Government of Saskatchewan
Ministry of Agriculture

ADF Project Final Report Format

1. **Project title and ADF file number.**
   Title: Herbicide screening in hemp (*Cannabis sativa*). ADF File Number: ADF 20150253.

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

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4. **Abstract/ Summary**: *An outline on overall project objectives, methods, key findings and conclusions for use in publications and in the Ministry database (Maximum of 500 words or one page* <u>*in lay language)*</u>.

Industrial hemp (*Cannabis sativa*) acreage has generally shown a steady increase in western Canada since it was first grown in 1998. The potential for further growth may be stimulated by recent regulatory changes. There are very few herbicides registered for use in hemp, particularly for broadleaf weeds. Quizalofop-ethyl is registered for grass weed control and ethafluralin is registered for grass and some broadleaf weed control. There is a need for more herbicide options for hemp growers.

The objective of this study was two-fold:

1) To screen hemp germplasm to determine variability in tolerance to broadleaf herbicides.
2) To provide data to Minor Use of Pesticides Program to support herbicide registration.

Field studies were conducted at the Goodale Research Farm in 2016 and 2017 to determine if hemp cultivars differed in their tolerance to post-emergence applications of bromoxynil and clopyralid and pre-seed applications of flucarbazone and sulfentrazone. Ten cultivars were evaluated including Canda, CFX-2, CFX-1, CRS-1, Delores. Grande, Joey Katani, Piccolo, and X-59. In 2017, additional field studies were added to evaluate tolerance of hemp to both pre-seed and post-emergence applied quinclorac, as well as pre-seed flucarbazone, tribenuron, and flucarbazone plus tribenuron. In 2018, the number of cultivars evaluated were dropped to six and post-emergence bromoxynil, quinclorac, quinclorac plus bromoxynil, and pre-seed flucarbazone, tribenuron, and flucarbazone plus tribenuron applications were evaluated for crop tolerance. Most hemp cultivars exhibited acceptable tolerance to post-emergence bromoxynil; however, X-59 exhibited higher levels of injury soon after application. All cultivars recovered from initial injury symptoms and no significant yield penalty was observed. Results from a growth chamber study indicate that CFX-2 is extremely tolerant to bromoxynil application and confirmed that X-59 was one of the most sensitive cultivars tested. Hemp cultivars did not demonstrate acceptable tolerance to post-emergence applications of clopyralid , quinclorac, or

quinclorac plus bromoxynil. Additionally, tolerance to pre-emergence applications of treatments containing flucarbazone was not acceptable. In limited studies, tolerance to pre-seed quinclorac and tribenuron application was acceptable; thus, further screening of these products may be warranted. Data from the bromoxynil studies will be supplied to the Minor Use Center in Ottawa with suggestions for labelling.

5. **Extension Messages:** *key outcomes and their importance for producers/industry (3-5 bullet points in lay language).*

    1. Hemp cultivars vary in their tolerance to post-emergence bromoxynil application; however, even the most sensitive cultivars recover from initial injury symptoms and experience no yield penalty. Yield benefits from reduced weed interference will outweigh any potential crop injury concerns.
    2. Hemp does not exhibit acceptable tolerance to post-emergence quinclorac or clopyralid.
    3. Hemp does not exhibit acceptable tolerance to pre-seed Inferno Duo (flucarbazone + tribenuron) application.
    4. Limited studies indicate that hemp may tolerate pre-seed applications of quinclorac and tribenuron; however, further field studies are required for validation.

6. **Introduction:** *Brief project background and rationale.*

Industrial hemp (*Cannabis sativa*) has been grown in Canada since 1998. The area devoted to hemp production increased dramatically over the past two decades from about 2700 ha in 2003 to over 56,000 ha in 2017; however, this trend was reversed in 2018 (Statistics Canada, 2019). 2018 acreage dropped by over 50% (16,600 ha) due to poor market demand and increased competition from China and Eastern Europe who converted fiber production to food production. Recent changes to hemp legislation allowing growers to harvest hemp flowers, buds, and leaves may open new opportunities for hemp producers and processors. The harvesting of these plant parts will enable processors to extract Cannabidiol (CBD) for the pharmaceutical market, which is expected to bring additional market opportunities.

There has been limited agronomic research on hemp on the Canadian Prairies. Research has identified the nutrient requirements of hemp (Vera et al. 2010) and the impact of seeding rate and row spacing on hemp yield and weed competition (Vera et al. 2006). Increasing seeding rate resulted in reduced weed biomass and higher seed yield (Vera et al. 20006); however, broadleaf weed interference remains problematic with the lack of registered herbicides.

The only published research on herbicide screening in hemp comes from Moldova (Chiriţă 2008). In this study, hemp tolerated acetochlor, metolachlor, and fluazifop but was sensitive to clopyralid, metribuzin, triasulfuron and tribenuron. This information is of limited use to Saskatchewan hemp producers since acetochlor is not available in western Canada, and metolachlor provides limited control of important broadleaf weed species in Saskatchewan. Fluazifop is a graminicide and quizalofop, which is also a graminicde with the same mechanism of action, is registered for use in hemp (Agriculture and Agri-Food Canada 2019). Ethafluralin was recently approved for use in hemp, which will provide a different mechanism of action for grass control plus some limited broadleaf weed control. (Pest Management Regulatory Agency 2018). Edge provides suppression to control of cleavers, chickweed, hemp-nettle, kochia, redroot pigweed, and wild buckwheat but will not control common cruciferous weeds (Saskatchewan Agriculture 2018). Therefore, additional broadleaf weed control options are required.

Screening for herbicide tolerance has been done periodically as part of both the Provincial and Federal Minor Use Programs (Johnson and Ulrich, unpublished data; Johnson et al. 2006; Johnson et al. 2007). As mentioned earlier, quizalofop has been approved by PMRA for the control of grass weeds in hemp. A Minor Use Priority Project for registration of bromoxynil was withdrawn when the sponsoring company (Bayer CropScience) withdrew its support due to tolerance concerns. More recently, anecdotal information and preliminary field trials (Ulrich and Johnson, unpublished data) indicate that there may be significant variation in bromoxynil tolerance within cultivars. The majority of the early studies with bromoxynil was done on the variety Finola, which was found to be quite sensitive to bromoxynil (Johnson and Ulrich, unpublished data). Recently, generic suppliers of bromoxynil have expressed interest in supporting a minor use registration.

Preliminary screening indicated that hemp tolerated pre-seed flucarbazone in some situations (Johnson et al. 2006; Johnson et al. 2007). Again, it may be possible to identify variation in crop response within the germplasm. Based on previous experience, other herbicides that may have potential for hemp to tolerate include clopyralid and sulfentrazone. Also, quinclorac tends to have a relatively narrow range of activity on plants; thus, it may also be a potential candidate for selective weed control in hemp.

This research was initiated to address the lack of broadleaf herbicide options available to hemp growers and to determine if varieties varied in their tolerance to specific herbicides. If some varieties demonstrated greater tolerance than others, there may be opportunities for breeding lines with improved herbicide tolerance.

References:

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Johnson, E.N., Ulrich, D.J., Holm, F.A., Sapsford, K. L. , May, W.E., Nybo, B., Hrynewich, B., Schell, H., Gampe, C., Kapinak, A., Stuber, G., Ife, T., Willoughby, O., and Sluth, D. 2007. Provincial Minor Use Pesticide Screening Program Report for 2007. 34 pp.

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Vera, C. L., Woods, S. M. and Raney, J. P. 2006. Seeding rate and row spacing effect on weed competition, yield and quality of hemp in the Parkland region Saskatchewan. Can. J. Plant Sci. 86: 911–915.

7. Objectives and the progress towards meeting each objective.

Objectives **(Please list the original objectives and/or revised objectives if Ministry-approved revisions have been made to original objective. A justification is needed for any deviation from original objectives)**	**Progress** **(e.g. completed/not completed)**
a) To screen hemp germplasm to determine variability in tolerance to broadleaf herbicides.	**Completed.**
b) To provide data to Minor Use of Pesticides Program to support herbicide registration.	**Will be completed after final report is approved by funding agency.**

Please add additional lines as required.

8. Methodology: *Specify project activities undertaken during entire project period. Include approaches, experimental design, methodology, materials, sites, etc.*

All studies were conducted under a Health Canada License for Controlled Drugs and Substances. All studies were conducted at the University of Saskatchewan Goodale Research Farm on a Bradwell fine sandy loam soil (37% sand, 40% silt, 23% clay), with 1.9% SOM and a pH of 7.0.

Crop Injury Assessment –All visual ratings were done using the Canadian Weed Science Society 0 to 100 scale where 0 represents complete tolerance and 100 represents complete mortality For tolerance trials, ratings <9% represents acceptable tolerance, 10% is just acceptable, and > 11% is unacceptable.

8.*1 Bromoxynil screening*

8.1.1 2016 – 2017 studies

This factorial study investigated the interaction of ten hemp cultivars (Canda, CFX-2, CFX-1, CRS-1, Delores. Grande, Joey Katani, Piccolo, and X-59) with bromoxynil rate (0, 280, and 560 g ai ha^{-1}). The varieties reflect a cross-section of varieties from 3 major seed suppliers in Canada. A fourth company declined to participate in the trial. Experimental design was split-plot with rate as main-plot and cultivar as sub-plot. Each treatment was replicated 4 times. Sub-plot size was 2 X 6 meters. The study was conducted following protocols established by the Pest Management Regulatory Agency’s Regulatory Directive DIR2013-03, Value Assessment of Pest Control Products. The hemp plots were seeded on canola stubble in both years. The trial area received a pre-seed application of glyphosate at 675 g ai ha^{-1}. Hemp was seeded on May 27, 2016 and May 30, 2017 at a rate of 150 seeds m-2. Bromoxynil was applied at the 3-4 leaf stage of the hemp. The entire area received a post-emergence application of clethodim to control grass weeds. Plots were kept weed-free of broadleaf weeds by hand weeding. Data collection included visual injury 7, 19, and 54 days after treatment, crop height 21 days after treatment and at harvest, and seed yield.

8.1.2 2018 study

In 2018, a large field study was conducted that included only 6 cultivars (Canda, CFX-2, CRS-1, Joey, Katani, and X-59) and the herbicide treatments listed in Table 1. The study was conducted following protocols established by the Pest Management Regulatory Agency's Regulatory Directive DIR2013-03, Value Assessment of Pest Control Products. Experimental design was split-plot with cultivar as main plot and herbicide / rate as sub-plot. Treatments were replicated 4 times. Pre-seed herbicide treatments were applied on May 23, 2018 and the plots were seeded on May 28 at a rate of 150 seeds m^{-2}. All plots were seeded on wheat stubble. Post-emergence herbicide treatments were applied at the 3-4 leaf stage of the hemp. The trial area received a pre-seed application of glyphosate at 675 g ai ha^{-1}. The entire area received a post-emergence application of quizalifop to control grass weeds. Plots were kept weed-free of broadleaf weeds by hand weeding. Data collection included visual injury 4, 17, and 44 days after application (DAA), NDVI measurements 4, 17 and 44 DAA, crop height 21 days after treatment and at harvest, and seed yield.

Table 1: Herbicide treatments applied in 2018 hemp study. Goodale. 2018.

No.	Herbicide	Application Timing	Rate (g ai ha^{-1})
1	Untreated		
2	Bromoxynil	POST	280
3	Bromoxynil	POST	560
4	Quinclorac*	POST	100
5	Quinclorac*	POST	200
6	Bromoxynil + Quinclorac*	POST	280 + 100
7	Bromoxynil + Quinclorac*	POST	560 + 200
8	Flucarbazone	PRE-SEED	15
9	Flucarbazone	PRE-SEED	30
10	Tribenuron	PRE-SEED	8
11	Tribenuron	PRE-SEED	16
12	Flucarbazone + Tribenuron	PRE-SEED	15 + 8
13	Flucarbazone + Tribenuron	PRE-SEED	30 + 16

*Merge adjuvant was applied with treatments containing quinclorac at a rate of 0.5% v/v. No adjuvants were applied with the PRE-SEED products.

8.1.3 Growth chamber study

A dose response experiment was conducted in the University of Saskatchewan phytotron in the fall of 2018. The experiment included four hemp cultivars (CRS-1, CFX-2, Joey, and X-59) with bromoxynil rates ranging from 0.25 to 32 times the 1X rate of 280 g ai ha^{-1}. The application rates were 0, 70, 140, 280, 560, 1120, 2240, 4480, and 8960 g ai ha^{-1}. Bromoxynil was applied at the 3-4 leaf stage of the hemp plants. Plants were harvested 27 days after application by clipping the plants at the soil level. Plants were then dried in an oven for 48 hours and weighed.

