Improving Competitive Ability and Herbicide Options in Domesticated Oat Production Systems (*Avena sativa* L.)

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Key Words: kochia, oats, dose response

Abstract

Domesticated oat (*Avena sativa* L.) is an economically important crop, ranking sixth in world cereal production and with production reaching approximately 25 million tonnes annually. It is largely utilized within the food industry and has increased in demand due to recent recognition of its health benefits attributed to beta-glucan. Oat yield reductions and poor grain seed quality have become more prevalent with increased resistant kochia populations. Multiple herbicide resistant (HR) kochia, along with a lack of herbicide registration for domesticated oat, have lead to a significant decrease in weed control efficacy. Thus, the initial objectives of this study are to quantify the efficacy of new herbicides for domesticated oat production. This project will be utilizing Group 2, 6, 14, and 28 PRE- and POST applicant herbicides. Oat yield and biomass was not significantly reduced within most treatments, indicating high crop tolerance. However, based on CWSS visual ratings, which were conducted after application indicated severe tissue damage and growth reductions attributed to several treatments. In contrast, fluthiacet-methyl, florasulam with bromoxynil, and pyrasulfotole with bromoxynil, and bentazon with 2,4-D could pose as alternative herbicide control options, as initial tissue damage was limited and provided reasonable kochia control. Future research is required to confirm efficacy of kochia control and oat tolerance, as apposing research indicates varying results.

Introduction

Domesticated oat (*Avena sativa* L.) is an economically important crop, ranking sixth in world cereal production and with production reaching approximately 25 million tonnes annually (Saskatchewan Ministry of Agriculture, 2011; O'Donoughue et al., 1995). A large portion of cultivated oat production is used as a fodder crop for hay or silage, with preference for livestock feed as a result of its excellent protein quality. In particular, oat is a valuable forage product for horses and poultry, as it has a high content of essential amino acids, a rich diversity of vitamins and mineral substances (Badaevaa et al., 2011). Oat is commonly used in the food industry for basic products such as oatmeal, flakes, and flour. Furthermore, recent recognition of nutritional benefits has lead to an increase in demand for the milling and processing of oats for human consumption. Dietary benefits are largely attributed to beta-glucan, a soluble fibre that aids in regulating blood sugar, lowering cholesterol, and reduces risk of heart disease (Saskatchewan Ministry of Agriculture, 2011).

In addition to these traits, oat has key agronomic characteristics such as high grain yield, medium maturity of approximately 95 days and high water use efficiency, which make it well adapted to the western portion of the Canadian prairies (Saskatchewan

Ministry of Agriculture, 2011). Although it is well adapted to the Canadian prairies, yield reductions and poor grain seed quality have become more prevalent with increased weed populations, particularly in the case of kochia (*Kochia scoparia* L) (Manthey et al., 1996; Christoffers et al.,2002).

Weed control within oat production systems is relatively limited in comparison to most cereal crop systems. Group 1 [acetyl Co-A carboxylase (ACC) inhibiting] and Group 2 [acetolactate synthase (ALS) inhibitors] herbicides are commonly used to control most grass and broadleaf weeds within a cereal crop. However, kochia populations with cross-resistance and multiple-resistance to Group 1 and Group 2 herbicides are becoming increasingly prevalent, which has resulted in decreased herbicide efficacy (Beckie, 2009). The oat industry has been negatively impacted by the increase in herbicide resistant (HR) weeds, as most registered herbicides for oats are Group 1 and Group 2 herbicides.

As a result of herbicide resistant kochia populations and a lack of registered herbicides, oat producers have few management options for weed control. In particular, Group 4 herbicide resistance populations have increased within the last 30 years, which is a prevalent concern, as this herbicide group is heavily relied on for grass weed control. Therefore, further research is required to determine the efficacy of new herbicides for domesticated oats in order to reduce kochia, provide producers with alternative options, and to reduce dependency on Group 1 and 2 herbicides.

Materials and Methods

The 2012-2013 field sites were initiated in the fall, located at the Scott Research Farm in Scott, Saskatchewan, and at the Kernen Research Farm at Saskatoon, Saskatchewan. The kochia and oat tolerance trial were all arranged in a randomized complete block design with four replications. The kochia trial had 10 experimental treatments (Table 3) resulting in a total of 40 plots. The oat tolerance trial had 25 experimental treatments, resulting in a total of 100 plots. Each plot was two meters wide and six meters long at the Kernen Research Farm, while plots were two meters wide and five meters long at the Scott Research Farm. The treatment factor was various combinations of herbicides.

CDC Seabiscuit was the oat cultivar used within the oat tolerance and the kochia trial. CDC Seabiscuit was developed from the cross 'OT396'/'HiFi' in 2001 at the Crop Development Centre, University of Saskatchewan, Saskatoon. The F1 generation was grown as a bulk population in a nursery in New Zealand. The F2 population was grown as a bulk population in Saskatoon, Saskatchewan (Canadian Food Inspection Agency, 2014). Oat cultivar selection was based on its competitive stature, high yielding capacities and its medium days-to-maturity (95 days) requirements, allowing it to be readily grown in both locations. All weeds were hand weeded out to reduce any competition. Kochia seed was collected from samples of previously threshed populations to establish a population for herbicide screening.

Data analysis was conducted using the SAS 9.3 program (SAS Institute. 2003) using the Proc Mixed procedure of SAS, to test the residual and random effect of the normality data. Data analysis will further include the mixed model procedure with the kenwardroger DDFM option, followed by a multi-treatment comparison using the Tukey test method at a significance level of 5%. Fixed factors within the analysis were treatment application with blocking as the random factor.

