86
41
34
46
52
Day (12-2pm)
Early (4-5am)
Night (12-1am)
Oats
Mustard


% Weed Weight of Check in Liberty Canola
(2014-Date 2, 2013-Date 1, 2012-Date 2)
%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
28
16
29
32
32
23
Day (12-2pm)
Early (4-5am)
Night (12-1am)
Oats
Mustard

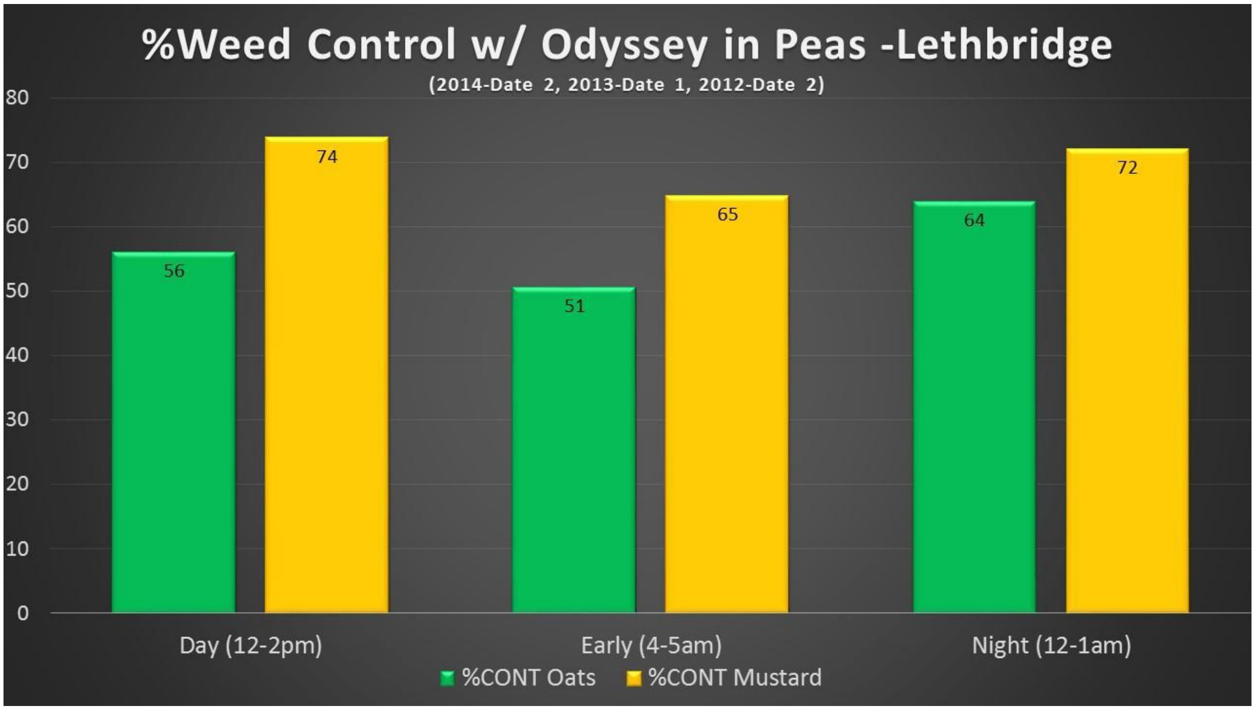

% Weed Weight of Check in Liberty Canola
(2014-Date 2, 2013-Date 1, 2012-Date 2)
%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
28
16
29
32
32
23
Day (12-2pm)
Early (4-5am)
Night (12-1am)
Oats
Mustard