8.2 Quinclorac screening

8.2.1 2017 study

X-59 hemp was seeded on canola stubble at a rate of 150 seeds m^{-2}. Seeding date was May 30, 2017. Quinclorac was applied pre-seeding and post-emergence at respective rates of 100, 125, 200, and 250 g ai ha^{-1}, and 75, 100, 150, and 200 g ai ha^{-1}. Merge adjuvant was not added to the post-emergence treatments which was an oversight on our part. Experimental design was RCBD with 4 replicates.. Data collection included visual injury 7, 19, and 54 days after treatment, crop height 21 days after treatment and at harvest, and seed yield.

8.2.2 2018 study

Quinclorac and a quinclorac plus bromoxynil tank-mix treatments were included in the 2018 study outlined in section 8.1.2

8.3 Flucarbazone / Tribenuron screening

8.3.1 2016 Flucabazone study

Ten hemp cultivars (Canda, CFX-2, CFX-1, CRS-1, Delores. Grande, Joey Katani, Piccolo, and X-59) were screened for differential tolerance to pre-seed flucarbazone. Since this was an initial screen, cultivars were seeded in single rows at 35 seeds m^{-1} of row in a randomized complete block design. The rows were 6 meter in length and there were 4 replicates of each cultivar. Herbicide treatments were applied 7 days prior to planting. Plots were seeded on canola stubble on May 27, 2016. Plots were cross-sprayed with 1X (15 g ai ha^{-1}) rate of flucarbazone at one end of the plot and 2X (30 g ai ha^{-1}) at the other end of the plot, leaving a 2m unsprayed check in the middle of the plot. The herbicides were applied one week prior to seeding. Since this was an initial screen to determine if further research was warranted, only visual injury assessments, plant density, and plant height data were collected.

8.3.2 2017 Flucarbazone / tribenuron study

Two cultivars (Grandi and Joey) received the following pre-seed treatments:

1. Untreated Check
2. Pre-seed flucarbazone 15 g ai ha^{-1}
3. Pre-seed flucarbazone 30 g ai ha^{-1}
4. Pre-seed tribenuron 8 g ai ha^{-1}
5. Pre-seed tribenuron 16 ai ha^{-1}
6. Pre seed flucarbazone and tribenuron at respective rates of 15 and 18 g ai ha^{-1}
7. Pre seed flucarbazone and tribenuron at respective rates of 30 and 16 g ai ha^{-1}

The cultivars were seeded on May 27, 2017 at a rate of 150 seeds m^{-2}. Plots were seeded on canola stubble. Treatments were applied in a randomized complete block design and were replicated 4 times. Due to inconsistent emergence of the hemp, treatments were not rated until 36 DAT. They were also rated at 56 DAT. Crop yield was also taken.

8.3.3 2018 study

Flucarbazone and a flucarbazone plus tribenuron tank-mix treatments were included in the study outlined in section 8.1.2

8.4 Clopyralid screening

8.4.1 2016 study
Ten hemp cultivars (Canda, CFX-2, CFX-1, CRS-1, Delores. Grande, Joey Katani, Piccolo, and X-59) were screened for differential tolerance to pre-seed clopyralid. Since this was an initial screen, cultivars were seeded in single rows at 35 seeds m^{-1} of row in a randomized complete block design. The rows were 6 meter in length and there were 4 replicates of each cultivar. Plots were seeded on canola stubble on May 27, 2016. Plots were cross-sprayed with 1X (150 g ai ha^{-1}) rate of clopyralid at one end of the plot and 2X (300 g ai ha^{-1}) at the other end of the plot, leaving a 2m unsprayed check in the middle of the plot. The herbicides were applied at the 3-4 leaf stage. Since this was an initial screen to determine if further research was warranted, only visual injury and plant height data were collected.

8.4.2 2017 study
This study was conducted to determine the effect of application timing on hemp tolerance to clopyralid . Clopyralid was applied to hemp (cv. Grandi) at 3 rates (75, 150 and 300 g ai ha^{-1}) over 3 application timings (2-leaf, 4-leaf, and 6 leaf). An untreated check was also included for a total of 10 treatments. Treatments were applied in a randomized complete block design and replicated 4 times. Plots were seeded on canola stubble on May 30, 2017 at a rate of 150 seeds m^{-2}. Data collection included visual injury 7, 19, and 54 days after treatment, crop height 21 days after treatment and at harvest, and seed yield.

8.5 Sulfentrazone screening

8.5.1 2016 study
Ten hemp cultivars (Canda, CFX-2, CFX-1, CRS-1, Delores. Grande, Joey Katani, Piccolo, and X-59) were screened for differential tolerance to pre-seed clopyralid. Since this was an initial screen, cultivars were seeded in single rows at 35 seeds m^{-1} of row in a randomized complete block design. The rows were 6 meter in length and there were 4 replicates of each cultivar. Herbicide treatments were applied 7 days prior to seeding. Plots were seeded on canola stubble on May 27, 2016. Plots were cross-sprayed with 1X (140 g ai ha^{-1}) rate of sulfentrazone at one end of the plot and 2X (280 g ai ha^{-1}) at the other end of the plot, leaving a 2m unsprayed check in the middle of the plot. The herbicides were applied one week prior to seeding. Since this was an initial screen to determine if further research was warranted, only visual injury assessments, plant density, and plant height data were collected.

9. **Results and discussion:** *Describe results accomplished during the entire project period under each objective listed under section 6. The results need to be accompanied with tables, graphs and/or other illustrations. Provide discussion necessary to the full understanding of the results. Where applicable, results should be discussed in the context of existing knowledge and relevant literature. Detail any major concerns or project setbacks.*

9.*1 Bromoxynil screening*

9.1.1 2016 – 2017 studies

Overall visual injury at the first rating date was much lower in 2017 than 2016 (Figure 1). Despite the lower injury, trends were similar with the lowest injury ratings recorded for CRS-1 and CFX-2 in both years while the highest injury ratings were recorded with X-59 (Figure 1). In 2016, the injury for X-59, Joey, and CFX-1 exceeded 10% at the second rating date (Figure 2). At the second rating date in 2017, all cultivars had recovered from the initial chlorotic injury and all ratings were less than 10% (data not shown). In both years, there was little injury evident late in the growing season (data not shown). In 2016, there was a cultivar by bromoxynil rate interaction for crop height taken 9-14 DAT (Table 1). Height measurements indicated that the 2X rate resulted in a significant height reduction in all cultivars with the exception of CRS-1 (Figure 3). In 2017, both cultivar and rate had an effect on crop height; however there was no interaction (Table 1). Applying bromoxynil at 280 or 560 g ai ha^{-1} reduced the height of all cultivars by an average of 4 cm in 2017 (data not shown). At crop maturity, cultivar was the only factor that had an effect on crop height in both years (Table 1); therefore, the height data was combined and presented in Figure 4. CRS-1, Canda, Joey, and Delores were significantly taller than the other cultivars. There was no cultivar or rate effect, or cultivar by rate interaction for crop yield in 2016 (Table 1). In 2017, there was a rate effect and the p-value of the cultivar by rate interaction was p=0.05 (Table 1). In 2017, X-59, Grandi, Joey, Piccolo, Katani, CFX-1, and CRS-1 yields from the 280 and 560 g ai ha^{-1} application did not differ from the untreated check (Figure 5). The 2X rates of Canda and CFX-2 yielded higher than the untreated check and the 1X rate of Delores was higher yielding than the untreated check (Figure 5). Although there was not a cultivar by rate interaction in 2016, it is interesting to note the similar yield trends of the cultivars for the 2 years. The trend for the 2X rate of Canda and CFX-2 was to yield higher than the untreated check as was the 1X rate of Delores. Although the decline in yield at the 2X rate for X-59 compared to the check was not significant in either year, the trend was consistent between years (Figure 5). This supports the observation that X-59 is one of the more sensitive cultivars to bromoxynil. Injury symptoms from bromoxynil application are illustrated in Figures 6 and 7.

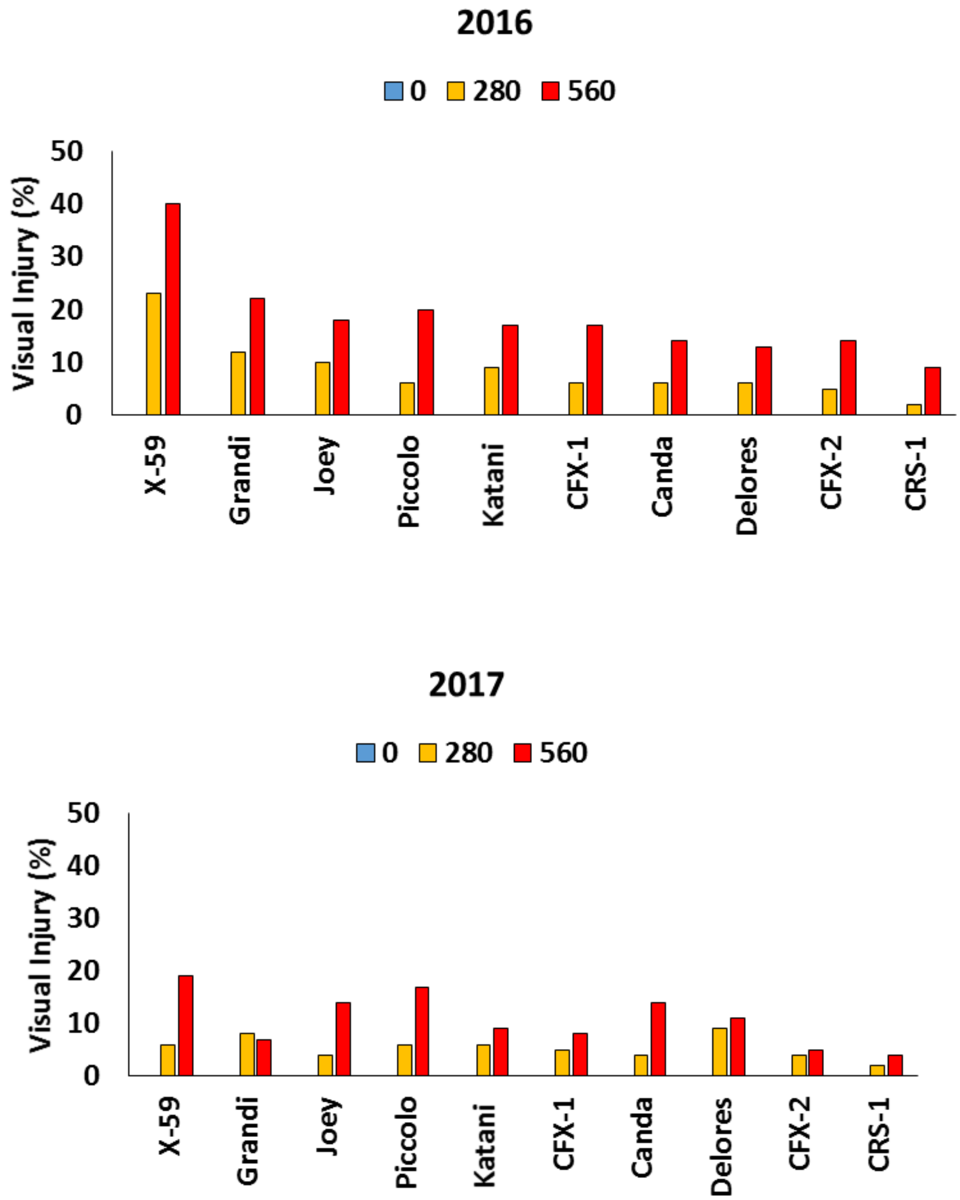


Figure 1: Effect of bromoxynil rate on visual injury to 10 different hemp cultivars at 7-10 DAA. Goodale Research Farm 2016 (top) and 2017 (bottom).

