2019 Annual Report for the

Saskatchewan Barley Development Commission

Project Title: Control of Japanese brome (*Bromus japonicus* L.) in barley

(#Skbly20160401)

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Project Identification

1. **Project Title:** Control of Japanese brome (*Bromus japonicus* L.) in barley
2. **Project Number:** (#Skbly20160401)
3. **Producer Group Sponsoring the Project:** Saskatchewan Barley Development Commission
4. **Project Location(s):** Scott, Saskatchewan; Lethbridge, Alberta
5. **Project start and end dates (month & year):** May 1, 2016 to December 30, 2019
6. **Project contact person & contact details:**

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Objectives and Rationale

7. **Project objectives:**

There are three main objectives of this study:

1) To determine crop tolerance to various herbicide combinations and application timing
2) To determine the best herbicide combination and application timing to control Japanese brome
3) Pursue a potential Minor Use Registration for control of Japanese brome in barley

Project Rationale:

Japanese brome (*Bromus japonicas L.*) is usually regarded as a noxious weed on rangelands and prairies because it competes with native perennials for water and nutrients (Anderson et al., 1999; Gartner et al., 1976). In North America, it is common in northern mixed grass prairies (Ogle et al., 2003) and can inhabit old fields, rangelands (especially depleted rangelands), pastures, hayfields, gardens, roadsides, industrial sites, and disturbed areas (Barkworth et al., 2007; Darbyshire, 2003; Davis, 1993; Kirkland and Brenzil, 2007; Whitson et al., 1992). Most notability, it is also a troublesome weed in cultivated cropland.

In Canada, Japanese brome has been reported in all provinces except Prince Edward Island and Newfoundland and Labrador (Brouillet et al. 2016). There are reports indicating that Japanese brome is expanding its range (Darbyshire 2003). In Ontario, there is an early record of this species from 1912 and additional scattered records until 1948, after which records increased rapidly (Dore and McNeill 1980). By 1980, Japanese brome was widely established in the southwestern counties and "threatening to spread throughout southern Ontario" (Dore and McNeill 1980). In western Canada, it was found in a few districts of Alberta but was not yet common in the 1960s (Budd and Best 1964); by 1980, it was described as "abundant in the dry lands of southern Alberta and adjacent British Columbia" (Dore and McNeill 1980). Now Japanese brome often occurs in mixed infestations with *Bromus tectorum* in the southern interior of British Columbia (Gayton and Miller 2012), southwestern and central Saskatchewan and Alberta (Kirkland and Brenzil 2007).

Japanese brome infestations are an increasing concern to producers. As a winter annual, it is capable of germinating in the late fall and overwintering as semi-dormant seedlings or rosettes. Japanese brome has excellent winter hardiness as it can survive freezing winter temperatures that are similar to or exceeds the hardiest winter wheat cultivars (O'Connor et al. 1991). This provides Japanese brome with a competitive advantage to spring crops, as it often germinates in the early spring (Beck 2016; Upadhyaya et al. 1986; Gartner et al., 1976). Japanese brome flowers in late May and are prolific seed producers, often producing between 38,000 and 94,000 seeds m^{-2} (Beck 2016). Downy brome, a related species to Japanese brome, can reduce winter wheat yields by 10%, 15% and 20% with weed densities of 24, 40 and 65 plants m^{-2}, respectively (Stahlman and Miller 1990). Yield loss in winter wheat was two to five times higher when downy brome emerged within 3 wk of winter wheat emergence, compared with downy brome that emerged 6 wk after wheat emergence (Blackshaw 1993). There is no information available on yield losses from Japanese brome interference in barley, however, Li et al. (2016) reported an economic threshold of four to five plants m^{-2} in wheat in China. As this weed is a prolific seed producer and an aggressive competitor, it is critical to limit Japanese brome infestation and population densities during early years of establishment.

Mechanical weed methods may increase, sometimes greatly, Japanese brome populations. Therefore, best way to prevent or minimize Japanese brome invasion is to minimize soil disturbance and utilize chemical control options for an effective management strategy. There are two acetolactate synthase (ALS)–inhibiting herbicides, pyroxsulam and thiencarbazone, registered for Japanese brome control (Anonymous, 2015). However, repeated use of ALS-inhibiting herbicides (propoxycarbazone-sodium, pyroxsulam and sulfosulfuron) has selected for ALS inhibitor–resistant biotypes. Heap (2015) reported herbicide resistant biotypes in winter wheat in Kansas, 2007. Furthermore, much of the registered products to control Japanese brome are not registered for barley production. Flumioxazin is a protoporphyrinogen oxidase (PPO) inhibitor that is registered as a pre- seed herbicide in spring wheat. There are two studies indicating that flumioxazin may provide suppression of Japanese brome (Lyon et al. 2013; Johnson et al. 2018), however, the use of flumioxazin for Japanese brome control in malt barley has not been evaluated.

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8. Methodology:

This study was located at Scott, Saskatchewan in 2017, 2018 and 2019 and Lethbridge, Alberta in 2017. The experiment set up was a randomized complete block design (RCBD) with four replications. The treatments consisted of four herbicides (glyphosate, flumioxazin, pinoxaden, and triallate) applied alone and in-combination at two application timings (fall vs. spring) (Table 1). The flumioxazin application rates were based on the current recommended pre-seed application rates for spring wheat of 70 and 105 g ai/ha (low vs. high). Triallate applications always occurred in the fall and were in-corporate prior to fall applications of flumioxazin. Pinoxaden applications occurred post-emergent at the 3-4 leaf stage of the barley. In total, there were seventeen herbicide combinations evaluated to control Japanese brome in malt barley (Table 1). Fertilizer was applied according to soil test recommendations. Pesticides were also applied as and when required (Appendix A1). Plant density was assessed by counting two one-meter rows in the front and back of the plot for a total of four rows per plot. The average of the four rows was converted to plants m^{-2} based on 10-inch spacing at Scott and a 9.5-inch row spacing in Lethbridge. Crop phytotoxicity was measured on a visual scale rate of 0 (no injury) to 100 (severe) relative to the control treatment. Ratings were done 7 and 21 days after application (DAA) of post-emergence pinoxaden. Weed control ratings at 7 and 21 DAA were also assessed based on a visual scale rate of 0 (check plots) to 100 (control) relative to the control treatment (Appendix B). Crop phytotoxicity ratings at 7DAA and 21 DAA were not collected at Lethbridge in 2017. Plant biomass was assessed for the malt barley and Japanese brome by collecting two 0.5 m^{-2} quadrats per plot at the front and back. The samples were dried and weighed to collected the dry weight. Japanese brome biomass samples were not collected at Lethbridge, 2017. Grain yield was determined from cleaned harvested grain samples and corrected to 14% moisture content. Quality parameters measured were thousand kernel weight (TKW) and bushel weight (BW).