A. Evaluating the efficacy of current herbicide productions as an alternative control methods for kochia *(Kochia scoparia* L.)

Objectives and Hypothesis

The objective of this study was to determine the efficacy of several herbicides on kochia. The hypothesis is that different herbicides will provide differential control of kochia.

Two weeks prior to seeding, a glyphosate application was applied to remove any early emerging weeds within all of the trials. Granular fertilizer was placed with the seed based on soil test recommendations of 52 kg ha^{-1} of 12-51-0. On May 21st, 2012 CDC Seabiscuit was sown with a 9-inch row spacing to establish a target population of approximately 200 plants per squared meter (89 kg ha^{-1}). Kochia was broadcasted immediately after seeding CDC Seabiscuit, using a valmar to establish a population density of 100 plants per square meter (1.16 kg ha^{-1}), followed by land rolling to aid in kochia establishment. Sulfentrazone, a PRE-emergent herbicide, was sprayed 7 to 10 days prior to seeding CDC Seabiscuit and kochia. POST applications were applied at the 2-4 leaf, and bentazon with 2,4-D applied at the 4-6 leaf stage. Due to excessive moisture, cool temperatures, and the competitive nature of oats, kochia establishment was severely limited, resulting in skewed control results at the Scott Research Farm. Therefore, altering the experimental design for the kochia trial was proposed, in which only kochia will be seeded. This will allow for a more competitive kochia population, in which credible data can be collected.

B. Evaluating crop tolerance to herbicide applications used to control kochia

Objectives and Hypothesis

The objective of this study was to determine tolerance of oats to several herbicides products. The hypothesis is that oats will have a tolerance to PRE and POST applicant herbicides at a 1x and 2x application rate.

Two weeks prior to seeding, a glyphosate application was applied to remove any early emerging weeds within all of the trials. Granular fertilizer was placed with the seed based on soil test recommendations of 52 kg ha^{-1} of 12-51-0. CDC Seabiscuit was sown on a fallow field at a depth of two to three cm with row spacing of 9-inches to establish a target population of 300 plants per squared meter (140 kg ha^{-1}). Pre-emergent herbicides, sulfentrazone, pyroxasulfone, and propyzamide were sprayed 7 to 10 days prior to seeding at a recommended 1x and 2x rate (Table 3). Post- emergent herbicide applications were applied at a recommended 1x and 2x rate at the 2-4 and 4-6 leaf stage (Table 3).

Data Collection Protocol

Oat plant counts were conducted by counting three counts of 1m-paired rows two weeks after emergence and after herbicide applications. Kochia plant counts were collected using 3 counts of .25m^2 to accurately determine the kochia population within each plot. Visual ratings were conducted for both the kochia and oat tolerance trial at 7 to 10, 14 to 21, and 28 days after application based on the Canadian Weed Science Society (CWSS) scale, in which growth reduction and chlorotic symptoms were rated. The scale ranges from 0 to 100, where 1 represents zero tissue damage and 100 represents fatal injury (Table 2).

Oat shoot biomass was collected at the soft dough stage, while kochia biomass was collected at the initial seed production. Shoot biomass was collected using two, 0.5 m^2 quadrats in each plot, it was then was placed in paper bags and dried for three days at a temperature of 130 ° C to determine the dry weight biomass. Oat plant height was measured during the late dough stage in each plot by sampling the front, back and middle to determine the average plant height of each treatment. Oat grain yield and moisture content was collected using a plot harvester and dried to 13.5% moisture at harvest. A 200g sub- sample was cleaned to obtain a true yield and quality. Thousand kernel weight was determined by counting 250 kernels of each sample and multiplying by four. Oat test weight was also determined from the cleaned sample and was expressed as kg/ hectoliter.

Table 1. Herbicide treatment list and application rate for kochia control

Treatment Number	Herbicide	Trade Name	Herbicide Rate (g a.i. ha^{-1})	Adjuvant Rate
1	Control	-	-	-
2	Sulfentrazone	Authority	105	None
3	Fluthiacet-methyl	Cadet	4	0.25% v/v Agral 90
4	Flumioxazin	Chateau	110	0.25% v/v Agral 90
5	Florasulam Bromoxynil	Benchmark	5 Florasulam + 280 bromoxynil	0.2% v/v Agral 90
6	Bentazon	Basagran (not Forte)	475	Mix with 370 g ai/ha 2,4-D ester 600
7	Aciflurofen	Blazer	296	0.5% v/v Assist
8	Pyrasulfotole Bromoxynil	Infinity	31g pyrasulfotole+ 170g bromoxynil	None
9	Topramezone	Impact	12.5	1% v/v MSO
10	Tembotrione	Laudis	90	1% v/v COC + 2% UAN (28%)

Table 2. Kochia control trial data collection

Type	Timing	Size
Weed Counts	2 weeks after in-crop herbicide application * alive: dead ratio	2 spots x 0.5m^2
Weed Control Rating	Pre-seed treatments prior to in crop herbicide applications Days after application: 7-10, 14-21, 28	-----
Kochia Biomass	Prior to or during seed production	2 samples x 0.5m^2

Table 3. Herbicide treatment list and application rate to determine oat tolerance