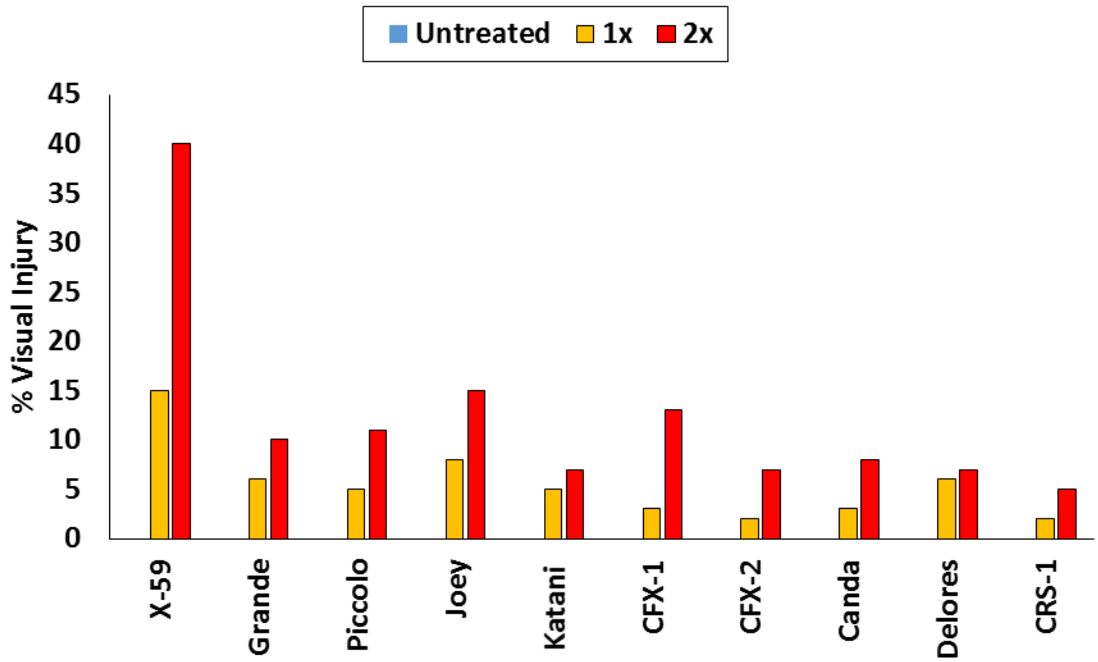


Figure 2: Effect of bromoxynil rate on visual injury to 10 different hemp cultivars at 14-21 DAA. Goodale Research Farm. 2016.

Table 2: p-values for effect of bromoxynil rate on crop height 9-14 DAA and at crop maturity, and seed yield of 10 hemp cultivars. Saskatoon Goodale Farm. 2016-17.

Source	Crop Height (cm) 9-14 DAT	Crop Height (cm) Maturity	Seed Yield (kg/ha)
2016			
Cultivar (C)	0.016	0.879	0.614
Herbicide Rate (H)	0.000	0.000	0.383
C X H	0.015	0.542	0.282
2017			
Cultivar (C)	0.002	0.000	0.179
Herbicide Rate (H)	0.003	0.056	0.006
C X H	0.582	0.330	0.051

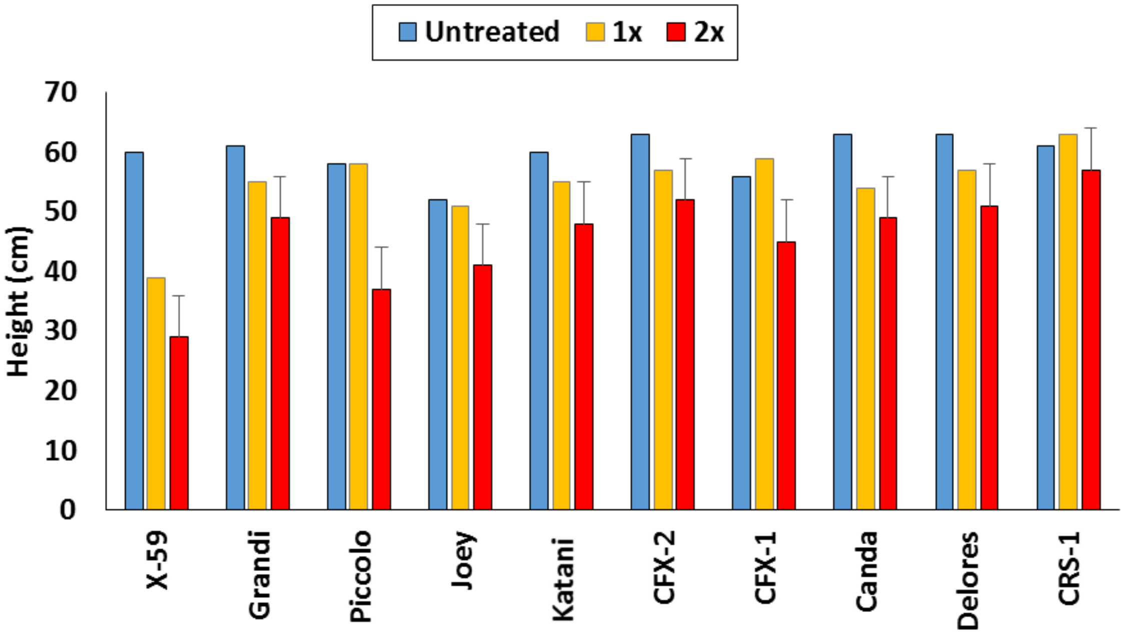


Figure 3: Interaction of bromoxynil application rate and cultivar on hemp height 9 DAA. Error bar represents the $LSD_{0.05}$ for the cultivar X herbicide rate interaction. Goodale Research Farm. 2016.

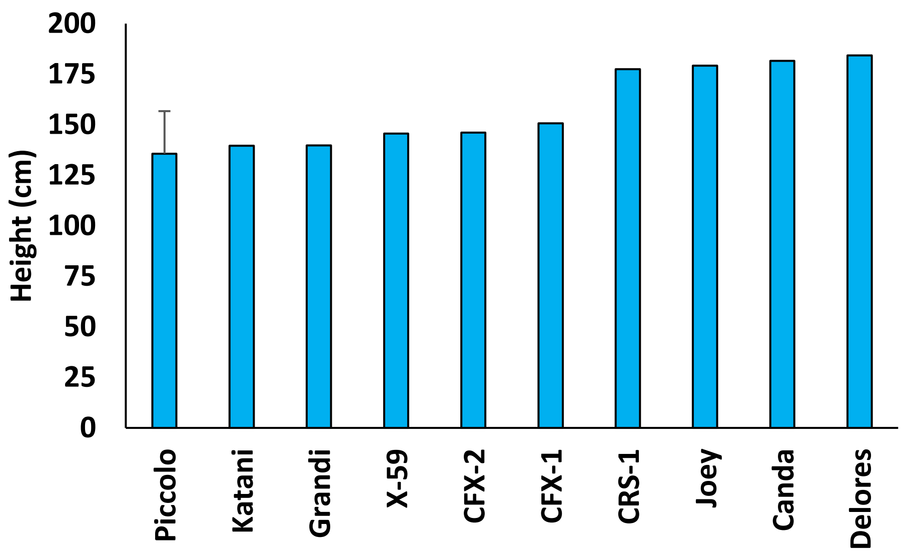
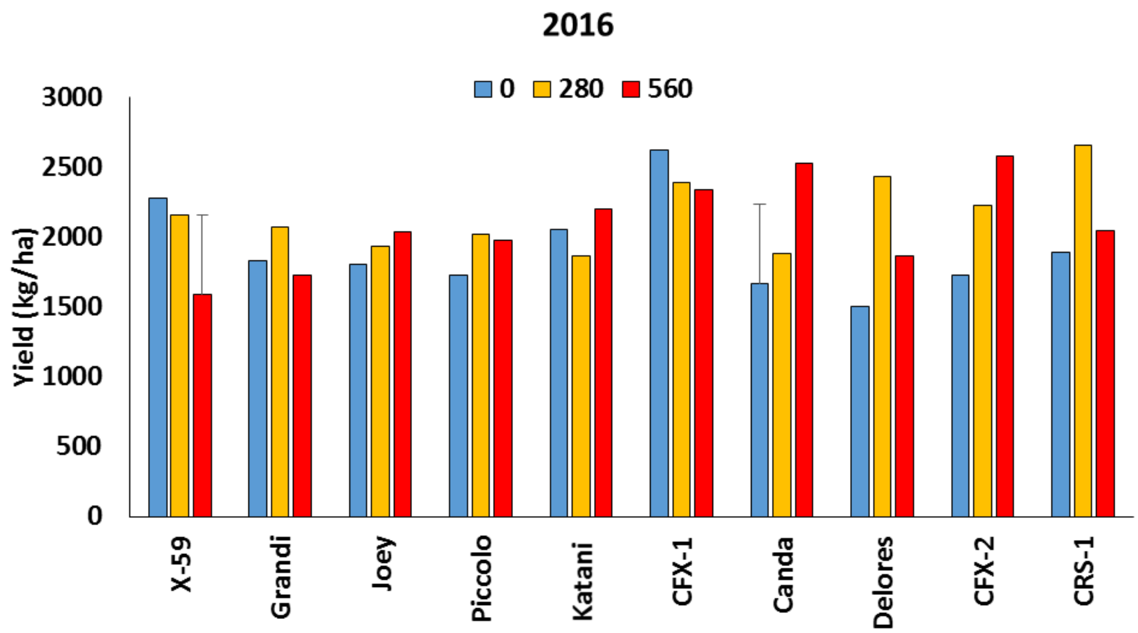


Figure 4: Height of hemp cultivars near crop maturity. Error bar represents the $LSD_{0.05}$. Means of 2 years. Goodale Research Farm. 2016-17.



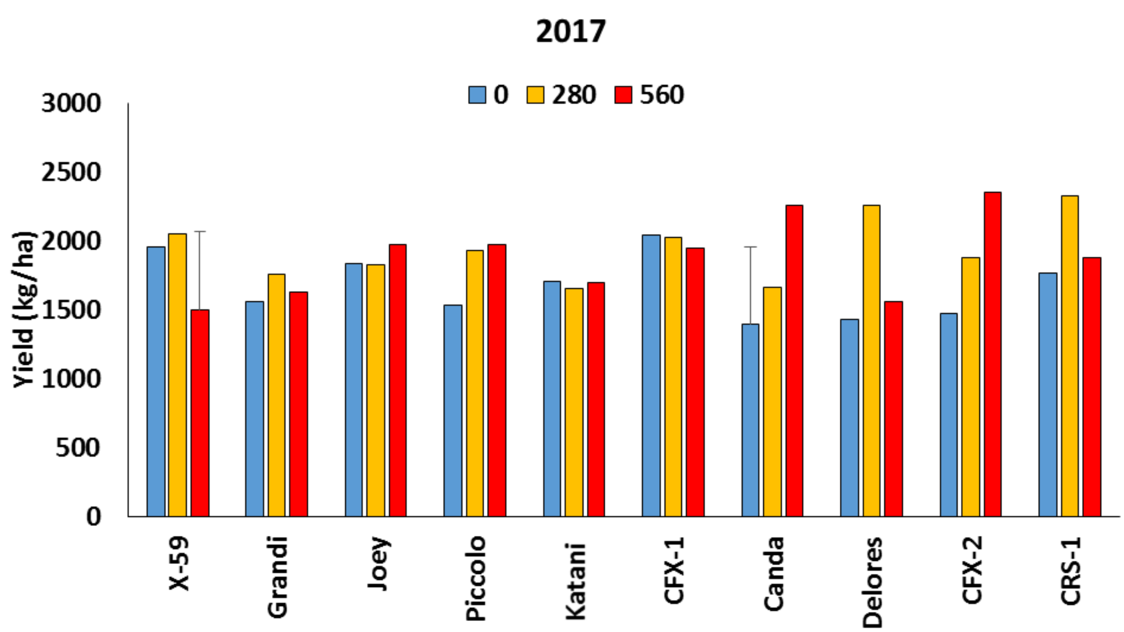


Figure 5: Effect of bromoxynil application rate on seed yield of 10 hemp cultivars (kg ha^{-1}) in 2016 (top) and 2017 (bottom). Error bar represents the $LSD_{0.05}$ for the cultivar X herbicide rate interaction. Goodale Research Farm. 2016-17.

Figure 6: Bromoxynil injury symptoms on X-59 taken about 10 days after application. Note the healthy new growth on the top of the plant. Goodale Research Farm. 2016.