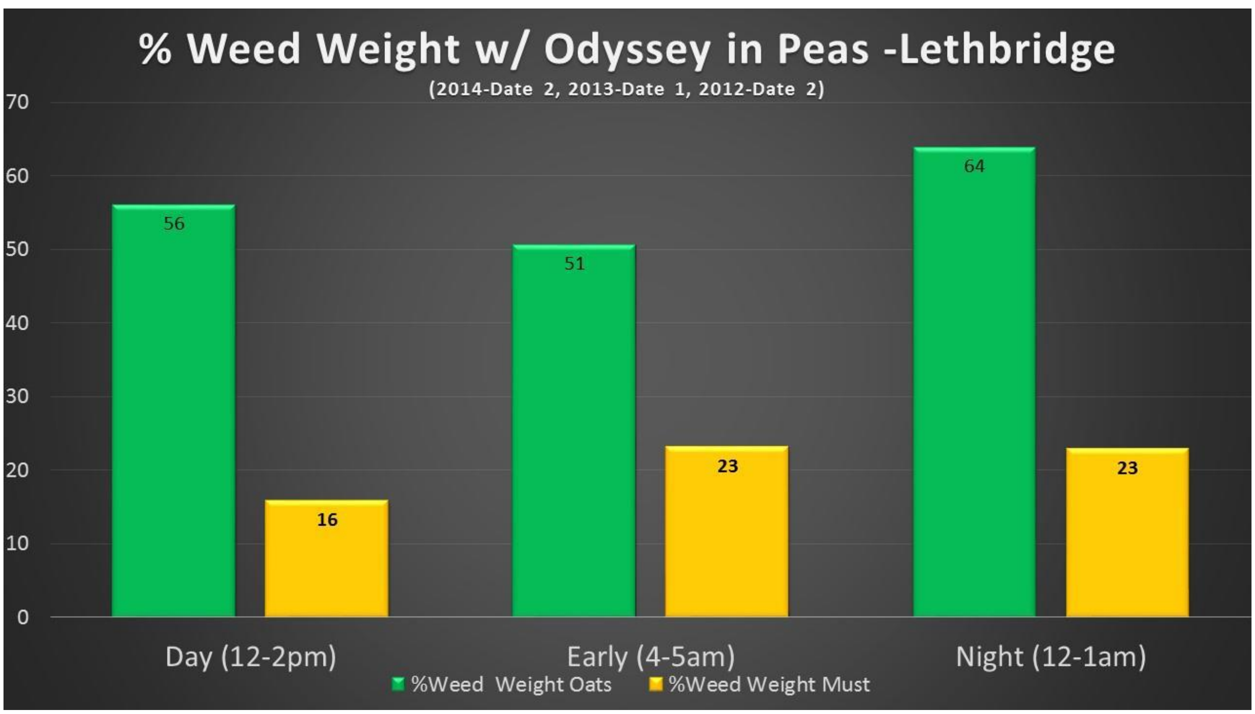


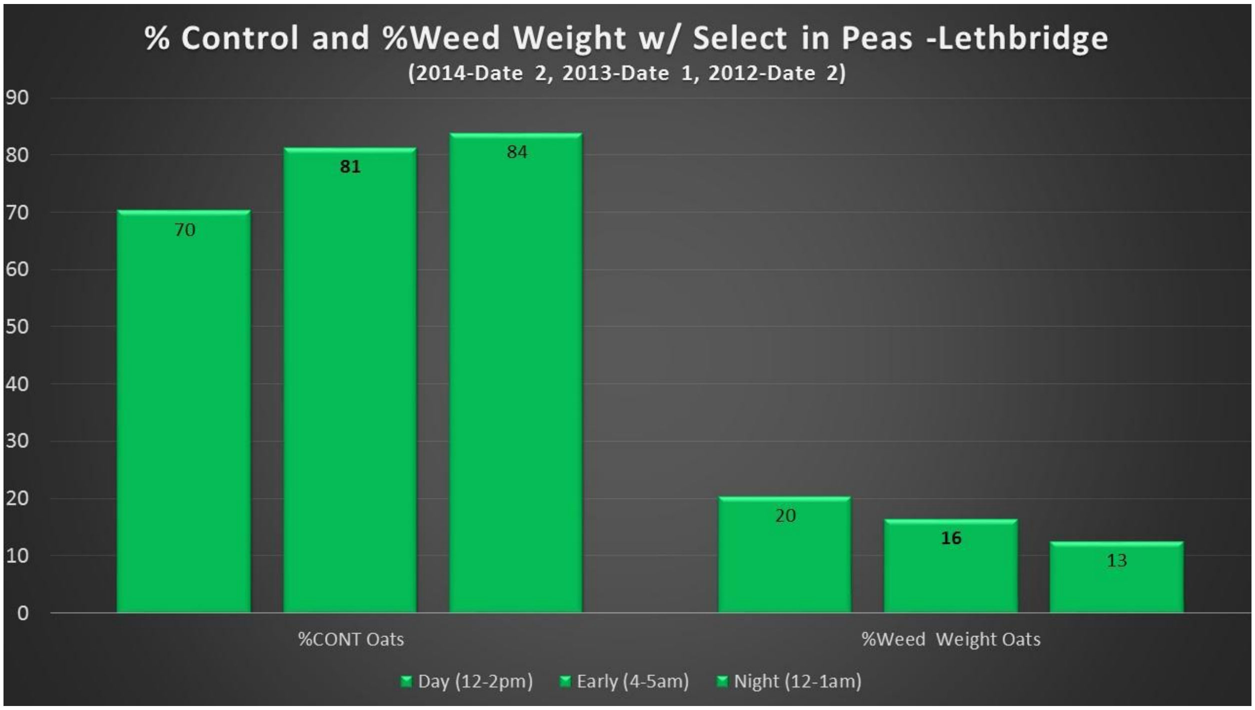
RR and LL Canola Highest Efficacy Rating – 2012-2014
NUMBER OF TIMES HAD HIGHEST RATING (FROM 18 TRIALS)
12
10
8
6
4
2
0
5
6
7
6
8
6
10
10
1
4
3
Early (4-5am)
Day (12-2pm)
Night (12-1am)
TIME OF DAY SPRAYED
RR + Mustard
RR + Oats
LL + Mustard
LL + Oats