Treatment Number	Herbicide	Trade Name	Herbicide Rate (g a.i. ha-1)	Adjuvant Rate
1	Control			0
2	Sulfentrazone	Authority	140	None
3	Sulfentrazone	Authority	280	None
4	Fluthiacet-methyl	Cadet	4	0.25% v/v Agral 90
5	Fluthiacet-methyl	Cadet	8	0.25% v/v Agral 90
6	Flumioxazin	Chateau	55	0.25% v/v Agral 90
7	Flumioxazin	Chateau	110	0.25% v/v Agral 90
8	Florasulam + Bromoxynil	Benchmark	5 Florasulam+ 280g Bromoxynil	0.2% v/v Agral 90
9	Florasulam + Bromoxynil	Benchmark	10 Florasulam + 560 Bromoxynil	0.2% v/v Agral 90
10	Bentazon	Basagran (not Forte)	475	Mix with 370g ai/ha 2,4-D ester 600
11	Bentazon	Basagran (not Forte)	950	Mix with 370g ai/ha 2,4-D ester 600
12	Aciflurofen	Blazer	296	0.5% v/v Assist
13	Aciflurofen	Blazer	592	0.5% v/v Assist
14	Pyrasulfotole+	Infinity	31g Pyrasulf + 170g	None

	Bromoxynil		Bromoxy	
15	Pyrasulfotole+ Bromoxynil	Infinity	62g Pyrasulf + 340g Bromoxy	None
16	Topramezone	Impact	12.5	1% v/v MSO
17	Topramezone	Impact	25	1% v/v MSO
18	Tembotrione	Laudis	90	1% v/v COC + 2% v/v UAN (28%)
19	Tembotrione	Laudis	180	1% v/v COC + 2% v/v UAN (28%)
20	Pyroxasulfone		200	None
21	Pyroxasulfone		400	None
22	Propyzamide	Kerb	900	None
23	Propyzamide	Kerb	1800	None
24	Thiencarbazone-methyl	Varro	5	0.25% v/v Agral 90
25	Thiencarbazone-methyl	Varro	10	0.25% v/v Agral 90

Table 4. Oat tolerance trial data collection

Type	Timing	Size
Crop Counts	2-3 weeks after emergence	3 spots x 1 m
Crop Injury Rating	Pre-seed treatments prior to in crop herbicide applications Days after application: 7-10, 14-21, 28	------
Plant Height	Late dough stage	5 individual plants
Oat Biomass	Soft dough stage	2 samples x 0.5m^2
Crop Yield	Grain kernel at 13% moisture	Entire plot
Thousand Kernel Weight	After harvest	250 kernels
Test Weight	After harvest	-----

Results

The random effects of experiments, years, years by location, and their interactions with herbicide treatments are anticipated to have no significant differences for any of the variables analyzed. Thus, future analysis will consist of pooled means for each variable analyzed; however, at this current time data analysis will be conducted separately for each location.

In the Kernen field trials, data analysis indicated a significant difference in wild oat yield (kg/ha) and biomass (kg/ha) production between treatments ($P < .05$). At Kernen and Scott Research Farms, the oat tolerance trial indicated significant differences between treatments ($P < .05$), with kochia biomass differences documented at the Kernen Research Farm ($P < .05$).

a. Acifluorfen

The POST application of acifluorfen at a rate of 296 g ai/ha and 592 g ai ha^{-1} on domesticated oats indicated high oat tolerance, as biomass production compared to the untreated control check at both Kernen and Scott Research Farm was similar. However, oat yield at the Kernen Research Farm indicates a statistically significant yield increase of 8% at a 1x rate compared to the untreated check (Figure 2). When applied to kochia at a 1x rate, visual ratings indicated substantial control of kochia; however, statistically a non-significant reduction was documented (Figure 5).

b. Bentazon & 2,4-D

The POST application of bentazon with 2,4-D at a rate of 475 g ai/ha of bentazon with 370g ai/ha of 2,4-D ester 600 and 950 g ai/ha with 370g ai/ha 2,4-D ester 600 on domesticated oats indicated high oat tolerance at both Kernen and Scott Research Farm (Figure 1-4). Application of bentazon & 2,4-D on kochia had similar results compared to aciflurofen, in which kochia biomass was slightly reduced (Figure 6).

c. Florasulam & Bromoxynil

The POST application of florasulam and bromoxynil at a rate of 5 g ai/ha of florasulam and 280 g ai/ha of bromoxynil, and 10 g ai/ha of florasulam and 560 g ai/ha of bromoxynil on domesticated oats indicated high crop tolerance at both Kernen and Scott Research Farm (Figure 1-4). Kochia biomass was severely reduced at the 1x rate, with a 98% reduction (Figure 5).

d. Flumioxazin

The POST application of flumioxazin at a rate of 55 g ai/ha and 110 g ai ha^{-1} applied to domesticated oats indicated moderate crop tolerance at both 1x and 2x application rates. Oat biomass and yield reductions were not documented at either Kernen or Scott Research Farm (Figure 1-4). Kochia biomass was significantly reduced compared to the untreated control check, with a 96% reduction (Figure 5). However, early season visual ratings indicated severe bleaching of the leaves and tissue death (Figure 6).

e. Fluthiacet-methyl

The POST application of flluthiacet-methyl at a rate of 4 g ai/ha and 8 g ai/ha on domesticated oats indicated high crop tolerance at both Kernen and Scott Research Farm (Figure 1-4). Kochia biomass was severely reduced at the 1x rate, with a 97% reduction (Figure 5). Visual ratings confirm crop tolerance, as little tissue damage was documented at the 1x and 2x rate (Figure 6).