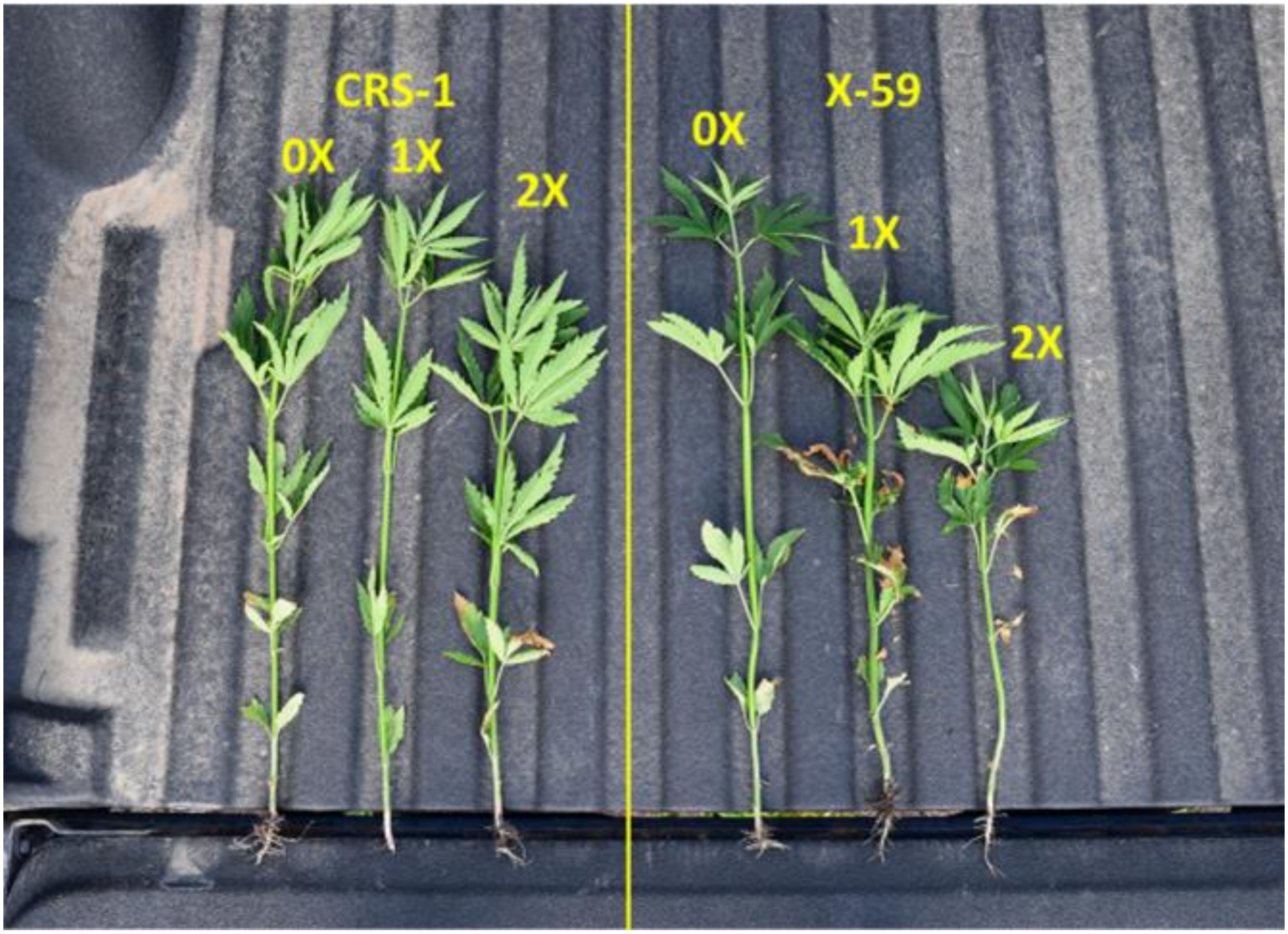


Figure 7: Differential tolerance of the hemp cultivars CRS-1 (left) and X-59 (right) to bromoxynil application. Photo taken 8 days after application. Goodale Research Farm. 2016.

9.1.2 2018 Results

Similar to previous years, X-59 exhibited the highest visual injury ratings soon after application (Figure 8). All other cultivars exhibited <10% visual injury at the first rating date. Symptoms were transient on all cultivars and the height of bromoxynil treated X-59 was similar to the untreated check at 19 DAA, indicating full recovery (Figure 9). Visual injury ratings later in the season were acceptable for all cultivars (data not shown). None of the bromoxynil treatments resulted in a lower yield than the checks for all cultivars tested (Figure 10).

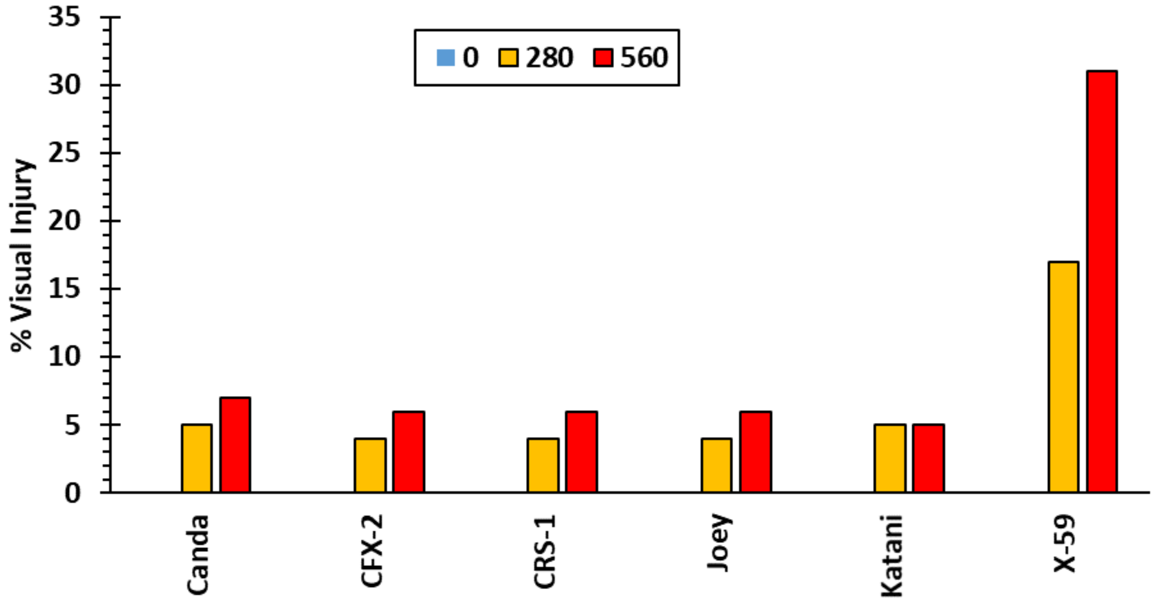


Figure 8: Effect of bromoxynil application rate on visual injury (%) to 6 hemp cultivars taken 4 DAA. Goodale Research Farm. 2018.

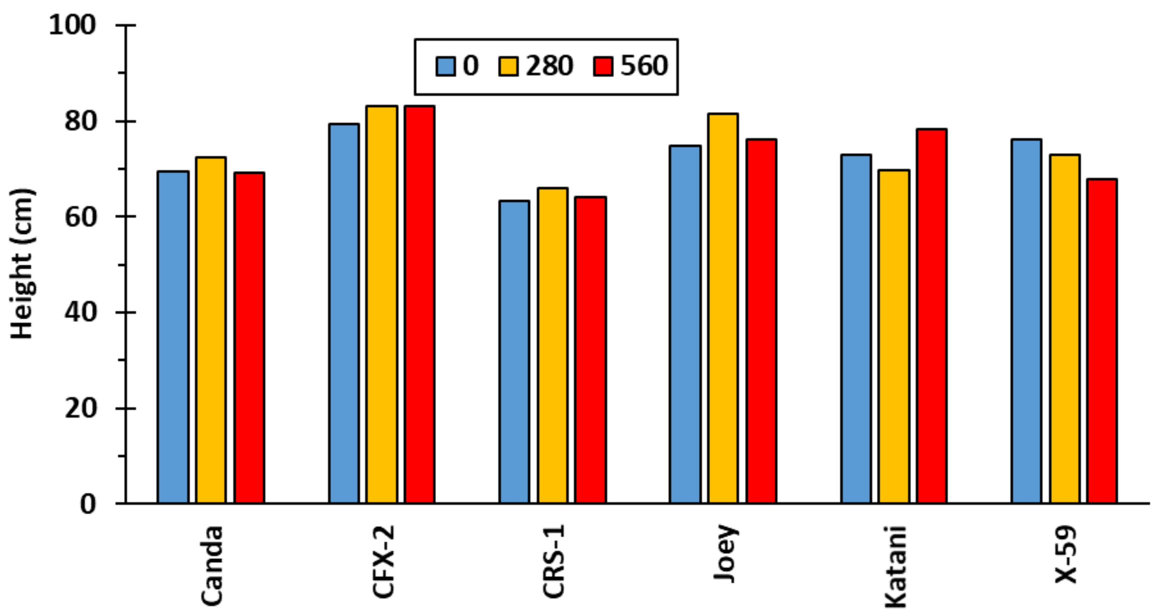


Figure 9: Effect of bromoxynil application rate on height (cm) of 6 hemp cultivar taken 19 DAA. Goodale Research Farm. 2018.

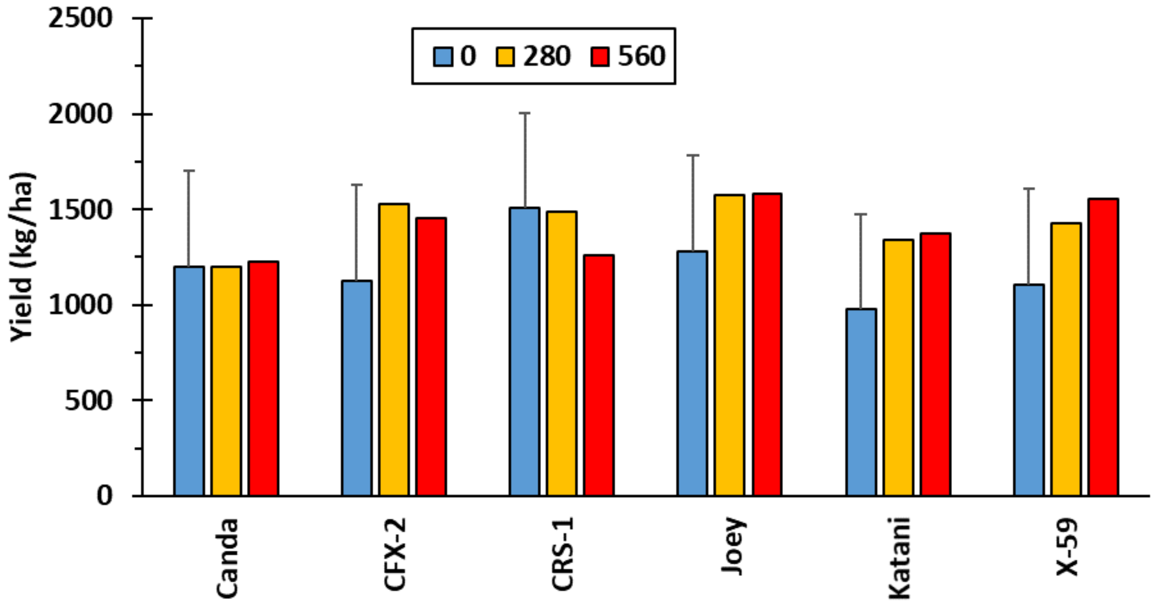


Figure 10: Effect of bromoxynil application rate on yield (kg/ha) of 6 hemp cultivars. Error bar represents the $LSD_{0.05}$. Goodale Research Farm. 2018.

9.1.3 Growth chamber results

Despite extremely high application rates, the biomass of CFX-2 was only reduced by approximately 30% at the highest application rate (Figure 11). Thus, the effective dose that reduced biomass by 50% (ED_{50}) was estimated to be 31900 g ai ha^{-1}, a rate that was 3.5X time higher than the highest rate applied (Table 3). This estimated ED_{50} is 5 to 7 times higher than the ED_{50}'s for CRS-1 and Joey, and 43 times higher than X-59. The ED_{50} for CRS-1 and Joey were similar (no statistical difference) and were about 7 times higher than X-59 ($p=0.0003$). The growth chamber study confirmed field studies that indicated lower bromoxynil tolerance of X-59 compared to other cultivars; however, the rate required to reduce the biomass of X-59 by 50% was still 2.5 times the 1X field rate of bromoxynil (280 g ai ha^{-1})

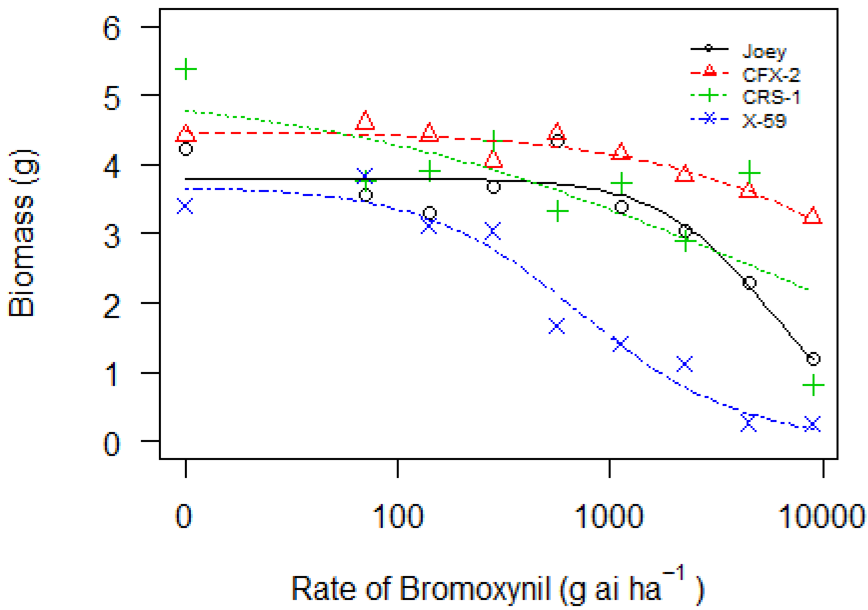


Figure 11: Effect of bromoxynil application rate on biomass (g) of 4 hemp cultivars. University of Saskatchewan. 2018.