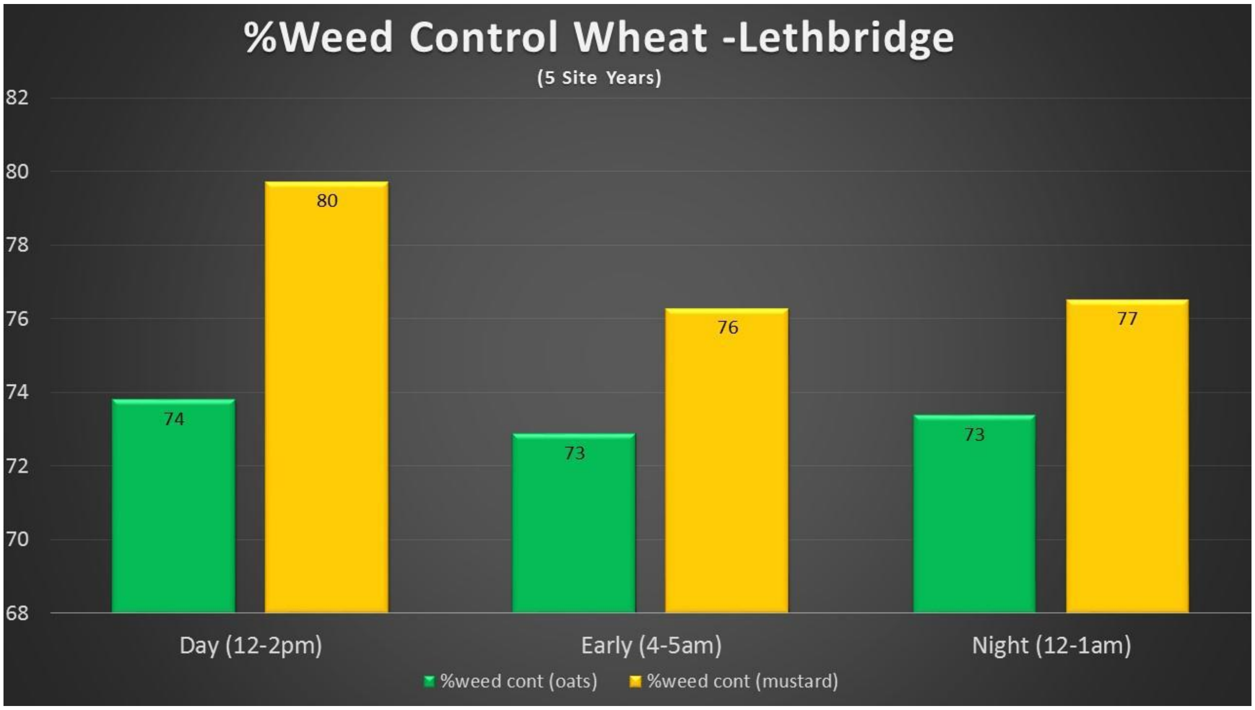
Odyssey-Mustard
DAY
NIGHT
EARLY

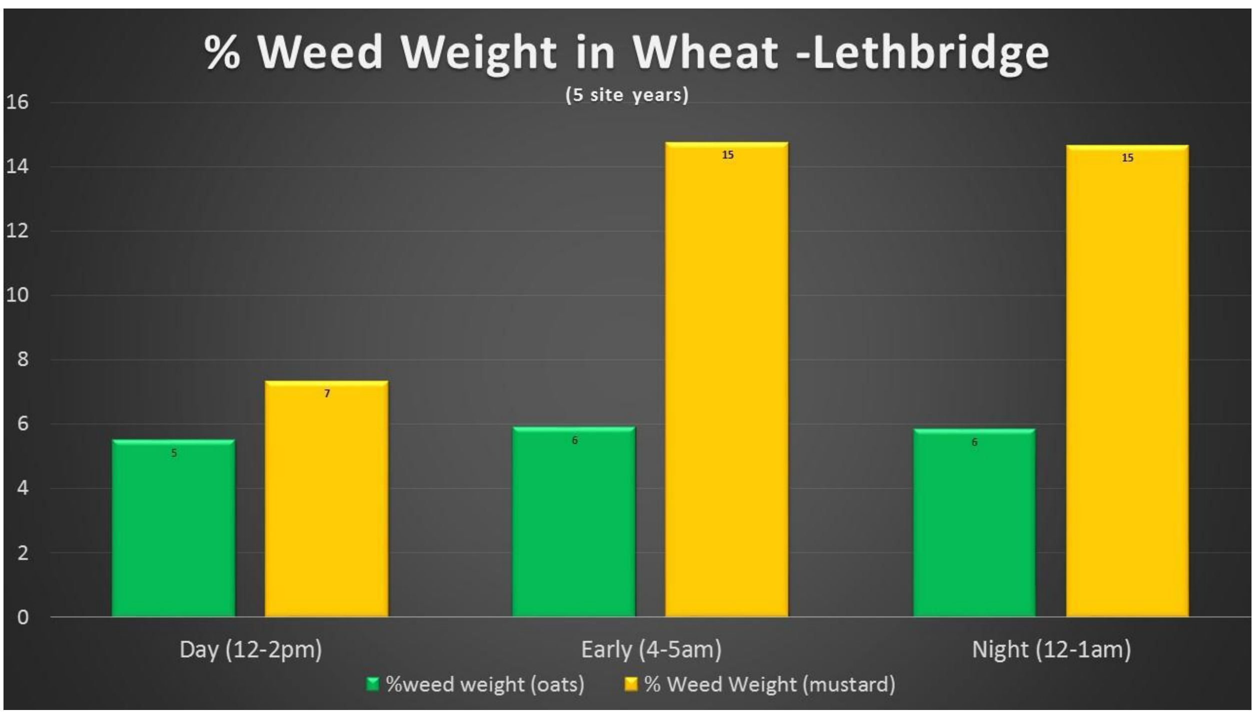

%Weed Control w/ Odyssey in Peas -Lethbridge
(2014-Date 2, 2013-Date 1, 2012-Date 2)
80
70
60
50
40
30
20
10
0
56
74
51
65
64
72
Day (12-2pm)
Early (4-5am)
Night (12-1am)
%CONT Oats
%CONT Mustard