Table 1. Treatment list, products, rates and herbicide application timings.

Treatment number	**Herbicide**	**Rate** (g a.i. ha^{-1})	**Application Timing**
1	Unsprayed Check		
2	Glyphosate [A]	900	Fall
3	Glyphosate	900	Spring
4	Flumioxazin [B] & Glyphosate	70 & 900	Fall
5	Flumioxazin & Glyphosate	105 & 900	Fall
6	Flumioxazin & Glyphosate	70 & 900	Spring
7	Flumioxazin & Glyphosate	105 & 900	Spring
8	Pinoxaden	60	POST-Emergent
9	Flumioxazin & Glyphosate & Pinoxaden	70 & 900 & 60	Fall & POST
10	Flumioxazin & Glyphosate & Pinoxaden	105 & 900 & 60	Fall & POST
11	Flumioxazin & Glyphosate & Pinoxaden	70 & 900 & 60	Spring & POST
12	Flumioxazin & Glyphosate & Pinoxaden	105 & 900 & 60	Spring & POST
13	Triallate	1400	Fall
14	Triallate & Flumioxazin & Glyphosate	1400 & 70 & 900	Fall
15	Triallate & Flumioxazin & Glyphosate	1400 & 105 & 900	Fall
16	Triallate & (Flumioxazin & Glyphosate)	1400 & 70 & 900	Fall & Spring
17	Triallate & (Flumioxazin & Glyphosate)	1400 & 105 & 900	Fall & Spring

[A] Glyphosate formulated as Roundup Transorb 540
[B] Flumioxazin formulated as Valtera
[C] Pinoxaden formulated as Axial

The data was separated by site-year due to differences in environmental conditions resulting in various responses of the crop and weed to the herbicide applications. To provide the clearest explanation of the results, the site years were separated. While this approach creates challenges for summarizing the results in a simple and precise manner, it would be inappropriate to compare values directly across site-years for many variables and misleading to simply average data across sites given the high variability and, at times, contrasting results. Data were analyzed using the Mixed procedure of SAS with the effects of treatment (herbicide x timing) considered fixed and replicate effects considered random. Individual treatment means were separated using Fisher's protected LSD test. The overall treatment effects and differences between individual means were considered significant at $P \leq 0.05$.

Growing Season Weather

Scott

The 2017 growing season started with great soil moisture in April and May with 30.9 mm and 69 mm of precipitation, respectively. Midseason growing conditions in June and July were very dry with less than half precipitation compared to the long-term average. Throughout the growing season, the temperature was very similar to the long-term average. Growing degree days were higher than the long-term average for the months of May to July and lower for August and September (Table 2).

The 2018 growing season started out moderately dry in April with only 8.5 mm of precipitation. May, June, and August were far below the long-term average, while July and August were above. Overall, when looking at the accumulated amount of precipitation in 2018 from April to October, there was 12.2 mm less than the long-term total. Throughout the growing season, May and September 2018 were both 5°C colder than the long-term average while May and June were 2-3°C warmer. The temperature was very similar to the long-term average in July and August (Table 2). Two destructive environmental events occurred during the growing season: a wind storm of 157 km hr^{-1} gust on June 9th and a hail storm on July 21st.

The 2019 growing season started out extremely dry in April with only 6.1mm of precipitation and continued into May with 12.7mm. The average temperatures of April and May fell well within the long-term average of 4.2°C and 9.1°C. The month of June also had normal temperatures (14.9°C) but precipitation increased by 28.6% (97.7mm) compared to the long-term average. July was a slightly colder month with a decline of 1.2°C lower than the long-term average with higher than normal precipitation of 107.8 mm compared to 69.4mm. August was far below the long-term rainfall average with 18mm and cooler temperatures throughout the majority of the month with a few exceptionally warm days. September temperatures on average were normal, however, temperatures were higher at the beginning of the month and were substantially lower in the last 2 weeks normal. Precipitation in September was 37% higher compared to the long-term average. There was also a snow fall event that occurred on September 29th. On average, there was 120.5 less growing degree days compared to the long-term average (Table 2). The majority of these days fell between July and August, resulting in a delayed crop maturity.

Table 2. Mean monthly temperature and precipitation accumulated from April to October in 2016, 2017, 2018 and 2019 at Scott, SK.

Year	**April**	**May**	**June**	**July**	**August**	**Sept.**	**Oct.**	**Average/Total**
Temperature (°C)								
2016	5.9	12.4	15.8	17.8	16.2	10.9	1.6	11.5
2017	3.0	11.5	15.1	18.3	16.6	11.5	3.8	11.4
2018	-2.2	13.6	16.6	17.5	15.9	6.4	2.1	10.0
2019	4.2	9.1	14.9	16.1	14.4	11.3	0.9	11.7
Long-term[z]	**3.8**	**10.8**	**14.8**	**17.3**	**16.3**	**11.2**	**3.4**	**11.1**
Precipitation (mm)								
2016	1.9	64.8	20.8	88.1	98.2	22.2	33.1	329.1
2017	30.9	69.0	34.3	22.4	53.0	18.9	20.9	228.5
2018	8.5	29.6	58	85.8	20.2	57.3	9.1	268.5
2019	6.1	12.7	97.7	107.8	18	41.8	6.6	284.1
Long-term[z]	**24.4**	**38.9**	**69.7**	**69.4**	**48.7**	**26.5**	**13.0**	**290.6**

[z]Long-term average (1985 - 2014)

Lethbridge

The growing season started with slightly less precipitation than the long-term average, June got drier and for the rest of the growing season conditions were very dry. The temperature was very similar to the long-term average throughout the growing season. For all the months of the growing season the growing degree days were below the long-term average (Table 3).