Table 3: ED_{50} values from bromoxynil application to 4 cultivars of hemp. Saskatoon. 2018.

	ED_{50} g ai ha^{-1}
CFX-2	31900
CRS-1	4356
Joey	5610
X-59	730

9.2 Quinclorac screening

9.2.1 2017 study

None of the pre- or post- applications of quinclorac resulted in unacceptable injury ratings, with no ratings exceeding 2% (data not shown). The highest 2 rates of the post- applications resulted in about an 8% height reduction in crop height (Figure 12). Pre- or post- application did not result in yield reductions when compared to the untreated check (Figure 13). These results should be taken with a note of caution. There was no surfactant added to the post- applications of quinclorac; thus, the study was repeated in 2018 to determine if a registered surfactant increases the potential for quinclorac injury.

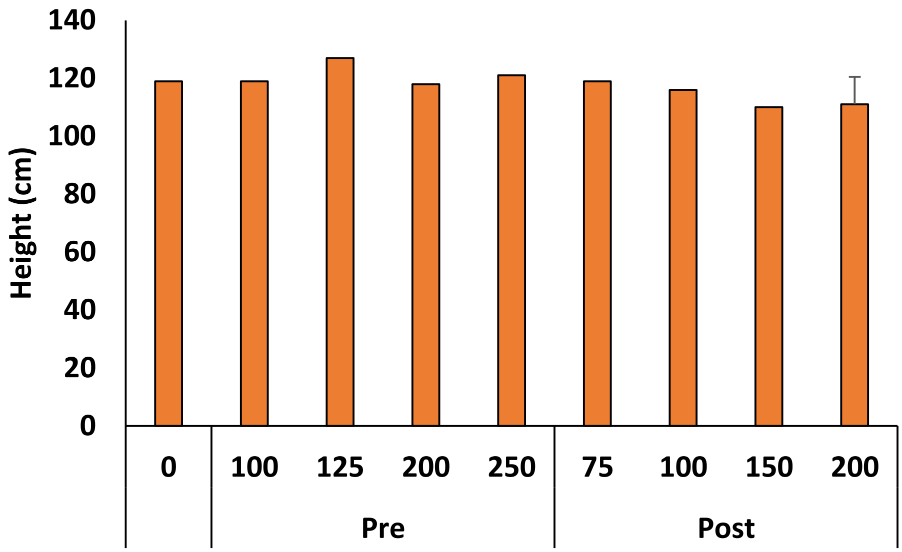


Figure 12. Effect of quinclorac application timing and rate on height of hemp (cm). Error bar represents the $LSD_{0.05}$. Goodale Research Farm. 2016-17.

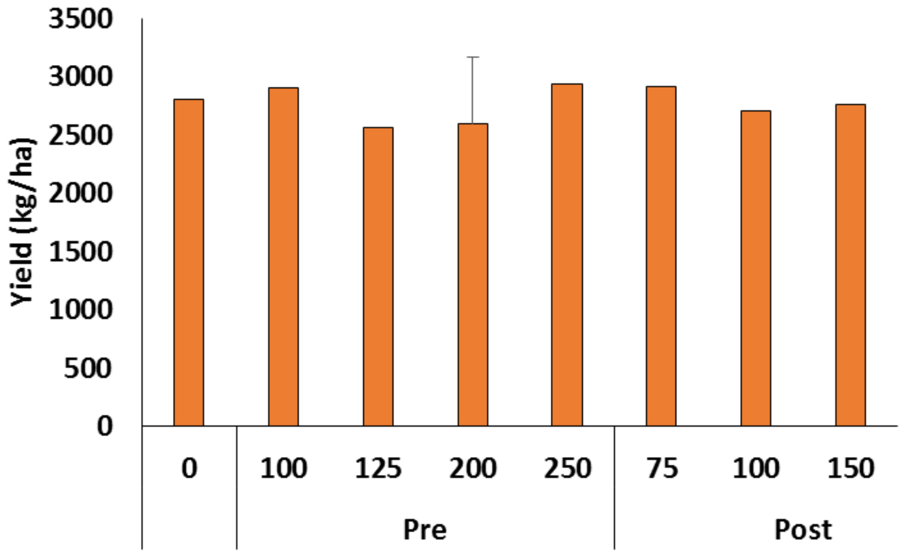


Figure 13: Effect of quinclorac application timing and rate on yield of hemp (kg ha^{-1}). Error bar represents the $LSD_{0.05}$. Goodale Research Farm. 2016-17.

9.2.2 2018 Study

Initial injury ratings 4 days after application failed to detect significant damage from quinclorac application (data not shown). Injury symptoms were evident at the second rating date (17 DAA; Figure 14) with all cultivars exhibiting injury symptoms. Most of the cultivars exhibited >10% visual injury to quinclorac alone with the exception of X-59 (Figure 15). All cultivars exhibited unacceptable injury to the quinclorac + bromoxynil tank-mix at 17 DAA (Figure 15). These ratings were confirmed with NDVI measurements using a hand-held greenseeker (Figure 16). Lowest NDVI readings were recorded with the quinclorac and bromoxynil tank-mix applications. Visually injury symptoms persisted throughout the growing season with generally unacceptable ratings recorded at 44 DAA (Figure 17). An interesting observation was that X-59 had higher injury ratings from quinclorac application at 44 DAA than those taken at 17 DAA; therefore, the rate at which symptoms appeared was much slower in this cultivar. Also, X-59 exhibited greatest recovery from the quinclorac + bromoxynil tank-mix at 44 DAA (Figure 17).

Despite unacceptable injury ratings, yields were not adversely affected with X-59 exhibiting a slight yield increase from the herbicide applications (Figure 18). Although yields were not affected, it is unlikely that a pesticide company would support this registration due to the high levels of visual injury. The lack of injury from post-emergence application of quinclorac in the 2017 trials was likely due to the absence of the Merge adjuvant.

Figure 14: Quinclorac injury symptoms in hemp. Goodale Research Farm. 2018.

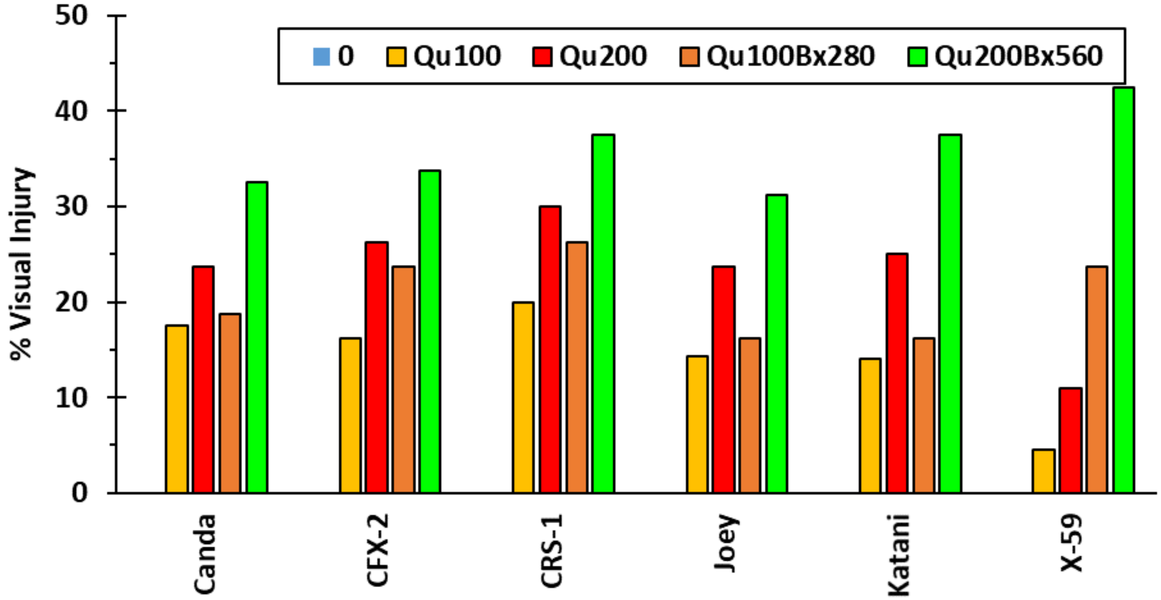


Figure 15: Visual injury ratings (%) from quinclorac and quinclorac + bromoxynil tank-mixes taken 17 DAA. Abbreviations: Qu = Quinclorac; QuBx = Quinclorac + bromoxynil tank-mix. Number following the abbreviation is the application rate in g ai ha^{-1}. Goodale Research Farm. 2018.

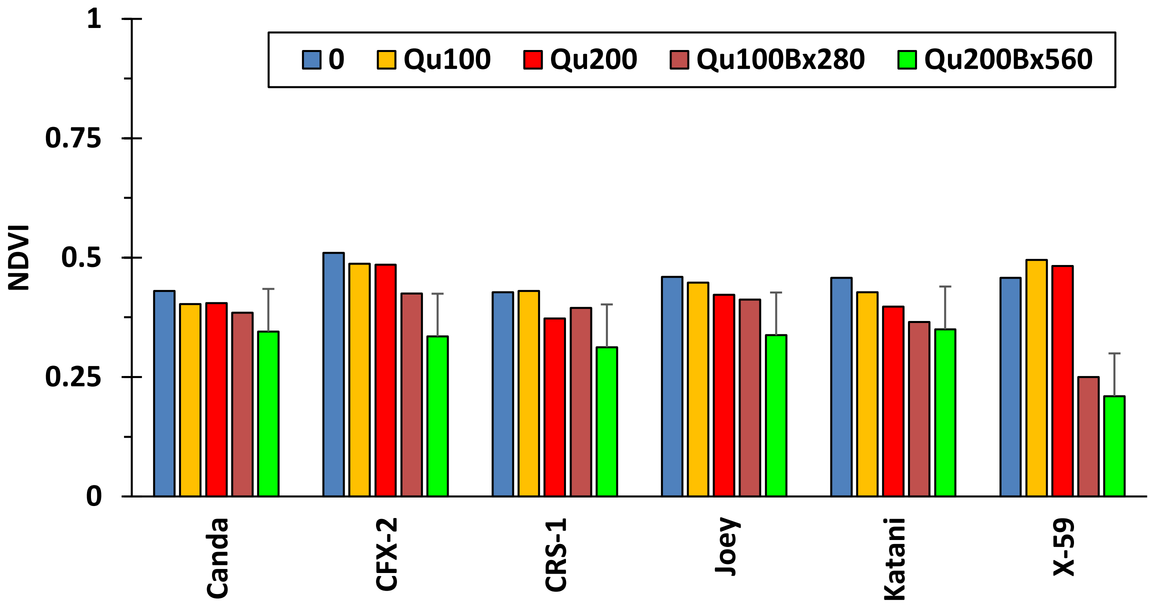


Figure 16: The effect of quinclorac and quinclorac + bromoxynil tank-mixes on NDVI measurements taken in 6 hemp cultivars. Measurements taken 17 DAA with handheld greenseeker. Error bar represents the $LSD_{0.05}$. Abbreviations: Qu = Quinclorac; QuBx = Quinclorac + bromoxynil tank-mix. Number following the abbreviation is the application rate in g ai ha^{-1}. Goodale Research Farm. 2018.