f. Pyrasulfotole & Bromoxynil

The POST application of pyrasulfotole and bromoxynil at a rate of 31g ai ha^{-1} of pyrasulfotole and 170g ai ha^{-1} of bromoxynil, and 62g ai ha^{-1} of pyrasulfotole and 340g ai ha^{-1} of bromoxynil on domesticated oats resulted in a yield increase of 9% compared to the control check at a 2x rate (Figure 2). Application of pyrasulfotole and bromoxynil at a 1x rate resulted in ideal kochia control, with a biomass reduction of 99% (Figure 5). Visual ratings were consistent with the documented findings, as limited stunting and chlorosis was noted on the domesticated oats (Figure 6).

g. Sulfentrazone

At the Kernen Research Farm, a PRE-emergent application of sulfentrazone at the at rate of 140 g ai/ha and 280 g ai ha^{-1} applied to domesticated oats indicated oat crop tolerance as biomass and yield reductions were not documented (Figure 1-4). Kochia biomass was statistically similar to the untreated check in terms of overall kochia biomass (Figure 5).

h. Tembotrione

The POST application of tembotrione at a rate of 90 g ai/ha and 180 g ai ha^{-1} applied to domesticated oats indicated crop tolerance, as biomass and yield reductions were not documented at either Kernen or Scott Research Farm (Figure 1-4). Kochia biomass was significantly reduced compared to the untreated control check, with an 87% reduction (Figure 5). However, early season visual ratings indicated severe tissue damage and significant growth reduction (Figure 6).

i. Topramezone

The POST application of topremezone at a rate of 12.5 g ai/ha and 25 g ai ha^{-1} applied to domesticated oats indicated oat crop tolerance at both Kernen and Scott Research Farm (Figure 1-4). Kochia biomass was significantly reduced compared to the untreated control check, with a 92% reduction in biomass (Figure 5). However, early season visual ratings indicated severe tissue damage and significant growth reduction (Figure 6).

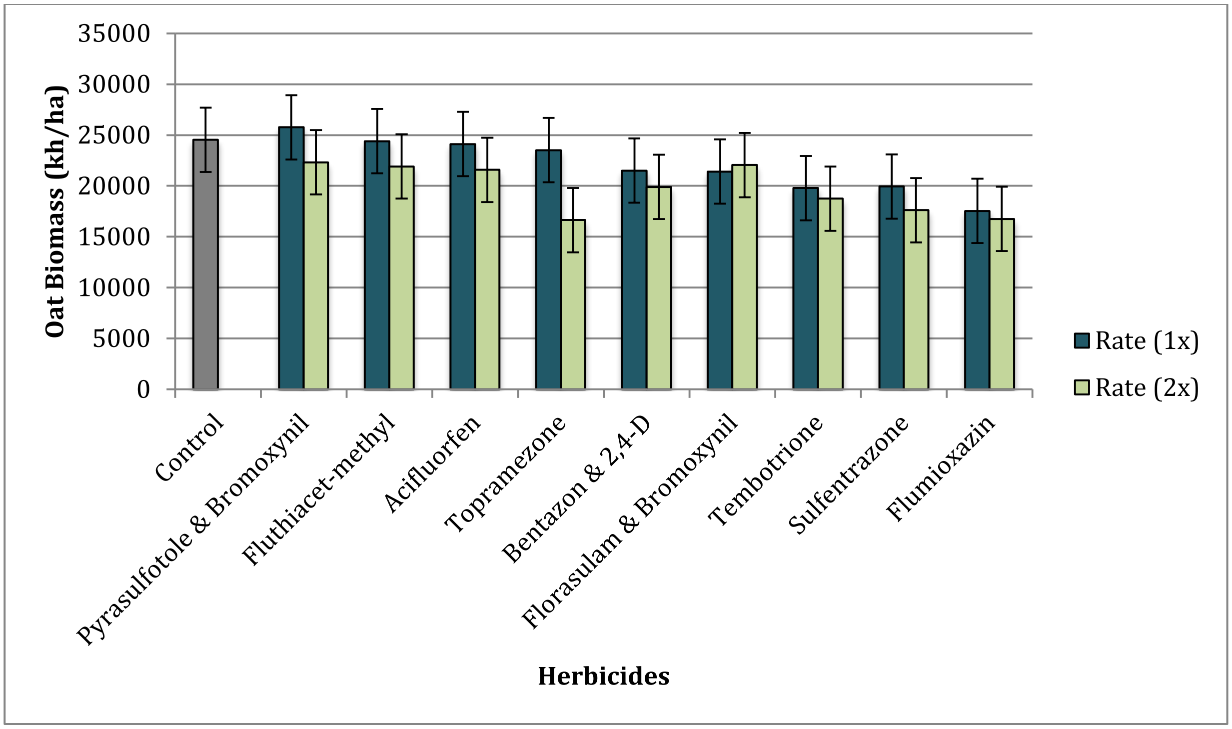

Figure 1. Determining oat crop tolerance to pre-emergent and post-emergent herbicide application via biomass production at Kernen, Saskatchewan.