% Weed Weight w/ Odyssey in Peas -Lethbridge
(2014-Date 2, 2013-Date 1, 2012-Date 2)
70
60
50
40
30
20
10
0
56
16
51
23
64
23
Day (12-2pm)
Early (4-5am)
Night (12-1am)
%Weed Weight Oats
%Weed Weight Must


% Control and %Weed Weight w/ Select in Peas -Lethbridge
(2014-Date 2, 2013-Date 1, 2012-Date 2)
90
80
70
60
50
40
30
20
10
0
70
81
84
20
16
13
%CONT Oats
%Weed Weight Oats
Day (12-2pm)
Early (4-5am)
Night (12-1am)


AXIAL + INFINITY
DAY
NIGHT
EARLY


%Weed Control Wheat -Lethbridge
(5 Site Years)
82
80
78
76
74
72
70
68
80
74
76
73
77
73
Day (12-2pm)
Early (4-5am)
Night (12-1am)
%weed cont (oats)
%weed cont (mustard)


% Weed Weight in Wheat -Lethbridge
(5 site years)
16
14
12
10
8
6
4
2
0
15
15
7
5
6
6
Day (12-2pm)
Early (4-5am)
Night (12-1am)
%weed weight (oats)
% Weed Weight (mustard)

LARA: Comparison of the herbicide efficacy average trends based on the application-timings during the Day (12 - 2 pm), Night (12 - 1 am) and Early morning (4 - 5 am)

Efficacy trend	Number of Trials	% of total		
Highest at Day-time	12	44%		
Higher at Day-time than Early morning	4	15%	59%	Day-time higher than Early morning
Lowest at Day-time	9	33%		
Mixed/No trend	2	7%		
Total	27	100%		

FS: Comparison of the herbicide efficacy average trends based on the application-timings during the Day (12 - 2 pm), Night (12 - 1 am) and Early morning (4 - 5 am)

Efficacy trend	Number of Trials	% of total		
Highest at Day-time	22	50%		
Higher at Day-time than Early morning	3	7%	57%	Day-time higher than Early morning
Lowest at Day-time	17	39%		
Mixed/No trend	2	5%		
Total	44	100%		

Fungicides ???

Summary

- Most herbicides work well in a wide range of conditions but there are different results based on environmental conditions

- Consider type of herbicide, contact vs systemic and mode of action
- Consider weather conditions such as temperature, relative humidity, wind and delta T

- **Pre-seed and in crop herbicides have most consistent results with day time applications**
- **Broadleaf weed control most sensitive to environmental condition**

- **Glyphosate and Liberty more sensitive to environmental conditions than wheat herbicides**
- **Grassy herbicides may be improved with night time application**

- **Early morning applications are least consistent**

- **If in doubt, spray wheat in the morning, canola in the afternoon and peas in the evening.**

- **Consider the power of the 5% rule which states that multiple small improvements may add to exponential improvements**

- **Fine tuning pesticide applications is likely an opportunity**

Thanks and Remember….
Don't "Spray" into the Wind!

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ken@farmingsmarter.com
@farmingsmarter
www.farmingsmarter.com

Appendix C

Popular Press Articles

June 14, 2012: Real Agriculture.com – Is the Night-time the right time to spray
http://youtu.be/khJSuECG2Ns

Alberta Farmer EXPRESS

Spray operators: It's OK to hit the snooze button

By Helen Mcmenamin
Published: October 5, 2012

The early bird gets the worm, and the best weed control, at least based on conventional wisdom that the best time to spray is when wind in lightest in the morning.

But the results of trials by Farming Smarter, southern Alberta's farm research group, indicate that spray operators don't have to set their alarms quite so early, or stay up so late.

"We figured spraying at night, at cooler temperatures when the herbicides would remain in the leaves longer, would probably be the best," says Ken Coles, Farming Smarter manager. "Some chemicals photo-degrade — they're broken down in sunshine, so we expected they might be more effective at night," Coles said.

"Also, plants close their stomata at high daytime temperatures — you'd think that would reduce herbicide effectiveness," he said. "These days, with autosteer and GPS guidance, it's not a big deal to work in the dark and it's something lots of people do. But, with the sort of impact we've seen, maybe we need to reconsider."

The researchers applied pre-seeding burn-down chemicals at three times — midnight to 1 a.m., 4 to 5 a.m., or noon to 1 p.m., all on a single day. They didn't expect to see big differences due to timing — after all, they reasoned, products are registered with high enough label rates to perform well under all conditions. They used three-quarter rates of burn-down chemicals when weeds were small, so they'd see differences. They used full rates when weeds were bigger and harder to kill.