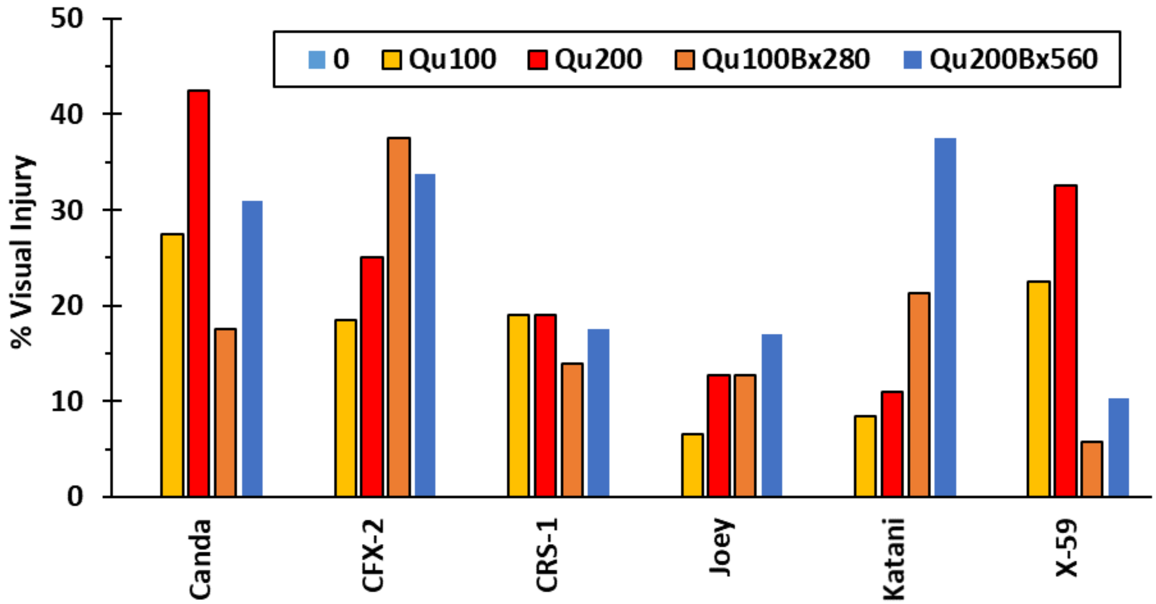


Figure 17: Visual injury ratings (%) from quinclorac and quinclorac + bromoxynil tank-mixes taken 44 DAA. Abbreviations: Qu = Quinclorac; QuBx = Quinclorac + bromoxynil tank-mix. Number following the abbreviation is the application rate in g ai ha^{-1}. Goodale Research Farm. 2018.

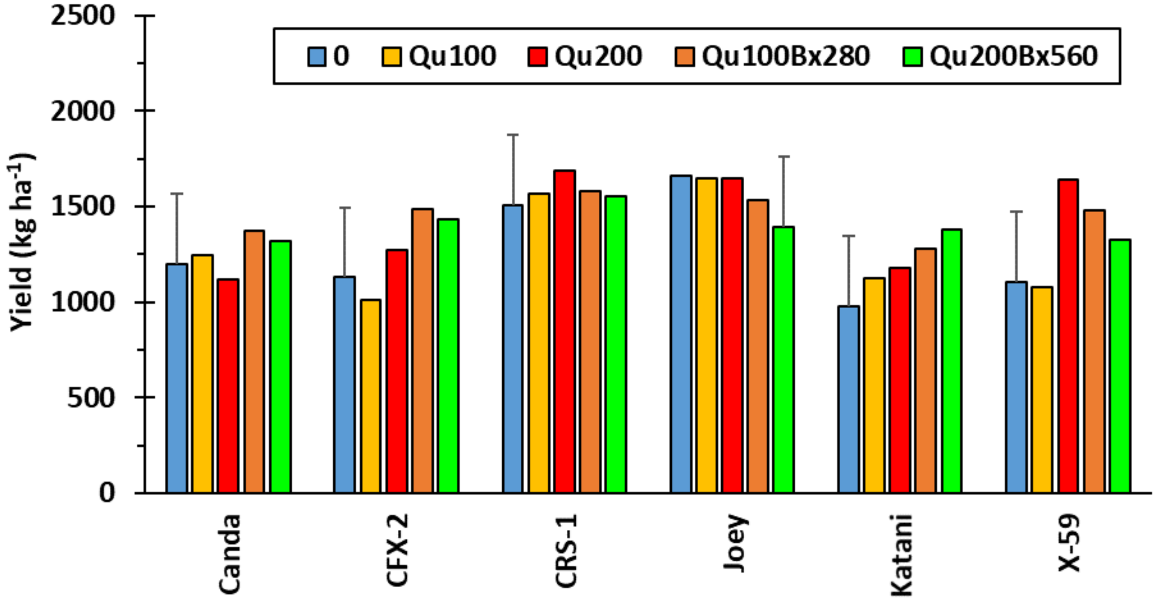


Figure 18: The effect of quinclorac and quinclorac + bromoxynil tank-mixes on yield of 6 hemp cultivars. Error bar represents the $LSD_{0.05}$. Abbreviations: Qu = Quinclorac; QuBx = Quinclorac + bromoxynil tank-mix. Number following the abbreviation is the application rate in g ai ha^{-1}. Goodale Research Farm. 2018.

9.3 Flucarbazone / Tribenuron screening

9.3.1 2016 flucabazone study

Single rows were seeded, so only the effect of the pre-seed flucarbazone application on hemp plant density is presented. There was a herbicide by cultivar interaction for plant density. X-59, CRS-1, and Joey had lower plant densities from flucarbazone application compared to the untreated check (Figure 19). Although not significantly different than the untreated check, the trend for lower plant densities from flucarbazone application was observed in CFX-2, Piccolo, Canda, and Delores. Flucarbazone application had the least impact on densities of CFX-1 and Katani (Figures 19 and 20).

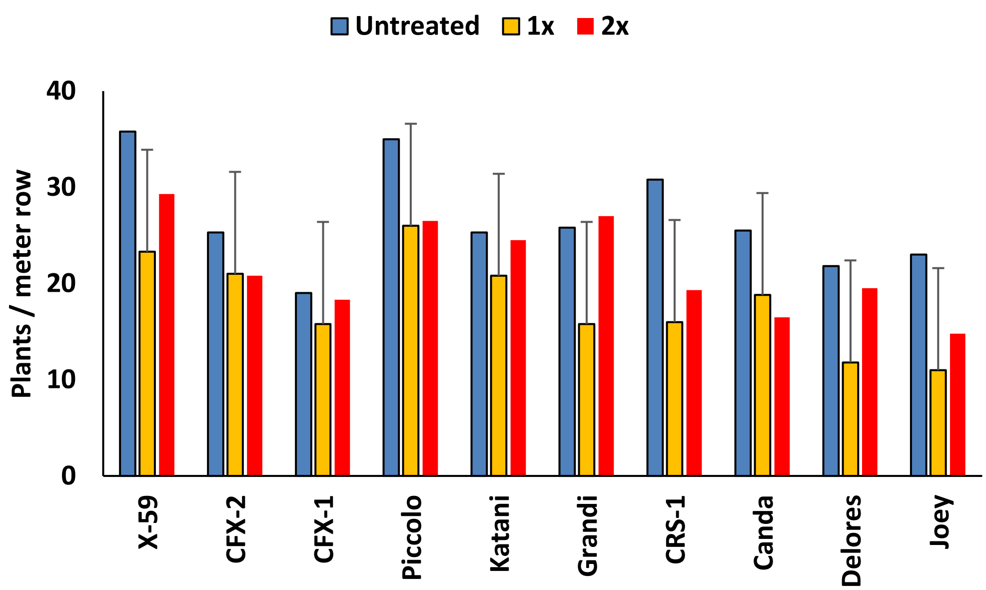


Figure 19: Interaction of flucarbazone application rate and cultivar on hemp plant density (plants m^{-2}). Error bar represents the $LSD_{0.05}$ for the cultivar X herbicide rate interaction. Goodale Research Farm. 2016.

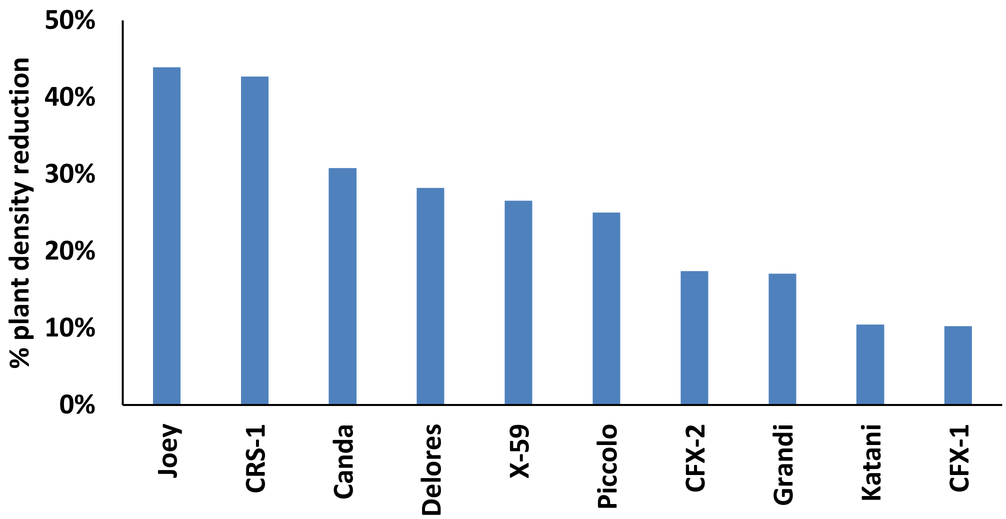


Figure 20: Effect of flucarbazone application on percent plant density reduction in hemp cultivars when compared to untreated check. Mean of 1X and 2X rates. Goodale Research Farm. 2016.

9.3.2 2017 Flucarbazone / tribenuron screening

Plant emergence in this trial was low and uneven; thus, results from this trial were inconsistent and difficult to interpret. Thus, a similar trial was repeated in 2018.

9.3.3 2018 Flucarbazone / tribenuron screening

The 2018 study provided very clear results in terms of the risk associated with flucarbazone and flucarbazone + tribenuron application. There were no cultivar by herbicide interactions, indicating that all cultivars responded similarly to the herbicides applied. Flucarbazone and flucarbazone + tribenuron application reduced plant density by as much as 40% (Figure 21); however, tribenuron alone did not have an effect. Visual stand reduction ratings taken at the same time as the plant counts (21 days after emergence) indicated very high levels of crop injury (Figure 22). The visual ratings would have taken into account that the plants were much smaller in the flucarbazone and flucarbazone + tribenuron treatments; whereas, they would have still been counted as living plants. Some plots exhibited extremely high levels of crop injury from treatments that included flucarbazone (Figure 23). NDVI measurements taken on July 12, 2018 indicated that injury from flucarbazone and flucarbazone + tribenuron application was still severe (Figure 24). Despite severe injury, crop yield was not affected by any treatment, indicating the compensatory ability of hemp to recover from low plant densities and herbicide injury (Figure 25). As is the case with quinclorac, pesticide companies would not support registration of a herbicide with that much crop injury even though yield was not affected. The lack of tribenuron injury indicates potential for use prior to seeding hemp.

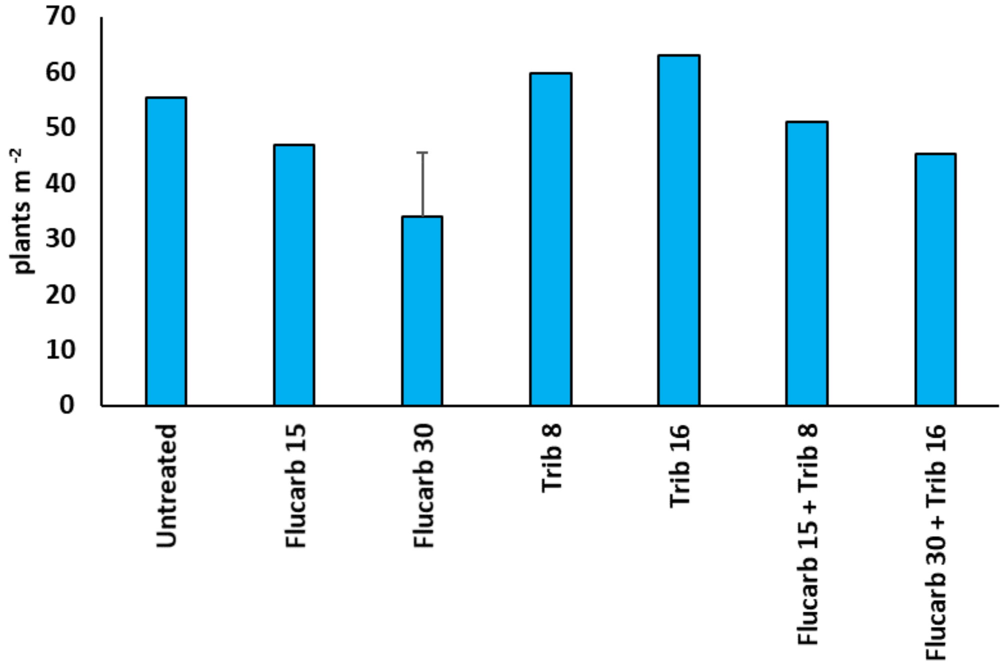


Figure 21: Effect of flucarbazone, tribenuron, and flucarbazone + tribenuron application on plant density (plants m^{-2}). Abbreviations: Flucarb = Flucarbazone; Trib = Tribenuron; Number following the abbreviation is the rate applied in g ai ha^{-1}. Error bar represents the $LSD_{0.05}$. Mean of 6 cultivars. Goodale Research Farm. 2018.