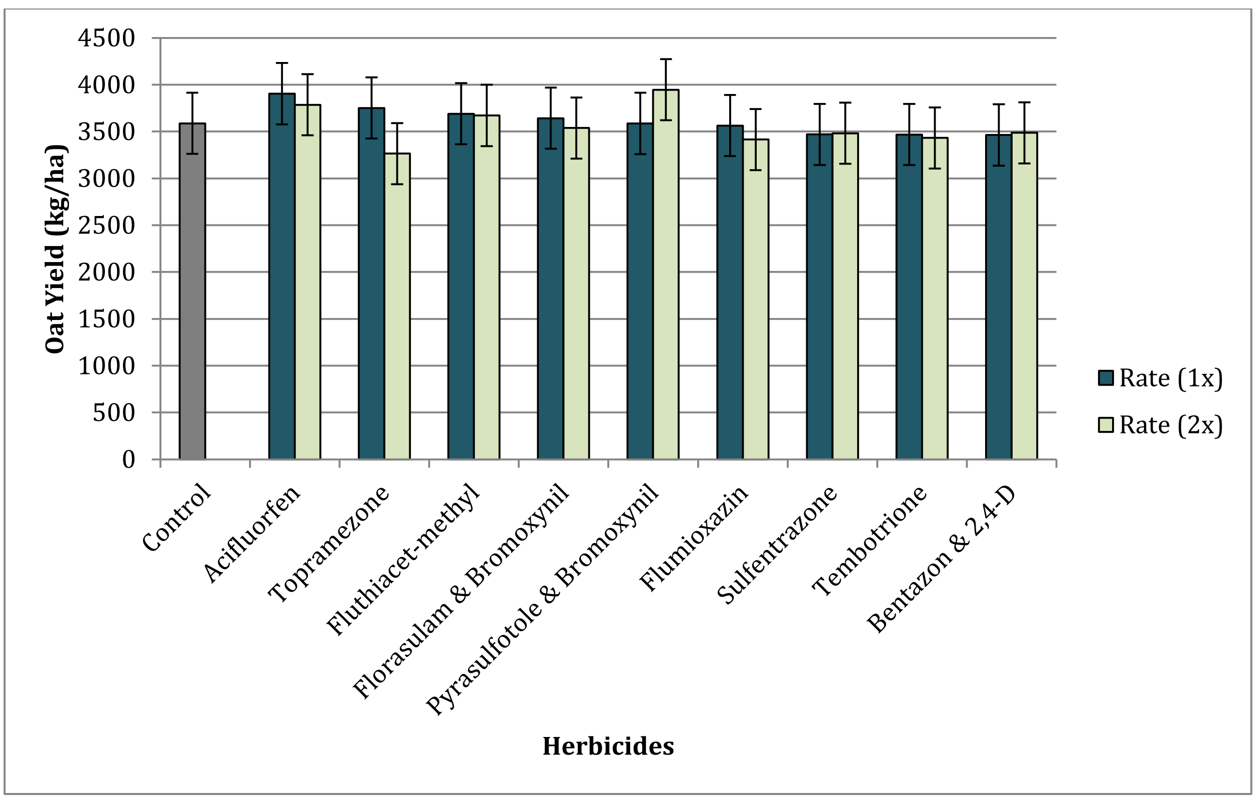

Figure 2. Determining oat crop tolerance to pre-emergent and post-emergent herbicide application via yield production at Kernen, Saskatchewan.

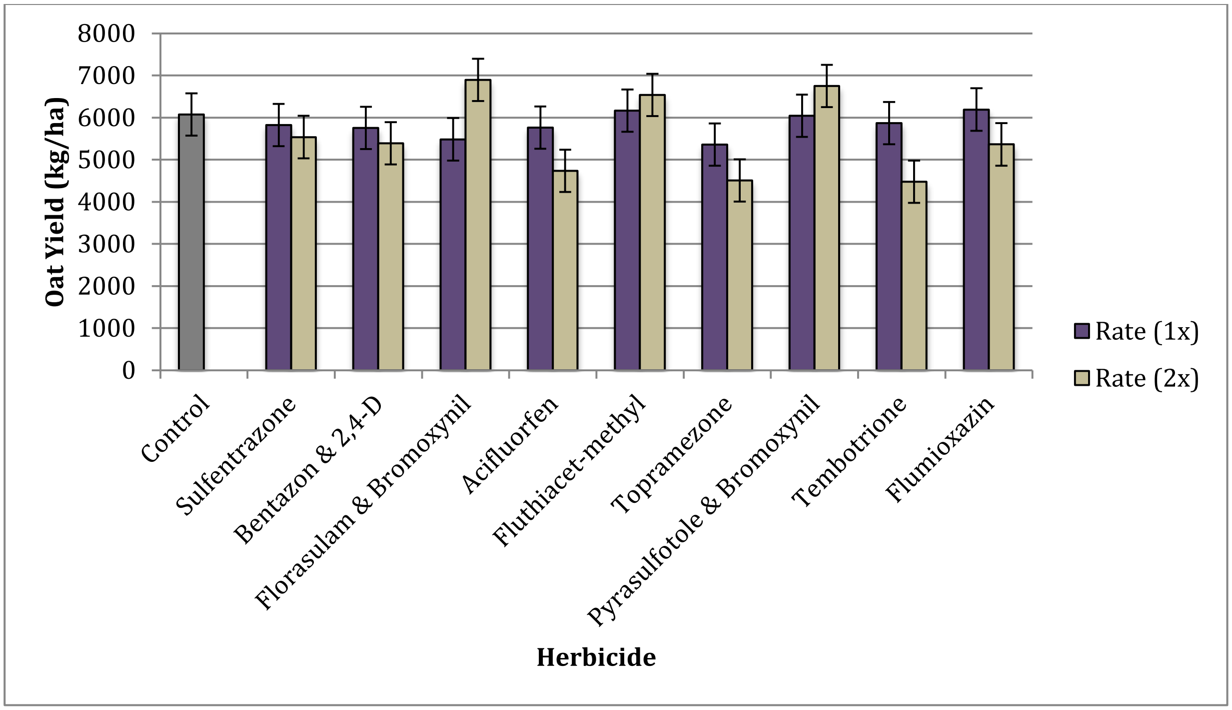

Figure 3. Determining oat crop tolerance to pre-emergent and post-emergent herbicide application via yield production at Scott, Saskatchewan.