Table 3. Mean monthly temperature, precipitation and growing degree day accumulated from April to October in 2016 and 2017 at Lethbridge, AB.

Year	**April**	**May**	**June**	**July**	**August**	**Sept.**	**Oct.**	**Average/Total**
Temperature (°C)								
2016	8	10.8	16.4	18.3	17.6	13.5	6.1	13.2
2017	11.1	12.7	16.1	20.4	18.7	13.8	6.2	14.1
Long-term[z]	**5.9**	**11.4**	**15**	**18.1**	**17.5**	**12.9**	**6.6**	**12.5**
Precipitation (mm)								
2016	13.8	65.5	12.8	32.4	30.1	19.4	14.2	188.2
2017	26.8	41.1	28.3	7.3	10.8	0	38.7	153.0
Long-term[z]	**35.1**	**49.5**	**83.6**	**38.4**	**37.8**	**39.8**	**23.1**	**307.3**

[z]Long-term average (1985 - 2014)

9. Results

Crop Establishment

Plant populations were measured to determine if pre-seed herbicide applications such as triallate and flumioxazin would influence overall crop establishment. Crop establishment at Lethbridge was quite variable among the treatments (P= 0.0444) (Fig. 1). The reductions occurred with fall and spring applied flumioxazin at both high and low rates. Additionally, the lowest plant density was recorded for the application of pinoxaden, however, as this product was applied after plant counts occurred the reduction can not be linked to the herbicide application. The differences in plant densities is likely associated with the dry weather conditions that persisted in Lethbridge and the location of the irrigation pivot rather than a response to herbicide application.

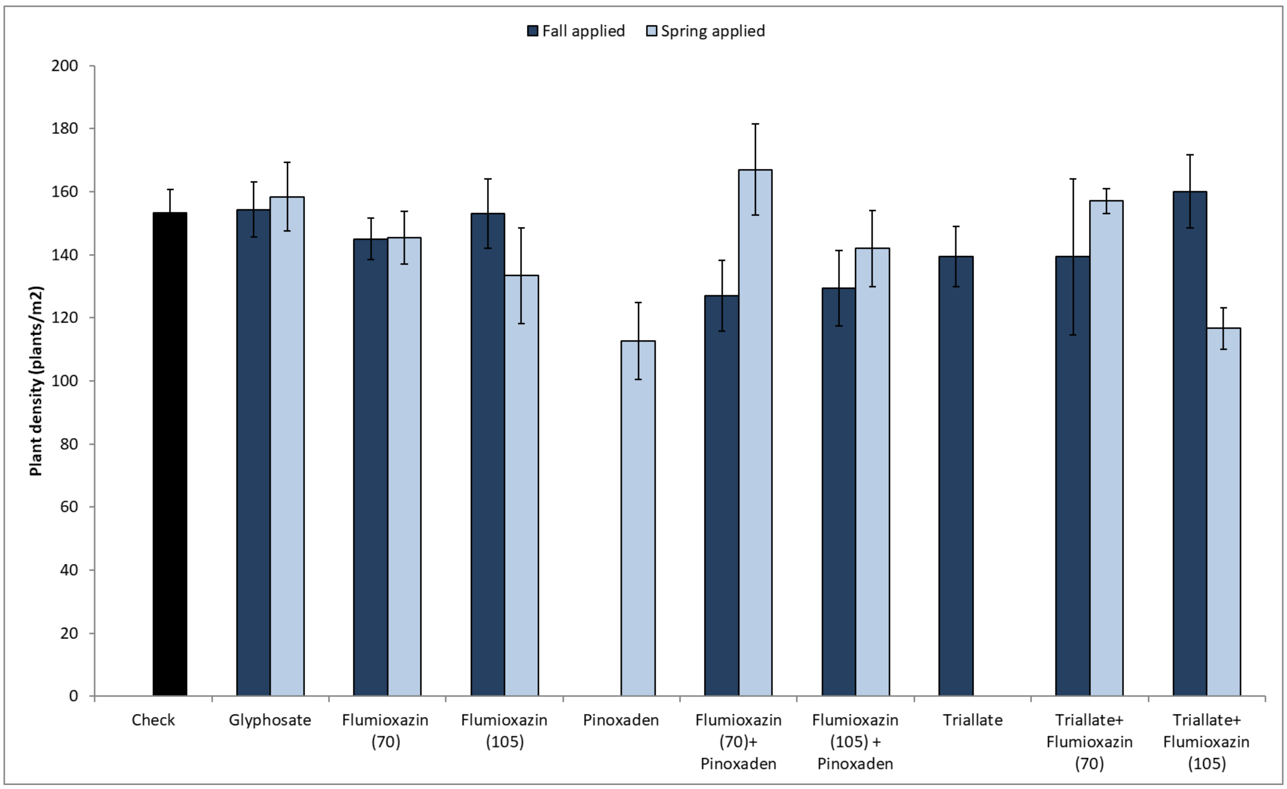

Figure 1. Plant density (plants m^{-2}) for all treatments at Lethbridge, AB in 2017. All treatments with flumioxazin included glyphosate.

Crop establishment in 2017 and 2018 at Scott, SK was relatively consistent among years and treatments with no significant effect (P=0.2318; 0.966) observed. However, in both years, plant densities tended to decrease with high rates of spring applied flumioxazin compared to fall applied flumioxazin and the untreated check (Fig. 2).