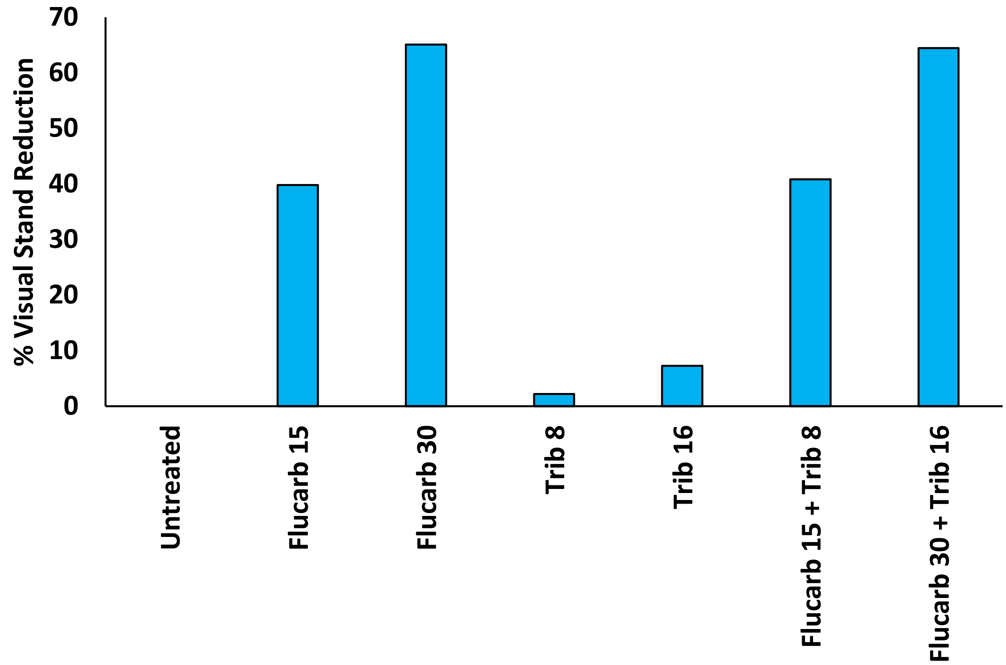


Figure 22: Visual stand reduction (%) from flucarbazone, tribenuron, and flucarbazone + tribenuron application in hemp. Ratings taken 21 days after crop emergence. Abbreviations: Flucarb = Flucarbazone; Trib = Tribenuron; Number following the abbreviation is the rate applied in g ai ha^{-1}. Error bar represents the $LSD_{0.05}$. Mean of 6 cultivars. Goodale Research Farm. 2018.

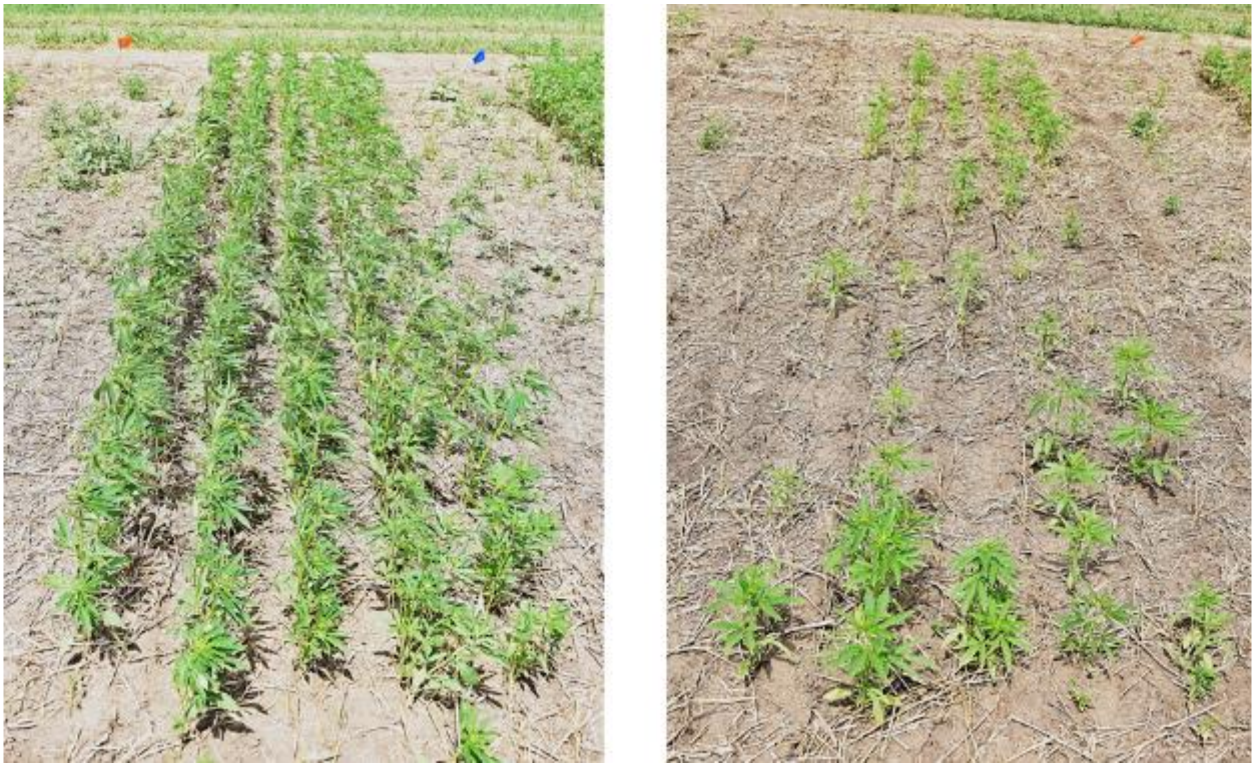


Figure 23: Untreated check (left) and pre-seed flucarbazone at 2X rate (right). Goodale Research Farm. 2018.

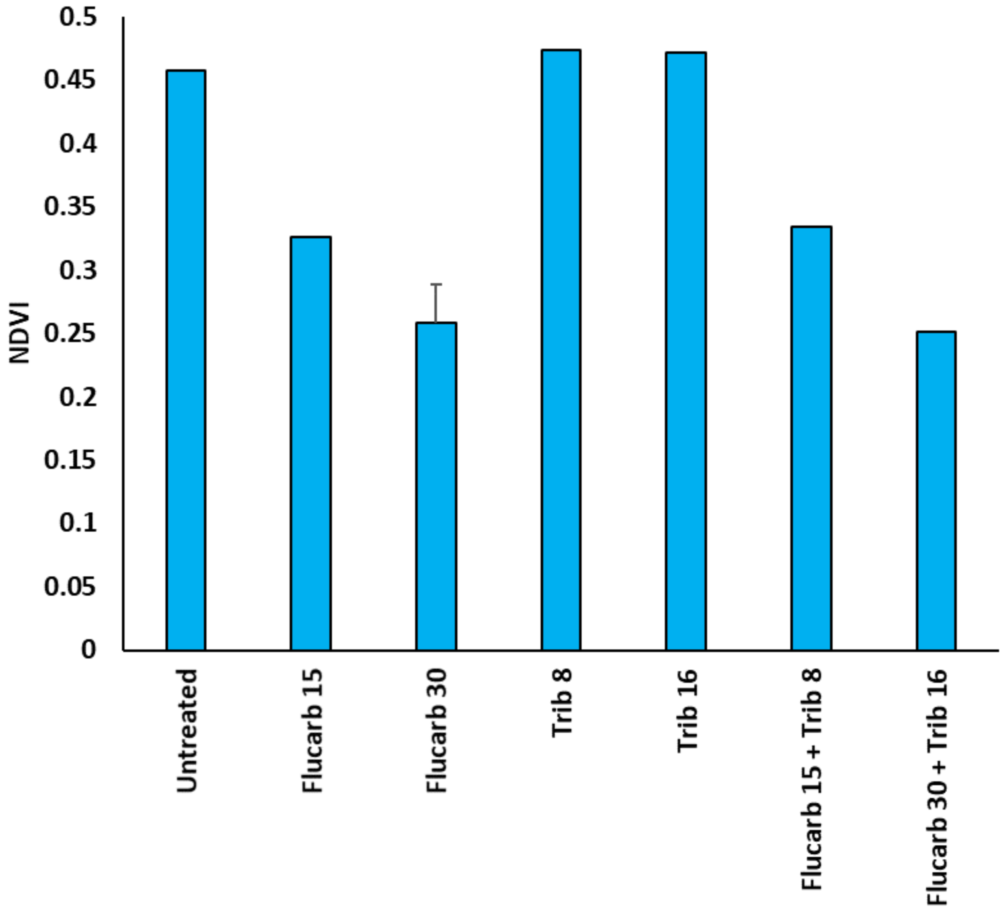


Figure 24: Effect of flucarbazone, tribenuron, and flucarbazone + tribenuron application on NDVI measurements in hemp taken on July 12, 2018. Mean of 6 cultivars. Abbreviations: Flucarb = Flucarbazone; Trib = Tribenuron; Number following the abbreviation is the rate applied in g ai ha^{-1}. Error bar represents the $LSD_{0.05}$. Goodale Research Farm. 2018.

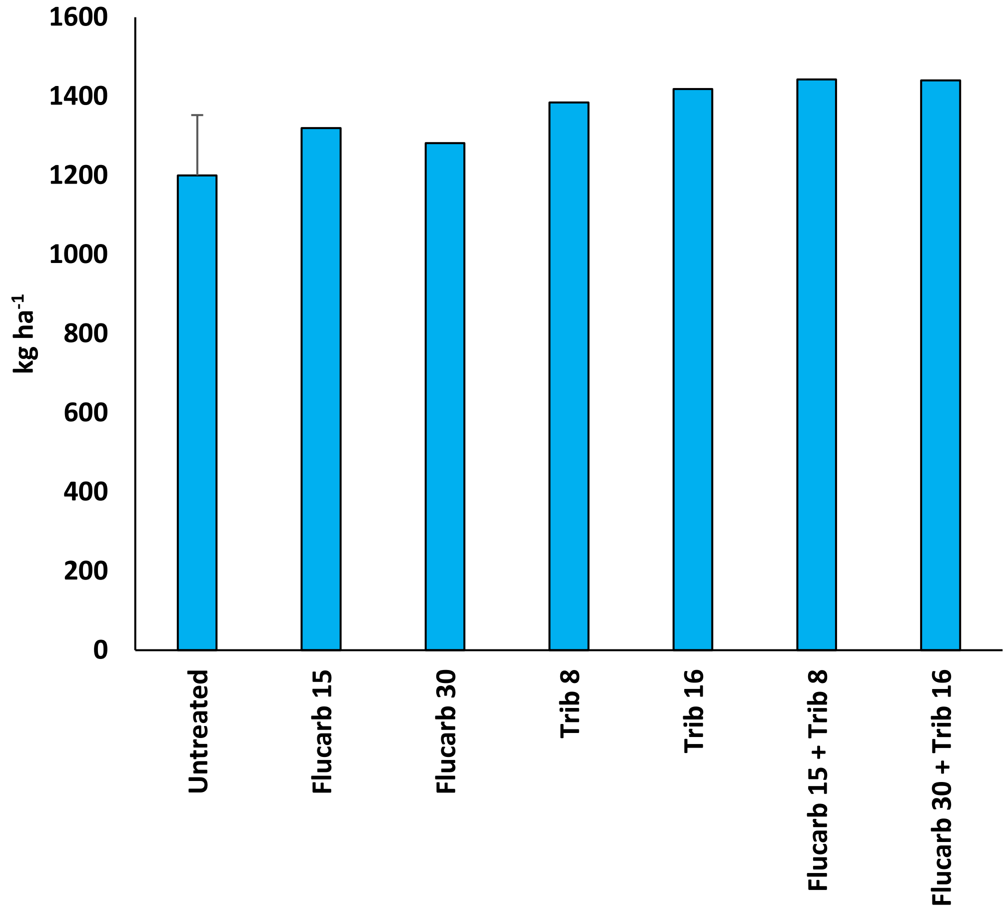


Figure 25: Effect of flucarbazone, tribenuron, and flucarbazone + tribenuron application on seed yield (kg ha^{1-}) in hemp. Mean of 6 cultivars. Abbreviations: Flucarb = Flucarbazone; Trib = Tribenuron; Number following the abbreviation is the rate applied in g ai ha^{-1}. Error bar represents the $LSD_{0.05}$. Goodale Research Farm. 2018.