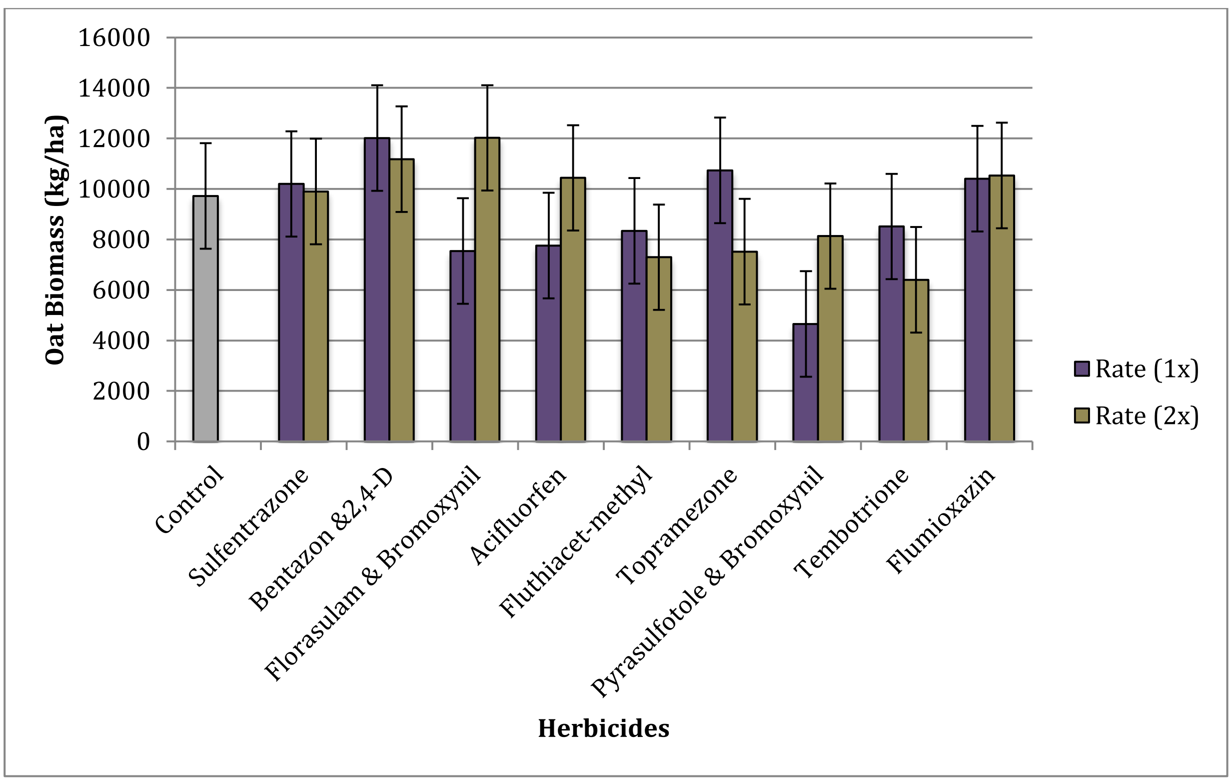

Figure 4. Determining oat crop tolerance to pre-emergent and post-emergent herbicide application via biomass production at Scott, Saskatchewan.