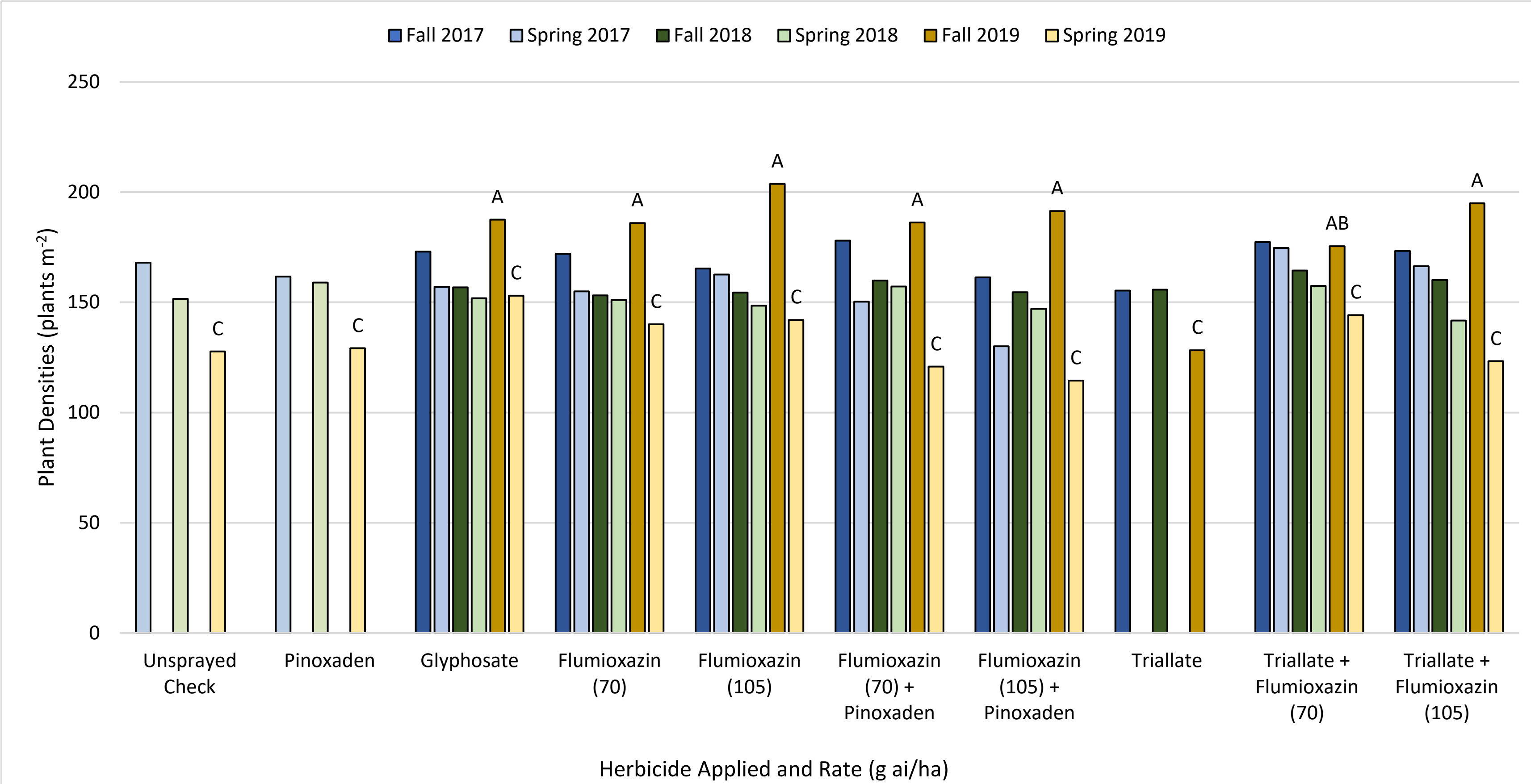

Figure 2. The plant densities (plants/m^2) were recorded in the spring approximately 2-3 weeks after emergence at Scott in 2017, 2018, and 2019. Pinoxaden was applied post-emergent on the crop at the 3-4 leaf stage, while glyphosate and flumioxazin were applied in the fall and spring (7 days prior to seeding). Triallate was only applied in the fall. There were no significant differences in treatment effect for 2017 and 2018. There was a significant effect of herbicide on plant densities in 2019 (P=<0.0001) and treatment differences are indicated by different letters.

The application of flumioxazin largely influenced crop establishment (P=<0.0001) at Scott, 2019. Fall applications of flumioxazin at both high and low rates resulted in higher plant densities than the spring applied flumioxazin, triallate applied alone, spring applied glyphosate, post-emergent pinoxaden and the unsprayed check. The reduction in plant densities observed for the unsprayed check, pinoxaden, spring applied glyphosate, and triallate treatments were not influenced by herbicide but rather a consequence of the Japanese brome depleting the soil water reserves in the fall followed by a very dry spring in 2019.

Crop Phytotoxicity

Visual phytotoxicity ratings at 7 DAA conducted at Scott in 2017, 2018 and 2019 indicated similar trends but the degree of crop damaged varied over the years. In all three years, fall and spring glyphosate applications resulted in negligible crop damage and typically plants were more vigorous compared to the unsprayed check. Minimal crop damage (< 5%) occurred with fall applications of flumioxazin at a low rate (70 g ai/ha) with increasing crop damage (5-8%) in the form of stunting occurred with fall applications at a high rate (105 g ai/ha) applied alone, with pinoxaden and with triallate in all three growing seasons. In 2017, spring applications of flumioxazin at both high and low rates with pinoxaden and triallate resulted in similar crop damage to fall applied treatments and all of which resulted in acceptable (<10%) crop injury. In 2018, visual crop phytotoxicity ratings indicated that spring applied flumioxazin caused greater crop damage compared to the fall applied, particularly at the high (105 g ai/ha) application rate. Spring applications of flumioxazin at the low rate (70 g ai/ha) applied alone, with pinoxaden and with triallate resulted in slight to moderate stunting of the crop but overall damage was less than 10% (acceptable). Crop damage was deemed unacceptable (>10%) with a high (105 g ai/ha) spring application of flumioxazin applied alone and continued to increase when combined with pinoxaden and triallate. Crop damage in 2019 was much more apparent with excessive stunting and chlorosis with spring applications of flumioxazin applied alone at both low and high rates (14-16%). Spring applied flumioxazin at the low and high rates combined with pinoxaden and with triallate had greater crop damage (16- 20%) than when flumioxazin was applied alone (Fig. 3).

Visual crop phototoxicity rates at 21 DAA indicated that herbicide injury generally declined over time and all injury resulting from flumioxazin in the spring and fall dropped below the acceptable level of 10%. In 2017, crop injury dropped below 7% for all herbicide treatments. Crop damage was slightly higher for spring applied herbicides compared to fall applied, with the exception of flumioxazin at a high rate combined with triallate, as both spring and fall timings resulted in similar damage (7%) (Fig. 4). In 2018, crop injury ratings were the lowest in all three years. The highest crop injury rating of 4% occurred with spring applied flumioxazin combined with triallate. Crop injury was the highest in 2019 with the majority of crop damaged caused by spring applications of flumioxazin combined with pinoxaden and triallate. Spring applications of flumioxazin with pinoxaden at the low (70 g ai/ ha) and high (105 g ai/ha) resulted in 9% and 7% crop injury while flumioxazin with triallate resulted in a 6% and 7% crop injury. Overall, combing multiple herbicides in the spring tended to increase crop damage throughout the three growing seasons.