For preseed products, they applied glyphosate alone, and the non-glyphosate herbicide components of Prepass, Clean Start and Heat, so they would avoid interactions of the active ingredients. They also tested a range of widely used in-crop herbicides in Roundup Ready canola, Liberty Link canola, peas and wheat.

Consistent results

No matter what herbicide they used, the rate and whether it was a preseed burn-off or in crop, the results were completely consistent. Weed control was best when the herbicide was sprayed between noon and 1 pm. The worst time to spray, for all herbicides, pre-seeding or in-crop, was between 4 and 5 am.

"I'm astounded," says Coles. "It's not what we expected at all. We thought a few things might be more effective during the day — it's not recommended to spray Liberty at night, but I really didn't think the impact would be so strong. And, I really thought that in the middle of the day, when the spray dries almost immediately, the chemical wouldn't get into the plant as effectively."

Coles said visual ratings showed as much as 80 per cent greater efficacy for Liberty sprayed at noon compared to spraying at 4 or 5 a.m. "It wasn't what I expected at all."

On the other hand, especially in spring, daytime temperatures mean that plants are growing rapidly, their metabolic rate is high, so the herbicide's active ingredient can move rapidly through the plant and work well on its target site. Even more surprising was that crop tolerance was better at noon. And, crop damage appeared to be worse when herbicides were sprayed at dawn. Once again, the results were totally consistent across all the herbicides.

Temperature effect

Coles suspects cool temperatures at night and especially in the early morning may have affected herbicide performance.

“We had quite wide temperature fluctuations, so that may be a big part of the differences in herbicide efficacy,” he said. “We’ll be studying that over the winter when we can look at the statistics and everything. We’ll also compare our results with those of Lakeland (Applied Research Association) at Bonnyville and SARDA (Smoky Applied Research and Demonstration Association) at Falher.”

Over the winter, the research groups will compare their results from their different locations where temperatures likely varied quite a bit. They’ll also look at biomass measurements and yields. Coles is hoping to add fungicides to next year’s testing for the effect of time of day on the effectiveness of pesticides.

Coles isn’t ignoring the reality of spraying — no matter how big your sprayer, there’s always too many acres to cover and the window of calm air or light breezes is too narrow. “We spray early in the morning because in southern Alberta that’s often the only time the wind calms enough to spray. But today, with new nozzle technology, we can spray safely in much higher winds than we could 10 years ago,” he said.

“Maybe it’s time to rethink the ideal time to spray and when to take a break from spraying and when to go with full rates rather than cutting back. Maybe it’s better to go out for a few hours after supper than to be out at the crack of dawn.”

Spraying at first light may cost you herbicide efficacy

Mid-day application sees best results / BY HELEN MCMENAMIN

"Autosteer allows you to do anything at any time," says Ken Coles, Farming Smarter manager. It's not far from that thought to figuring that spraying in the dark should give better results.

"It's cooler, so herbicides remain on the leaves and are absorbed better," says Coles. "And maybe the stomata that close during the heat of the day are open at night, possibly allowing more herbicide absorption. And there's no risk of photodegration with chemicals that can be degraded in sunshine."

Currently Farming Smarter is looking into the benefits of nighttime spraying. By assessing both in-crop and pre-seeding burn-off herbicides, and separating out the ingredients of premixes, they'll be able to see which ones might be affected by changing conditions of mid-day, midnight and dawn spraying. So far, Coles has been "astounded" by the results.

It seems, unexpectedly, that from one year of comparisons of spraying times that most herbicides are most effective when sprayed in the middle of the day, as opposed to spraying late at night or early in the morning.

Effects of spray timing on mustard.

Early morning least effective

As part of its project, Farming Smarter looked at herbicides as pre-seeding burn-off and in-crop. The pre-seeding trials looked at glyphosate alone (Vantage Plus), saflufenacil (included in Heat), carfentrazone (included in CleanStart) and fluorasulam (included in Prepass). Early in the season, each one was used at 75 per cent of the recommended rate of the commercial mixture so the herbicide would have less than ideal conditions that would highlight small differences in effectiveness.

Later, when weeds were bigger, the researchers figured that would be enough of a challenge for the herbicides.

The researchers were surprised to find the least effective spray time was at 4 a.m. to 5 a.m.

"Two weeks after spraying, the early morning-sprayed plots were definitely the worst," says Coles. "We were astounded to see such big differences. We don't often see such clear-cut differences as we saw in this trial.

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"CleanStart (carfentrazone) was the only herbicide that didn't show big differences. Its performance in the early morning was very similar to when it was sprayed at noon or midnight. Maybe we saw a loss of activity for that chemical sprayed at mid-day when it can be degraded by the sunshine."

Differences among the three times of day were even bigger when weeds were cut from each plot 35 days after spraying.

Vantage Plus performance dropped by as much as 19 per cent when sprayed between 4 a.m. to 5 a.m. Prepass ingredient, fluorasulam, was around 13 per cent less effective in the early morning and saflufenacil (the Heat ingredient) lost four or five per cent early in the morning. Carfentrazone (Heat ingredient) had similar activity at all three times.