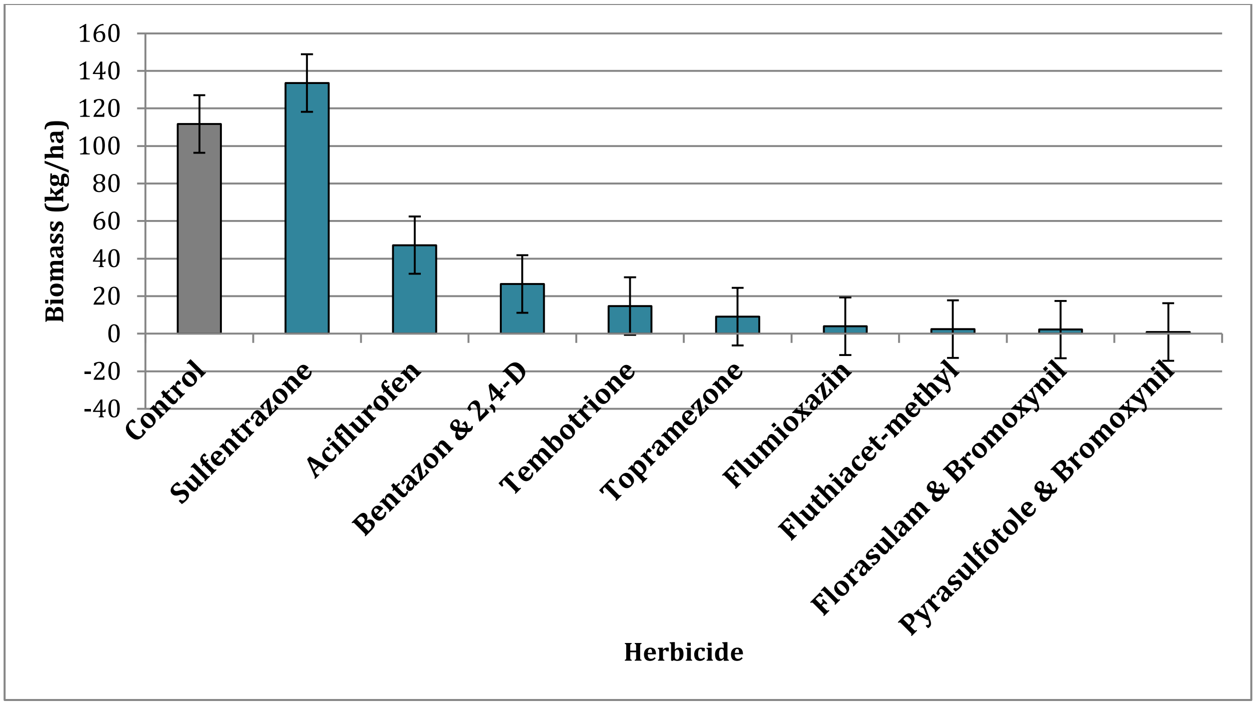

Figure 5. Effect of pre- emergent and post- emergent herbicide application on kochia biomass at Kernen, Saskatchewan.

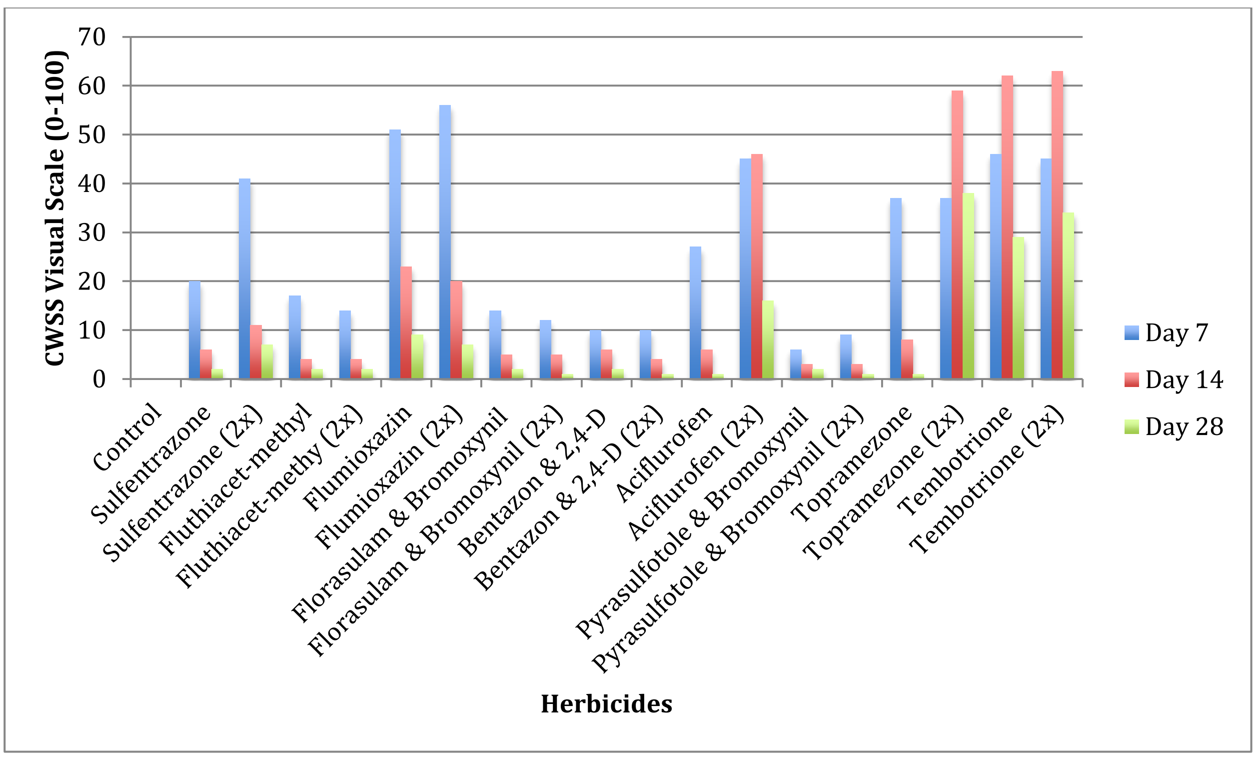

Figure 6. Canadian Weed Science Society visual ratings scale based on chlorosis and growth reduction of oat tolerance to pre- emergent and post-emergent herbicides at Kernen, Saskatchewan.

Discussion

Kochia is increasing more challenging to control in both agricultural and non-cropping areas. This species has developed widespread resistance to several herbicides with differing modes of action, including acetolactate synthase inhibitors and photosynthesis inhibitors. Resistance is also beginning to appear against the synthetic auxins and glyosphate based herbicides. Therefore, alternative PRE and POST herbicides are needed for effective kochia management.

Florasulam combined with bromoxynil resulted in excellent kochia control, with a biomass reduction of 98%, along with minimal oat yield and biomass losses at both Kernen and Scott Research Farm. Florasulam is a Group 2 herbicide that is highly susceptible to resistance, as 90% of current kochia populations are resistant to Group 2 (Beckie and Tardif, 2012). However, as it is mixed with bromoxynil, the likeliness of introducing resistant kochia biotypes is reduced, as bromoxynil has very few resistant biotypes, and multiple modes of action are deployed, which is an effective method in delaying the development of herbicide resistance (Beckie and Reboud, 2009).