Visual crop phototoxicity ratings were not reported data at Lethbridge, 2017.

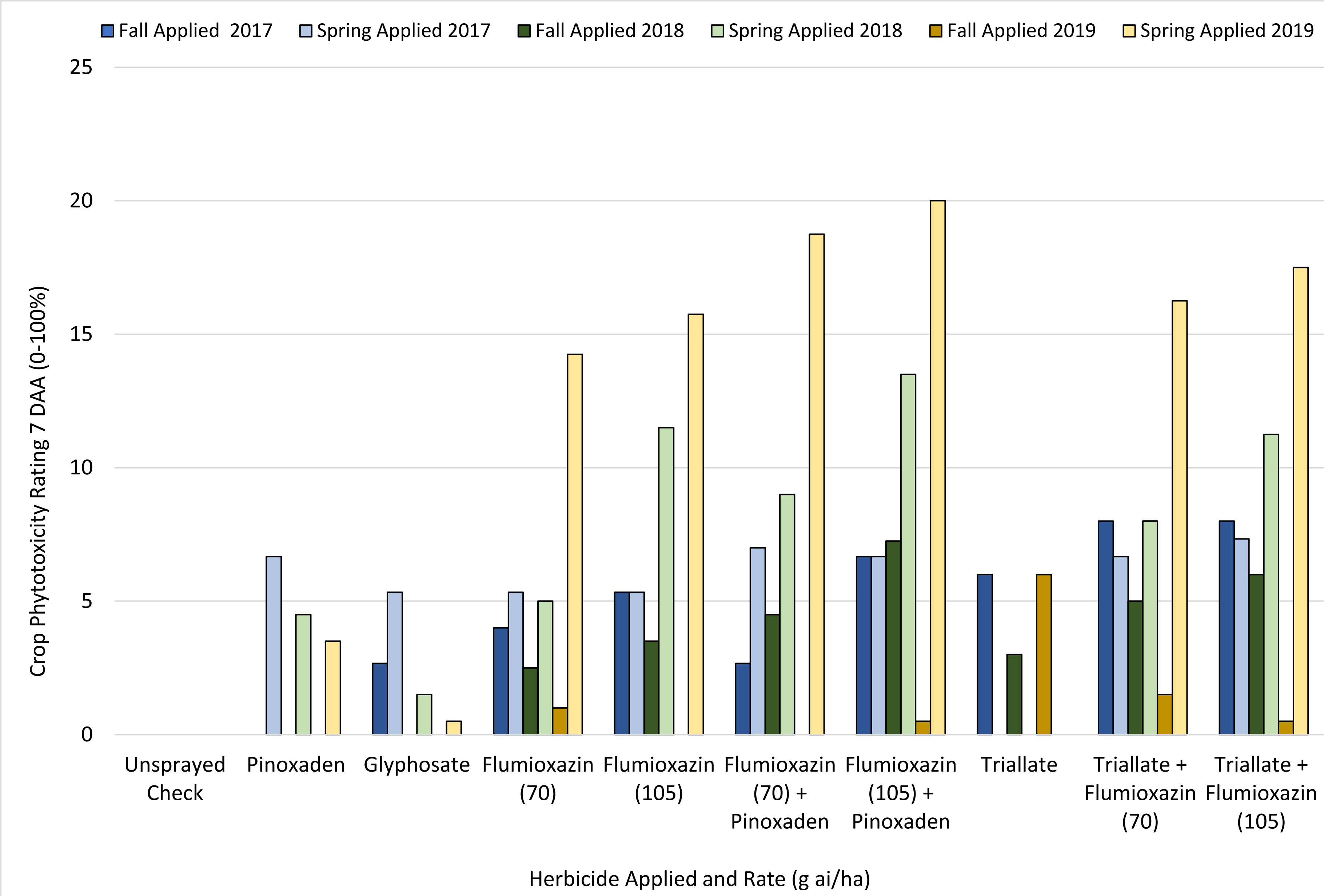

Figure 3. Crop phytotoxicity rating conducted 7 DAA (days after post-emergent application) on malt barley at Scott in 2017, 2018, and 2019. Pinoxaden was applied post-emergent on the crop at the 3-4 leaf stage, while glyphosate and flumioxazin were applied in the fall and spring (7 days prior to seeding). Triallate was only applied in the fall.