9.4 *Clopyralid screening*

9.4.1 2016 study

Single rows were seeded, and some small differences in visual injury ratings were recorded between the 10 cultivars at the 2X rate (Figure 26); however, all cultivars had >10% visual injury from the 2X application.

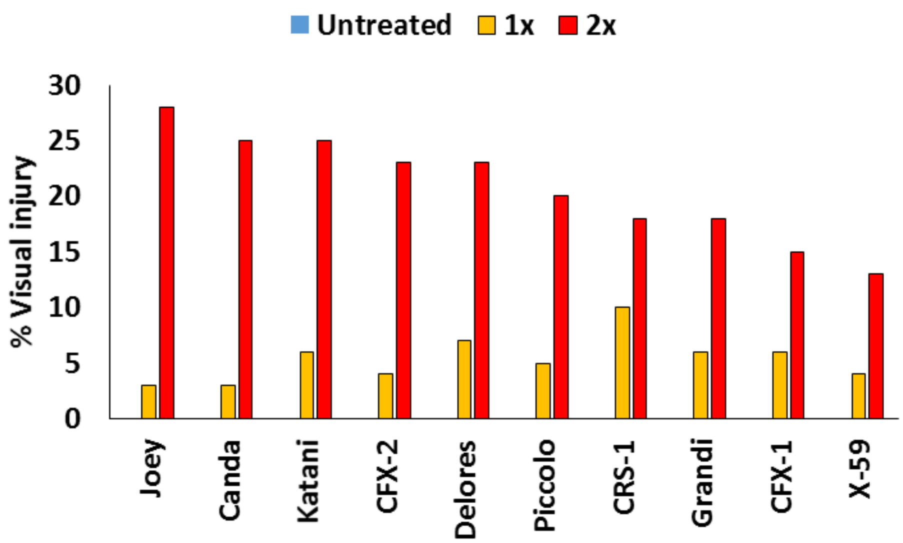


Figure 26: Visual injury ratings (%) on 10 hemp cultivars from post-emergence clopyralid application. Ratings taken 23 DAA. Goodale Research Farm. 2016.

9.4.2 2017 study

Visual injury ratings taken 15 days after the herbicide was applied indicated that injury increased as rate was increased, particularly at later growth stages (Figure 27). Injury was less than 10% at the 75 and 150 g ai ha^{-1} rate at the 2-leaf stage and the 75 g ai ha^{-1} rate at the 4-leaf stage. All rates resulted in >10% injury when applied at the 6-leaf stage (Figure 27). Injury subsided somewhat as the season progressed; however >10% injury was recorded 58 days after treatment when 300 g ai ha^{-1} was applied at the 2 and 6-leaf stage (Figure 28). Application of clopyralid at the 6-leaf stage resulted in 15 to 18% lower yields than when applied at the 2 or 4 leaf stage (Figure 29). Injury symptoms from a 300 g ai ha^{-1} application at the 6-leaf stage are shown in Figure 30. Despite less injury at earlier growth stages, there does not appear to be sufficient tolerance to pursue registration of clopyralid on hemp.

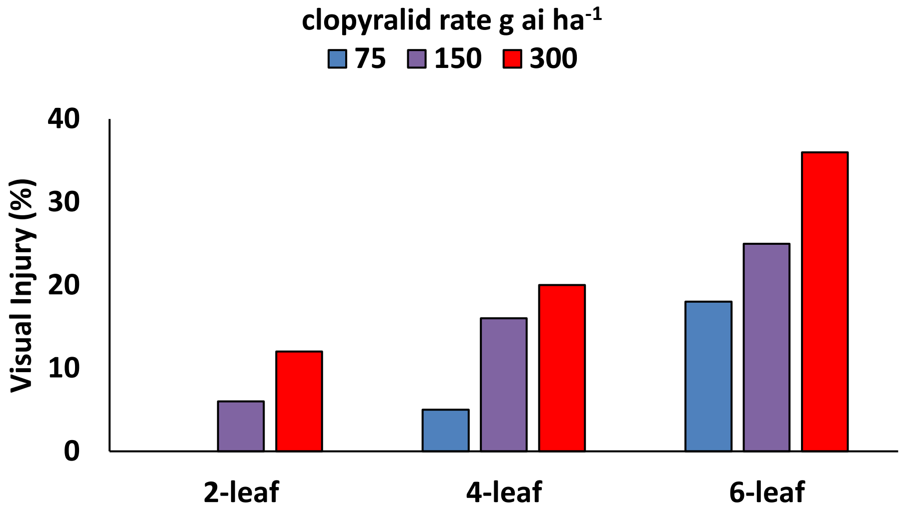


Figure 27: Effect of clopyralid rate on % visual injury in hemp when applied at the 2, 4, and 6-leaf stage of hemp. Ratings taken 15 DAA. Goodale Research Farm 2017.

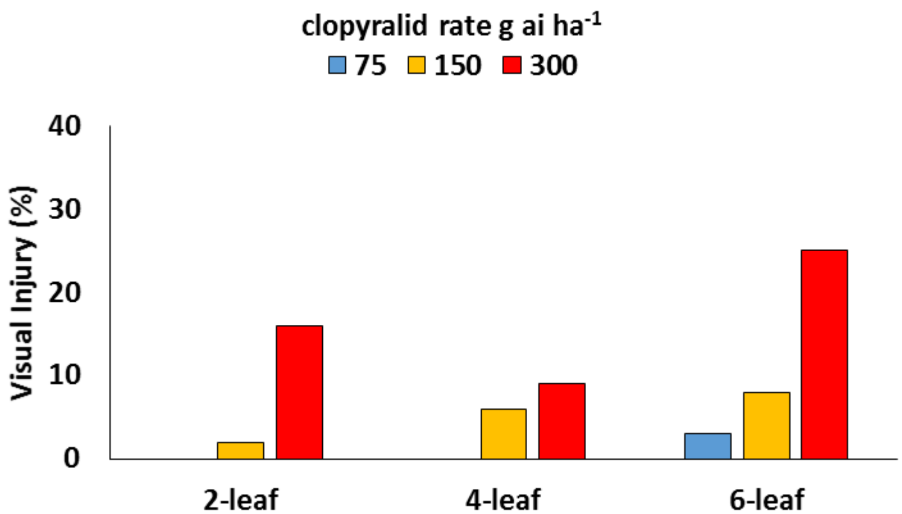


Figure 28: Effect of clopyralid rate on % visual injury in hemp when applied at the 2, 4, and 6-leaf stage. Ratings taken 58 DAA. Goodale Research Farm 2017.

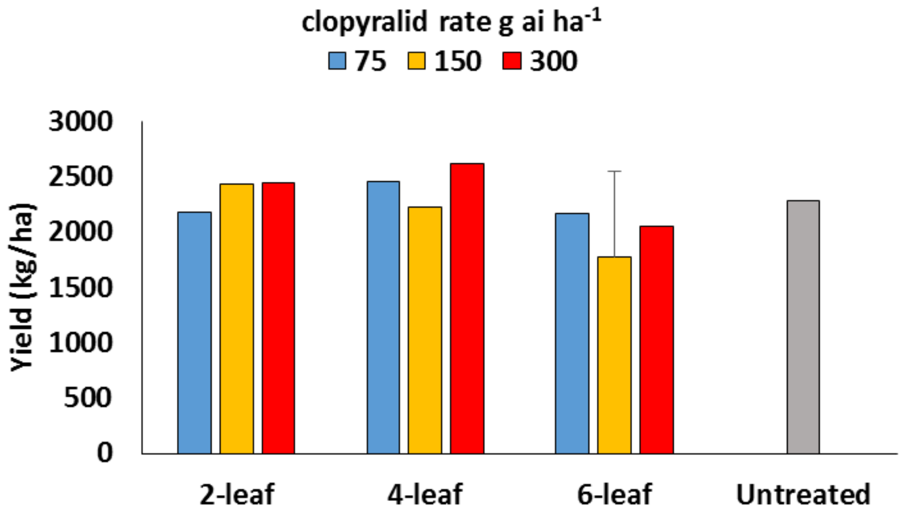


Figure 29: Effect of clopyralid rate on seed yield of hemp when applied at the 2, 4, and 6-leaf stage. Error bar represents the $LSD_{0.05}$. Goodale Research Farm. 2017.

Figure 30: Injury symptoms from a 300 g ai ha^{-1} application of clopyralid to hemp at the 6-leaf stage. Goodale Research Farm. 2017.

9.5 Sulfentrazone screening

9.5.1 2016 study

Injury from sulfentrazone application appeared on all cultivars at the seedling stage (Figure 31). Symptoms also appeared at later development stages shortly after a rainfall. Based on these results, and previous results conducted at Scott, SK (Johnson and Ulrich, unpublished data) where significant injury occurred, it was decided to discontinue any further screening for sulfentrazone tolerance.

Figure 31: Sulfentrazone injury symptoms on hemp seedlings (top) and emerged plants (bottom). Goodale Research Farm. 2016.

10. **Conclusions and Recommendations:** Highlight significant conclusions based on the findings of this project, with emphasis on the project objectives specified above. Provide recommendations for the application and adoption of the project findings.

10.1 Bromoxynil sreening

The studies determined that cultivars differed in their tolerance to bromoxynil; however, most cultivars exhibited acceptable tolerance to bromoxynil. X-59, the most sensitive cultivar, was still able to recover from initial chlorosis and necrosis without experiencing a yield penalty. Thus, a statement such as the following will be recommended to the Minor Use Center for inclusion on the label if bromoxynil is registered in hemp.

"Hemp cultivars can differ in their sensitivity to bromoxynil. Some cultivars can experience temporary leaf chlorosis and necrosis, as well as stunting, particularly with overlap application. The injury is transitory and there is usually no yield penalty associated with the injury. Yield improvement from weed control will outweigh any risks from crop injury."

The high level of tolerance exhibited by CFX-2 in the growth chamber study indicates that there is potential to breed for tolerant varieties.

10.2 Quinclorac screening

The 2018 studies demonstrate that hemp does not have acceptable tolerance to post-emergence quinclorac, and registration should not be pursued. There may be potential for pre-emergence application of quinclorac to hemp based on 2017 results; however, further field trials are required for validation.

10.3 Flucarbazone / tribenuron screening

Results from 2018 indicate that hemp does not exhibit sufficient tolerance to pre-seed application of products containing flucarbazone and should not be pursued. Pre-seed tribenuron may be a potential candidate for registration. It does not provide residual weed control; however, it may be useful for pre-seed management of hard-to control weeds such as dandelion and narrow-leaved hawksbeard.

10.4 Clopyralid screening

Hemp does not exhibit consistent tolerance to sulfentrazone; thus, pursuing registration is not recommended.

10.5 Sulfentrazone screening

Hemp does not exhibit sufficient tolerance to sulfentrazone; thus, pursuing registration is not recommended.

11. **Is there a need to conduct follow up research?** Detail any further research, development and/or communication needs arising from this project.

Follow-up experiments to validate tolerance of hemp to pre-seed quinclorac or tribenuron is needed if the hemp industry wants to pursue registration of these products.

12. **Patents/ IP generated/ commercialized products:** List any products developed from this research.

13. **List technology transfer activities:** Include presentations to conferences, producer groups or articles published in science journals or other magazines.

    Johnson, E. N. and C. J. Willenborg. 2018. Minor Use and hemp herbicide screening. Canadian Hemp Trade Alliance Annual Conference. Canadian Hemp Trade Alliance. Winnipeg, MB. Nov. 20-22, 2018. (Invited Speaker).

A short presentation of the 2017 and 2018 results were presented by Eric Johnson to the Provincial Minor Use Priority Setting Meeting held in January and December of 2018.

This report and bromoxynil data generated from this project will be forwarded to the Minor Use Center in Ottawa to assist in the registration of bromoxynil.

14. List any industry contributions or support received.

15. Acknowledgements. Include actions taken to acknowledge support by the Ministry of Agriculture and the Canada-Saskatchewan Growing Forward 2 bilateral agreement (for projects approved during 2013-2017) or Canadian Agriculture Partnership (For projects approved beyond 2017).

The authors of this report recognize the support of the Canada-Saskatchewan Growing Forward 2 bilateral agreement and the support was acknowledged when results were presented to the hemp industry.

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

Growing Forward 2 A federal-provincial-territorial initiative

Government of Saskatchewan Ministry of Agriculture

Canada