Weather around the time of spraying, of course, has a huge impact on herbicide efficacy. This spring was generally cool and very humid, so that at the coolest, most humid time of the day (the 4 a.m. to 5 a.m. spraying time,) plants would be thoroughly chilled. At the first spraying for the Farming Smarter trial, May 4, the temperature was 2 C. The second burn-off spray day, May 22, wasn't so cold, but the pattern of herbicide performance was similar.

In-crop performance

Farming Smarter and applied research associations at Bonnyville and Falher also compared the performance of in-crop herbicides sprayed at the same three times. Liberty-Link canola was sprayed with Liberty (glufosinate) or Lontrel and Select (clopyralid and clethodim) and Roundup Ready canola with Vantage Plus (glyphosate). Peas were treated (clethodim). Four herbicides or tank-mixes were tested on wheat: OcTTain XL(fluroxypyr and 2,4-D). Axial and Infinity (pinoxaden, prasulfotole and bromoxynil), Everest (flucarbazone) and Barricade (thifensulfuron and tribeuron).

The herbicides in the trial include chemicals from Groups 1, 2 and 4, as well as Groups 6, 9, 10 and 27. Rates of all chemicals were cut to 75 per cent to highlight differences in performance. Coles and the other researchers haven't analyzed their results yet. But their preliminary reviews of the in-crop herbicides don't show the clear differences they saw in the burn-off chemicals.

Even though some chemicals were as much as 19 per cent less effective when sprayed at dawn in this trial, the difference may mean little if label rates are used.

"Herbicides are formulated to perform well at label rates under almost any conditions," says Coles. "But, at least for most of the burn-down chemicals, it seems you don't need to be out at first light."

Rather than looking to autosteer to allow herbicide spraying in the dark, as originally planned, Coles is now looking to spraying technology for better herbicide performance.

"With low-drift nozzles, we can now spray in winds over 20 km per hour," he says. "So, getting out early, before the wind comes up, is becoming much less important." —

Spraying at first light may cost you herbicide efficacy

Just because you can use autosteer to spray at any time of the day or night doesn't mean you should. New research on spray timing may surprise you

BY HELEN MCMENAMIN

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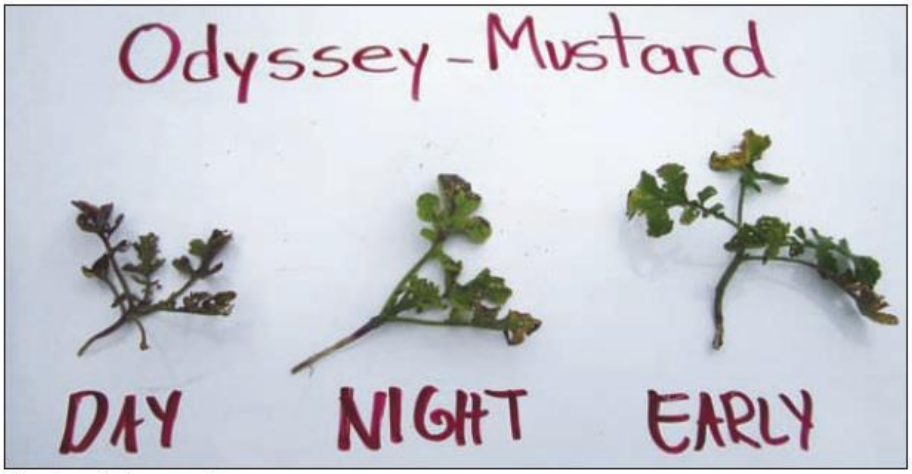

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This article originally ran in the Fall 2012 edition of "Farming Smater" magazine. Learn more about this organization at www.farmingsmarter.com.

Helen McMenamin is a freelance writer based in Alberta.

December 11, 2013: Real Agriculture.com – The nozzle sprays at midnight

https://soundcloud.com/realagriculture/ken-coles-recaps-farming

Alberta Farmer
EXPRESS

Does the time of day matter when applying herbicides

Burn-down trials suggest applying herbicides at dawn may be less effective

By Farming Smarter, Ken Coles

The test plot on the left was sprayed with Carfentrazone at noon, while the side on the right was sprayed at dawn. *Photo: Farming Smarter*

Have you ever evaluated your weed control and come across confusing differences between fields? Perhaps they were even sprayed on the same day with the same chemical?

The good news is you might not be crazy. Well, at least not more than normal.

We just rated our burn-down trials for a third year where we sprayed glyphosate and three tank mix partners at noon, midnight and early dawn.

I have to admit that starting out I didn't expect to see any differences. Having worked in research for many years, I know companies are very good at registering products that perform well in as many conditions as possible. It just makes good sense.

But the verdict is, time of day can impact weed control more than you might think. For the most part, there isn't too much to worry about, but we may have an opportunity to fine tune our spray timing especially in more difficult situations such as with hard-to-kill, larger weeds or dense infestations.