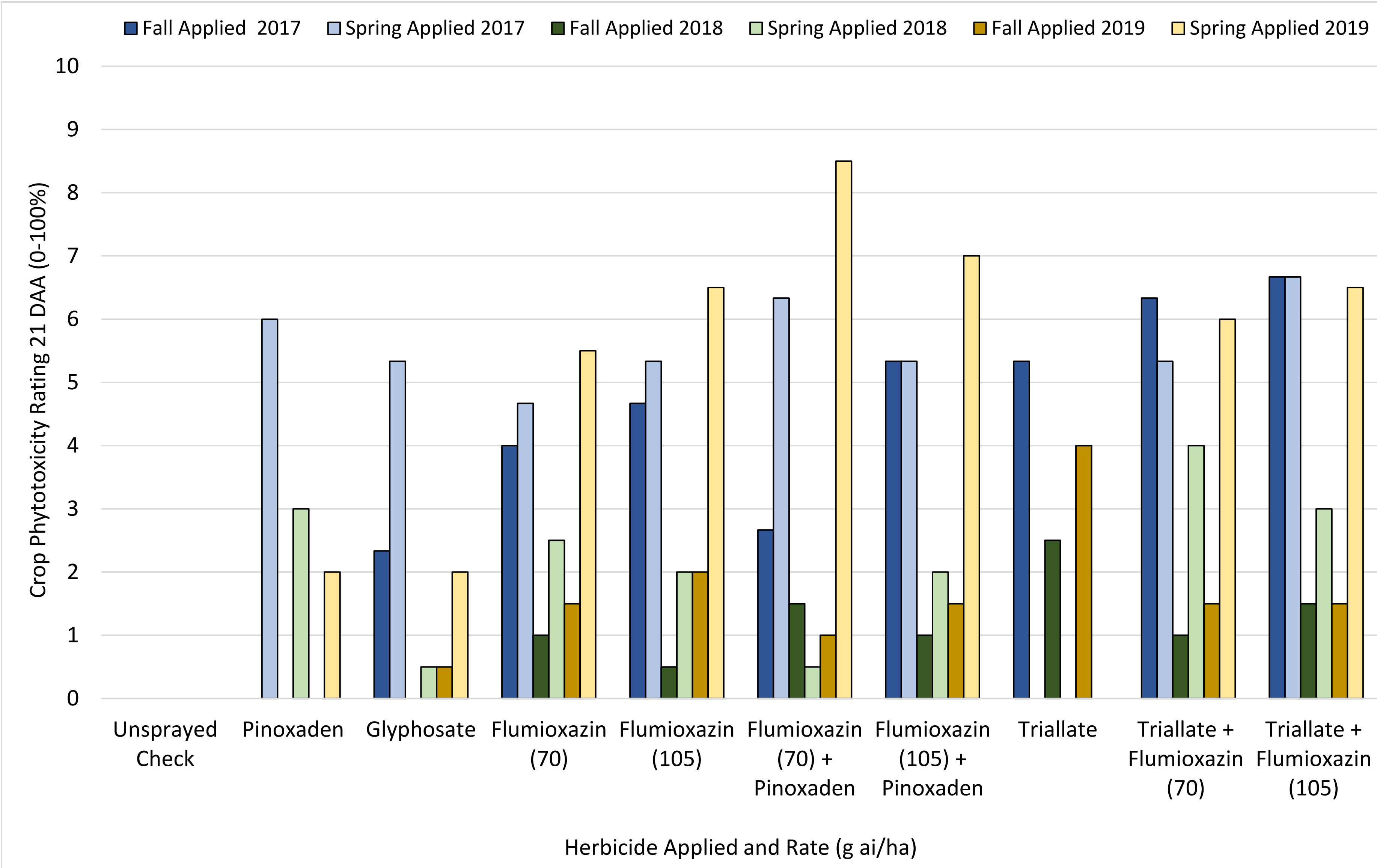

Figure 4. Crop phytotoxicity rating conducted 21 DAA (days after post-emergent application) on malt barley at Scott in 2017, 2018, and 2019. Pinoxaden was applied post-emergent on the crop at the 3-4 leaf stage, while glyphosate and flumioxazin were applied in the fall and spring (7 days prior to seeding). Triallate was only applied in the fall.

Herbicide Efficacy

Herbicide efficacy ratings will be discussed based on year as the environmental conditions in each growing season varied drastically. Discussing the herbicide response to weed control under different environments will provide producers greater insight as to how the herbicide will perform under different conditions.

At Lethbridge 2017, weed control ratings conducted at 7 DAA indicated differences in herbicide efficacy among the treatments (P <0.0001) and the trends remained the same until 21 DAA (P<0.0001). The most effective treatments had very good to excellent weed control with 97 to 100% at both 7 and 21 DAA. These treatments included glyphosate applied in the spring, flumioxazin applied in the spring at both high and low rates alone and with pinoxaden post-emergent. Weed control was considered poor (<60%) when triallate was used in combination with flumioxazin in the spring and fall with both high (105 g ai/ ha) and low application rates (70 g ai/ha). Fall applications of all combinations (glyphosate, flumioxazin alone, flumioxazin with pinoxaden, and triallate) resulted in very poor weed control (Fig. 5 and 6).

At Scott 2017, weed control ratings conducted at 7 DAA and 21 DAA also indicated a treatment response (P= 0.0009; <0.0001). Weed control ratings at both 7 DAA and 21 DAA indicated good to fair suppression of Japanese brome with all herbicide combinations, except pinoxaden applied alone as weed control was poor. There was very little difference in efficacy between the two application timings (fall vs. spring), rate (70 vs 105 g ai/ha) or combination utilized. These trends contrast the visual weed control ratings conducted at Scott 2018 in which timing played a very large role in efficacy. Spring glyphosate applications provide very good weed control early on (90%) and continued until 21 DAA (85%) while fall applied glyphosate weed control was very poor during the entire growing season (<25%). Japanese brome weed control at 7 DAA was very good to excellent (92- 100%) with spring applications of flumioxazin at the two application rates (70 and 105 g ai/ha) applied alone and in combination with pinoxaden and triallate (Fig. 5). Spring applications had consistent efficacy throughout the growing season with visual control ratings exceeding 85% at 21 DAA (Fig. 6). In contrast, fall application of flumioxazin applied alone and with pinoxaden and triallate was very poor (<35%) at the low application rate (70 g ai/ha) at both 7 DAA and 21 DAA. Efficacy slightly increased with fall applications when flumioxazin was applied at 105 g ai/ha, however, weed control was still considered poor (<50%).

Fall applications were much more effective in 2019 than reported in 2018. Initial efficacy ratings at 7 DAA indicated that fall flumioxazin at 70 and 105 g ai/ha provided good control (80%) but efficacy declined by 30% over time. The higher application rate of flumioxazin provided slightly greater control than the lower application rate, this was particularly true at 21 DAA (Fig. 5 and 6). Efficacy also increased when multiple herbicides were utilized in the fall and spring. Fall flumioxazin (70 and 105 g ai/ha) with pinoxaden provided good weed control (80%) at 7 DAA and provided very little suppression (62% and

65%) at 21 DAA. Spring flumioxazin (70 and 105 g ai/ha) with pinoxaden provided excellent weed control (88%) at 7 DAA and provided little suppression (50% and 60%) at 21 DAA, respectively. The most effective combination in the fall was flumioxazin (70 and 105 g ai/ha) with triallate as it initially provided good control (82%) with a slight decline to 65% and 73% at 21 DAA, respectively. Similarly, spring applied flumioxazin (70 and 105 g ai/ha) with triallate provided excellent control (90%) at 7 DAA with marginal suppression (65% and 70%) at 21 DAA, respectively. Additionally, regardless of year or location, single applications of pinoxaden and triallate resulted in poor Japanese brome control at both 7 DAA and 21 DAA (Fig. 5 and 6).