Pyrasulfotole with bromoxynil also provided the greatest kochia control, reducing 99% of the kochia stand with insignificant yield and biomass reductions, indicating high oat crop tolerance at both 1x and 2x application rates. In contrast, Martinson et al. (2011), documented significant oat damage when pyrasulfotole with bromoxynil was applied to oats. This study recommended using florasulam with MPCA, which is similar to bromoxynil, as it provided diverse weed control with minimal oat yield loss. Reddy et al. (2013) concluded that applications of pyrasulfotole and bromoxynil with atrazine on sorghum could be used to selectively control broadleaf weeds; however, foliar bleaching of leaves occurred 3-7 days after application, but resulted in 97% kochia control. It could be concluded that pyrasulfotole with bromoxynil could be used as alternative herbicide option, as it can be readily used on cereal crops to control broad-leaf weeds. Pyrasulfotole with bromoxynil could be used as a kochia control product; however, as foliar bleaching was documented, and there is evidence to suggest that significant oat yield loss can be caused by the application pyrasulfotole with bromoxynil. Therefore, further studies are required before recommendation can be made for the use of kochia control in oats production systems.

Similarly, applications of fluthiacet-methyl on domesticated oats resulted in insignificant yield and biomass reductions, indicating high oat crop tolerance. Furthermore, fluthiacet-methyl decreased kochia biomass by 97% at a 1x application rate. However, further studies are required, as very few studies have documented the effects of fluthiacet-methyl on oats, as this is dominantly used for broad leaf weed control in corn (Steward et al. 2009).

Acifluorfen at a 1x application rate resulted in an 8% oat yield increase compared to the untreated control check at the Kernen Research Farm (Figure 2). This increase in oat yield is likely attributed to lower yields in the control, as several control treatments where located closer to flooding zones. Therefore, this small increase in yield is less dependent on herbicide application and likely attributed to environmental conditions.

Visual ratings conducted 7 days after application indicated significant leaf burning, foliar bleaching and slight growth reduction, particularly at a 2x application rate. Based on this assessment, acifluorfen applications are not recommended, regardless of the yield and biomass data (Figure 6). Oat crop tolerance to applications of bentazon with 2,4-D was documented, as yield and biomass reductions at both Kernen and Scott Research Farm was not significant. Bentazon with 2,4-D and acifluorfen resulted in similar kochia control, in which biomass reductions were statistically similar to the untreated control check. However, kochia biomass was significantly reduced to the point in which kochia would unlikely result in any oat- kochia competition. Therefore, in a producer's view, bentazon with 2,4-D herbicides could serve as a kochia control alternative.

Applications of flumioxazin, topramezone, and tembotrione on domesticated oats at a 1x and 2x rate resulted in statistically in-significant yield and biomass reductions at both Kernen and Scott site locations. Flumioxazin, topramezone, and tembotrione were all effective in reducing kochia biomass by 97%, 92% and 87%. However, based on visual ratings conducted seven days after application, significant plant tissue damage was documented. Flumioxazin, Group 14, resulted in substantial foliar bleaching and tissue death, particularly at a 2x rate application. Topramezone and tembotrione, Group 27, also resulted in substantial foliar bleaching along with significant growth reduction. Although statistically yield and biomass was not affected, these three herbicides should not be implemented in any oat production systems based on visual ratings (Figure 6).

The PRE- emergent application of sulfentrazone at a 140 g ai ha^{-1} rate resulted in kochia biomass statistically similar to the untreated check in terms of overall kochia biomass (Figure 5). However, Lloyd et al. (2011) concluded that PRE application of sulfentrazone with glyphosate (1.7 kg ae ha^{-1}) resulted in significant kochia control immediately after application, but noted diminishing affects sequentially after application. Reduced efficacy at the Kernen site location could be attributed to the clay content and soil pH, as sulfentrazone is a weak acid; pKa = 6.56 (FMC Corp. 1989). Therefore, in soil solution it could exist either as the neutral form at pH < 6, or as an anion at pH > 7. Both the neutral and anionic form would be present between pH 6 and 7 (Grey et al. 1997). Grey et al. (1997) concluded that the water solubility of sulfentrazone is pH dependent and that clay loam was the most adsorptive towards sulfentrazone. Thus, the availability of soil-applied sulfentrazone to be absorbed by plants is strongly influenced by soil type and pH. These finding also correspond with the oat tolerance findings, as yield and biomass reductions were not documented at the Kernen site. As efficacy is dependent on soil pH and type, the crop tolerance is likely to vary depending on site location; therefore, recommendation to oat producers is unlikely until further research is documented on the effects of sulfentrazone on oat production in multi-soil type locations.

Conclusion

In conclusion, kochia control was effective within several treatments, including tembotrione, topramezone, flumioxazin, fluthiacet-methyl, florasulam with bromoxynil, and pyrasulfotole with bromoxynil, with reduced efficacy with applications of acifluorfen and bentazon with 2,4-D. Sulfentrazone was an ineffective control method for kochia populations, which is likely attributed to the soil pH and clay content in the Kernen soils. Oat tolerance in both locations was relatively similar, as yield and biomass was statistically unaffected by the herbicide applications. However, the application of tembotrione, topramezone, flumioxazin, acifluorfen caused significant tissue damage and growth reduction. Therefore, based on visual ratings, I would not recommend these herbicides to producers. However, fluthiacet-methyl, florasulam with bromoxynil, and pyrasulfotole with bromoxynil, and bentazon with 2,4-D could pose as alternative herbicide control options as initial tissue damage was limited and provided reasonable kochia control.

Acknowledgements

The authors are grateful for technical assistance provided by Gerry Stuber & U of S Weed Ecology and the Western Applied Research Corporation at Scott.

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