We still need to collect weed biomass data this season and spend some time analyzing the results, but we're seeing some trends that might be valuable. Since early weed control has proven to be important in protecting yield, it may impact your bottom line and help keep a few more weeds from setting seed in your fields. The clearest trend so far is that spraying at the crack of dawn led to the poorest control in most cases. This was especially true for glyphosate alone and with the tank mix partner CleanStart, (Carfentrazone). Most farmers would likely not see these differences when spraying entire fields but with small plots we can evaluate differences side by side. Carfentrazone is a contact herbicide and like Liberty, it is best sprayed midday (see photo at top).

- **From the Grainews website:** **Factors line up for sclerotinia in 2014**

Understandably, it's most important to get the job done with narrow windows to get fields sprayed and seeded. But, it's also important to get things done right. Honestly, high-clearance and high-speed sprayers, GPS guidance, and low-drift nozzles have drastically improved spraying capacity and flexibility.

The next challenge for us is to determine what's causing the differences that we are seeing. It seems likely temperature and relative humidity relationships are playing a significant role, as well as light intensity. The early-morning applications tend to occur at the coolest part of the day when relative humidity is the highest. Other studies have also shown that leaf orientation to the sun can play a role with certain weed species.

We'll explore this further with our in-crop studies in peas, canola and wheat. But remember, in this case the early bird doesn't get the worm. So you might as well catch a few more winks!

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Morning good for fungicides

0 Comments Posted Jul. 3rd, 2014 by Barb Glen

Farmers who like to get out into the field early will like the early results from a study on spray timing for fungicides.

Morning looks like a better time than noon or midnight for applying them.

"So far, what we've seen is a trend toward the morning application being best for our fungicide," said Alberta Agriculture crop pathologist Michael Harding.

"We've seen that response in two crops, in peas and barley. It's been most dramatic in the pea crop. We haven't really seen any significant differences in wheat or canola, but it may have had more to do with disease pressure than with fungicide."

Farming Smarter is in the third year of a three-year study on spray timing. It is investigating results from spray applications in the early morning, at noon and at midnight. Harding talked with participants of a June 24 field school about the results specific to fungicides.

Complete results from the study have yet to be compiled, but Harding said one of the keys to preventive fungicide is proper coverage on the parts of the plant where fungus can invade.

For example, it's most important to protect the flag leaf when preventing stripe rust in wheat, but broader coverage of the plant is required when guarding against mycosphaerella in peas.

Harding speculates that morning application might prevent fungicides from drying too quickly on plant surfaces, which allows better distribution of the active ingredients.

Dew might also help distribute the chemical. Some crops close slightly at night, which leaves the canopy more open in the early morning.

As a result, sprayed fungicide can penetrate deeper and touch a wider area of the plant.

The spray timing trials for fungicide were conducted on wheat, barley, canola and peas using various products registered for control of fungal diseases in those crops.

"We are seeing some differences on the fungicides," Harding said.

"We're not seeing anything earth shattering. We're not suggesting you make any life altering decisions based on what we've found so far, but we do see some differences, and right now the trend is indicating that morning, for many situations, could be a good time to be putting fungicides on."

The Western Producer

Is spraying by moonlight effective?

Ken Coles, left, of Farming Smarter tells participants at the June 24 Lethbridge field school about spraying trials that explore the effectiveness of herbicides when applied in the morning, midday and midnight. | Barb Glen photo

Posted Jul. 4th, 2014 *by* Barb Glen

Posted Jul. 4th, 2014 by Barb Glen0 Comments

Improving effectiveness | Researchers tested various types and rates of chemicals and how they respond to spray timing

It’s midnight in the canola field and all is quiet, except for the distant chirping of crickets — and the rumble and hiss of the sprayer.

Equipment technology has evolved to where night spraying is no harder than day spraying, which can be handy when timing is crucial and acres are many.

But does spraying at night provide effective weed control?

A three-year study undertaken by the Farming Smarter research group based in Lethbridge sought to find the answer.

Now wrapping up Year 3, researchers have bad news for early birds. The common practice of morning spraying for pre-seeding burn-down is less effective than either midnight or midday, with midday showing best results.

Initial results for in-crop spraying show midday herbicide applications have the highest efficacy in peas and canola, while midnight applications provided best control of grassy weeds.

Information about the trials was a topic of discussion at the Farming Smarter field school, which ran June 24-26 in Lethbridge.

“The advent of autosteer has sort of expanded the opportunity to spray at night time, and some guys are crazy enough to do it,” said director Ken Coles.

“You do the outside round (first), you make sure you know where your potholes are, and it does give you an expanded window of operation.”

However, most registered herbicides were tested for daytime application, so trials designed by Agriculture Canada research scientist Bob Blackshaw sprayed crop plots at dawn (4 to 5 a.m.) noon (12-1 p.m.) and midnight (12-1 a.m.)

Plots included Liberty Link and Roundup Ready canola, peas and wheat. Various types and rates of chemicals were tested, creating reams of data that will be crunched over the coming months.

“When I started off in this endeavor, I really didn’t think, to be honest, that we would see the differences that we have,” said Coles.

“I think it’s one of these opportunities that if we have a better understanding of which herbicides work under which conditions, we might be able to come up with a bit of a schedule that will maximize our efficacies.”