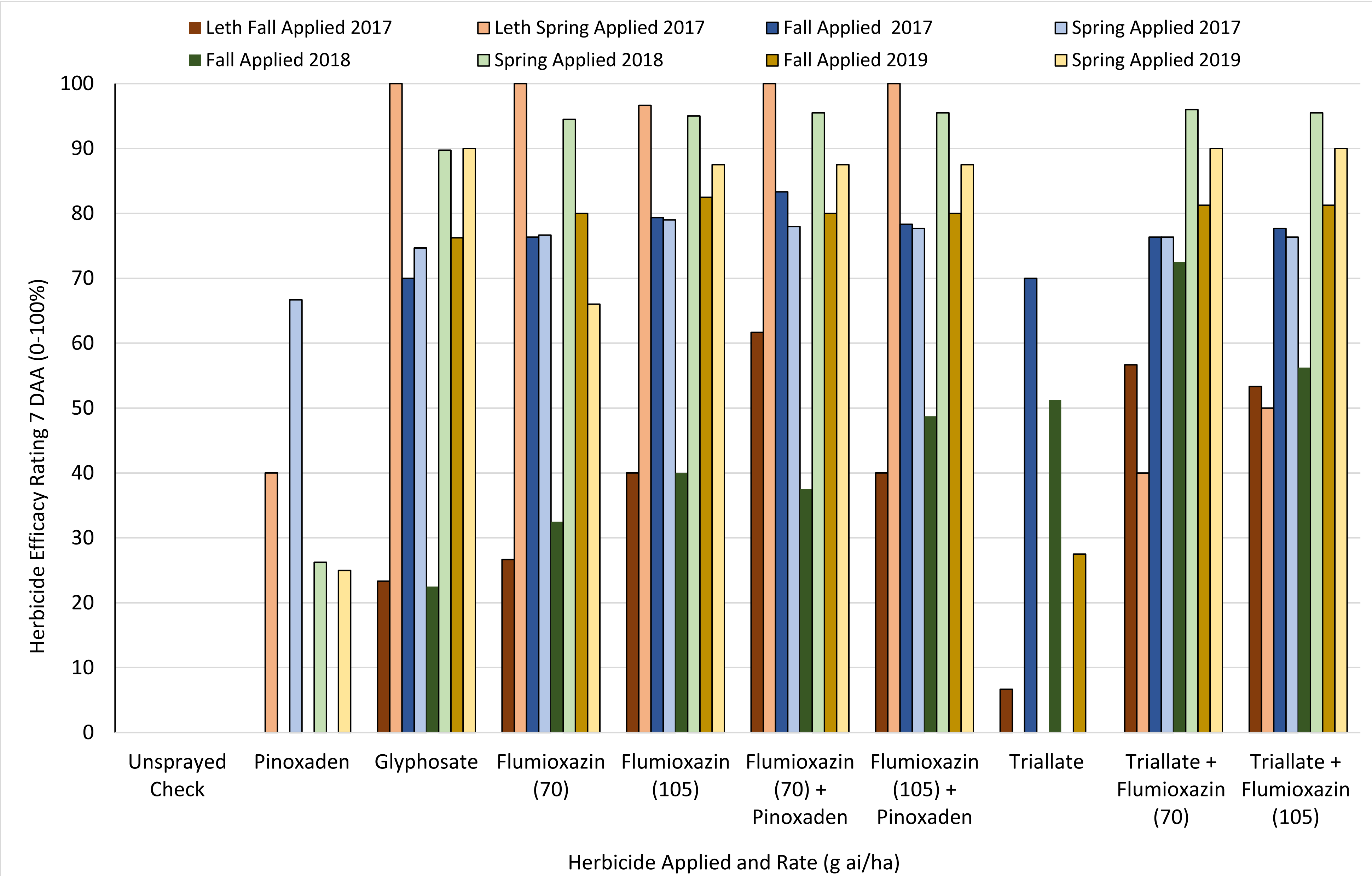

Figure 5. Visual weed control (herbicide efficacy) ratings conducted 7 DAA (days after post-emergent application) on Japanese brome at Lethbridge in 2017 and Scott in 2017, 2018, and 2019. Pinoxaden was applied post-emergent on the crop at the 3-4 leaf stage, while glyphosate and flumioxazin were applied in the fall and spring (7 days prior to seeding). Triallate was only applied in the fall.