Differences between the spray timings were more significant in early growth stages, but tended to level out before harvest, according to early data.

Blackshaw said research results brought surprises but also assurances about night spraying.

“Some of this research has shown that in some cases with some herbicides there’s not a large negative effect, so I think producers that still want to do that, especially if they get behind because of adverse weather conditions … it’s not an absolute no-no.”

However, he said for some herbicides, spraying in the daytime provides better results.

“I think that’s especially true for early in the year … when we have cooler conditions.”

It has proven more difficult to analyze how herbicides with different modes of action respond to spray timing. Blackshaw said he thinks it plays a role, but more research is needed for definitive answers.

However, temperature at time of spraying definitely makes a difference, Blackshaw told farmers at the field school.

He said daytime temperatures of at least 10 C are needed for herbicides to be effective.

“The crop needs to grow so it can metabolize the herbicide and break it down so it’s not injured, and the weed needs to grow so that the herbicide can actually do the job on it.”

It means reasonably warm, sunny conditions. The more actively weeds are growing, the better the herbicide can kill them.

Coles said temperatures generally reach their 24-hour lows in the early morning, when relative humidity is highest and dew is heaviest. That will affect chemical efficacy.

Dew might help the chemical spread on the plant, and leaves may be more hydrated, but that doesn’t necessarily mean the plant is efficiently translocating the ingredients because it is not photosynthesizing.

The Alberta Canola Producers Commission and the Alberta Barley Commission funded the night spraying research

Alberta Farmer EXPRESS

Spray fungicides before breakfast and herbicides at lunch

Morning may be best for spraying fungicide, but save your herbicide application for midday

By Jennifer Blair *Reporter*
Published: July 9, 2014

Preliminary results of Michael Harding's night-spraying research show that morning may be the best time to spray fungicides. *Photo: Jennifer Blair*

Time of day counts when it comes to spraying for weeds and diseases, a study being conducted by Farming Smarter suggests.

"If we have a better understanding of which herbicides work better under different conditions, we might be able to come up with a schedule that will maximize our efficacies," said Ken Coles, the Lethbridge organization's general manager.

"Whenever you do that, you have an opportunity to get better weed control, maybe a little less weed seed bank in the soils, and in certain cases… yield advantages."

Coles and his team set out to determine if night spraying might be a better option for producers who have a narrow window to spray.

"The advent of auto steer has expanded the opportunity to spray at nighttime, and some guys are crazy enough to do it," he said. "It does give you an expanded window of operation."

Most registered herbicides have little data on nighttime application, when there can be "significant differences in environmental factors." Coles' team sprayed four different crops — wheat, pea, canola, and barley — at three different times of day: In the morning between 4 and 5, from noon to 1 p.m., and between midnight and 1 a.m.

"We're starting to stumble upon what we thought were patterns," he said. "When we sprayed under normal types of conditions… early was the least efficacious, night was somewhere in between, and noon was usually the best."

- **From the Grainews website: Know when to apply fungicide**

In southern Alberta — where producers have been taught, “if you want to spray, you get up early and you beat the wind” — the cool temperatures and high humidity of early morning seemed to work against the herbicides, which perform best in hotter, drier conditions.

“When we come in at 4 or 5 in the morning, that’s actually where the lowest temperature of the day tends to be, and it’s also the highest relative humidity. Often, we’ll have large amounts of dew,” said Coles.

“We’ve sprayed in dew and had lots of luck, but so far in most conditions, that’s actually the least effective time to be spraying for most of the herbicides we’ve got going on.”

But each product performed differently under different conditions. Wheat herbicides worked best overall “under most circumstances,” while a product like Liberty performed best at midday.

“If I were forced to schedule a day, I would spray the wheat herbicides when it’s the coolest or early in the morning,” said Coles. “I would save my glyphosate and my Liberty for the middle of the day, and then I would spray my peas in the evening.

“It’s not perfect information by any means, but that’s the trend we’ve been seeing.”

Spray fungicides early

But the conditions that make herbicides least effective may actually make fungicides work best.

“So far, what we’ve seen is a trend toward the morning application being best for our fungicides,” said Michael Harding, research scientist at Alberta Agriculture and Rural Development.

“The dew and the cool conditions make it so that the fungicides don’t dry as quickly, and they may redistribute better throughout the canopy.”

With fungal infections, preventing the spread of the disease is critical.

“Most of the time, we can’t really cure them. Once we start seeing the symptoms, it may be too late to do anything about it,” said Harding.

“We want to get them on preventively, and we want to hit our target.”

Spraying at a time when temperatures are lower and relative humidity is high increases penetration low in the canopy where stem rots like ascochyta in pea or sclerotinia in canola attack plant stems, causing lodging at harvest time.

“We actually saw our biggest results in peas,” he said, adding barley also responded well to the morning application.

“We haven’t really seen any significant differences in wheat or canola, but that may have had more to do with disease pressure than with fungicides.”

So far, the study’s preliminary findings suggest that morning application is best for fungicides, but the results aren’t “earth shattering,” said Harding.

“We’re not suggesting you make any life-altering decisions based on what we’ve seen so far, but right now, the trend is indicating that morning for many situations could be a good time to be putting fungicides on.”