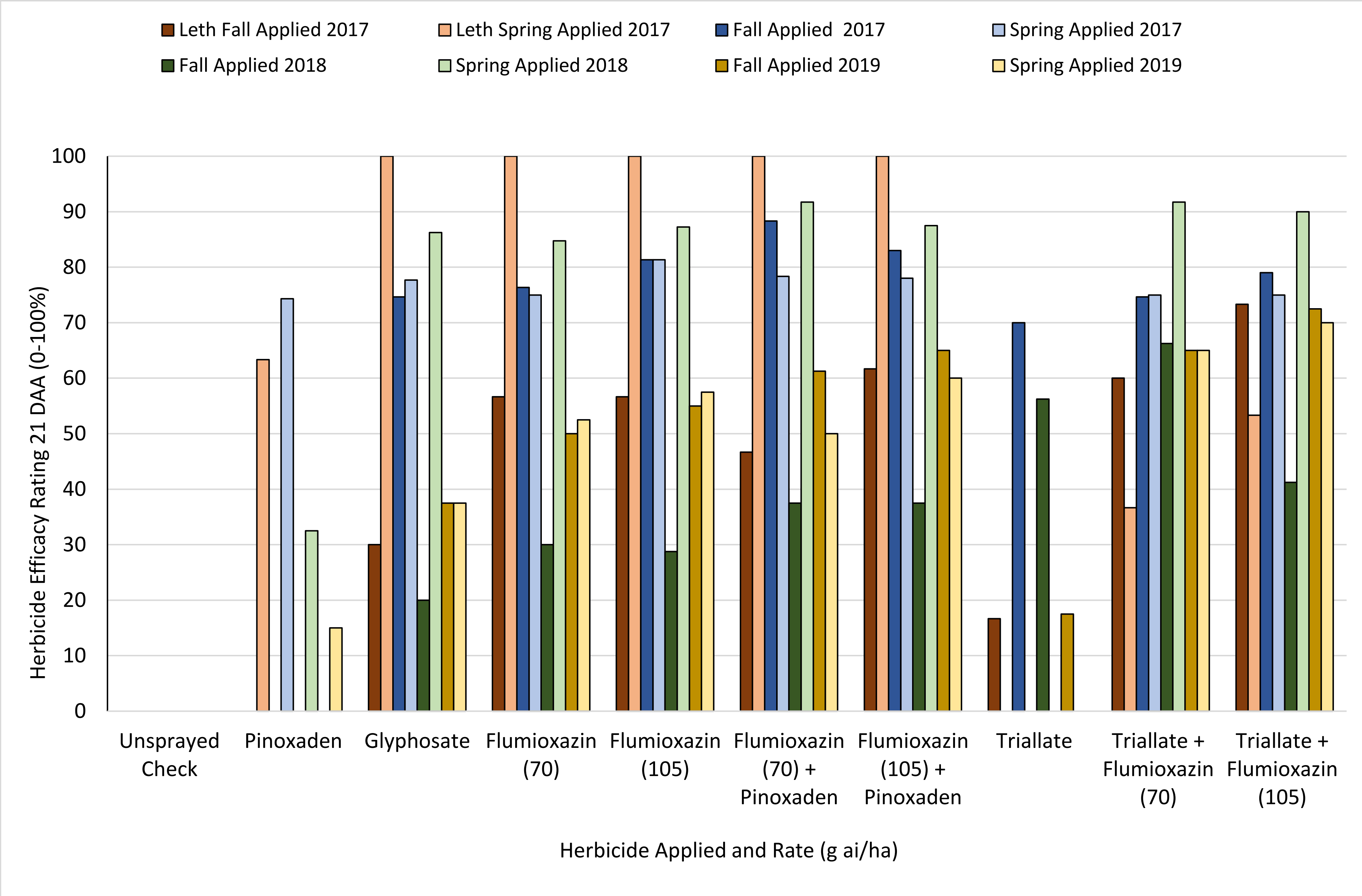

Figure 6. Visual weed control (herbicide efficacy) ratings conducted 7 DAA (days after post-emergent application) on Japanese brome at Lethbridge in 2017 and Scott in 2017, 2018, and 2019. Pinoxaden was applied post-emergent on the crop at the 3-4 leaf stage, while glyphosate and flumioxazin were applied in the fall and spring (7 days prior to seeding). Triallate was only applied in the fall.

Weed Biomass

In 2017, the least effective herbicide combination was flumioxazin applied alone at a low rate (70 g ai/ha) in the fall, pinoxaden applied alone and a fall application of glyphosate. Although these were the least effective herbicide applications, Japanese brome production was reduced by 20%, 41% and 49% compared to the unsprayed check, respectively. Japanese brome production was further reduced by fall applications of flumioxazin at the high rate (105 g ai/ha) applied alone and with pinoxaden and spring applications of flumioxazin at the low rate and to a greater extent at the higher rate. The greatest reductions occurred with the use of triallate and flumioxazin at both high and low application rates with the greatest reduction occurring with triallate and flumioxazin at 105 g ai/ha in the spring by 87% reduction compared to the unsprayed check (Table 4).

In 2018, the fall applications of flumioxazin at both low and high application rates resulted in substantial Japanese brome growth that were comparable to the untreated check. Japanese brome growth was slightly reduced when flumioxazin at both high and low rates in the fall were combined with pinoxaden but the presence of Japanese brome was still similar to the unsprayed check. Fall glyphosate was 34% more effective than the fall flumioxazin combinations. While fall applications were minimally effective, spring applications of glyphosate and all flumioxazin combinations were highly effective. The most effective combination was triallate with flumioxazin at a low rate and to a greater extent at the higher rate. These two combinations resulted in a 96% and 97% reduction in Japanese brome biomass compared to the unsprayed check (Table 4).

The timing of fall and spring applications of flumioxazin was less apparent in 2019 compared to 2018. Fall flumioxazin applied alone and in combination with pinoxaden on average reduced Japanese brome biomass by 60% compared to the unsprayed check. However, higher applications rate of flumioxazin were slightly more effective (1.8%) than the lower application rate. The application rate of flumioxazin and timing also played a role when used in combination with triallate. For example, spring applied flumioxazin at 105 g ai/ha was the most effective followed closely by the spring application of flumioxazin at 70 g ai/ha applied with triallate, followed by the fall application of flumioxazin at 105 g ai/ha with triallate (Table 4).

Lethbridge did not collect weed biomass (kg/ha) in 2017.

Table 4. Japanese brome biomass (kg/ha) was collected at Scott, SK in 2017, 2018, and 2019.

Herbicide Product & Rate	Application Timing	2017	2018	2019
		Japanese Brome Biomass (kg/ha)		
Unsprayed Check		539^{A}	726^{AB}	997^{AB}
Pinoxaden	Post- Emergent	321 ^{AB}	5191^{ABC}	1074 ^{A}
Glyphosate	Fall	273^{AB}	481^{ABC}	622 ^{BCD}
Flumioxazin (70 g ai/ha)	Fall	432^{AB}	853^{A}	398 ^{DEC}
Flumioxazin (105g ai/ha)	Fall	213^{AB}	848^{A}	417 ^{DEC}
Flumioxazin (70 g ai/ha) & Pinoxaden	Fall & Post-Emergent	253^{AB}	653^{AB}	402 ^{DEC}
Flumioxazin (105g ai/ha) & Pinoxaden	Fall & Post-Emergent	221^{AB}	562^{ABC}	368 ^{DEC}
Triallate	Fall	226^{AB}	232^{BC}	910 ^{AB}
Triallate & Flumioxazin (70 g ai/ha)	Fall	137^{AB}	318^{ABC}	219 ^{E}
Triallate & Flumioxazin (105 g ai/ha)	Fall	144^{AB}	429^{ABC}	270 ^{DE}
Glyphosate	Spring	259^{AB}	19^{BC}	690 ^{ABC}
Flumioxazin (70 g ai/ha)	Spring	255 ^{AB}	50^{BC}	314 ^{DEC}
Flumioxazin (105g ai/ha)	Spring	221 ^{AB}	37^{BC}	270 ^{DE}
Flumioxazin (70 g ai/ha) & Pinoxaden	Spring & Post-Emergent	147 ^{AB}	20^{BC}	382 ^{DEC}
Flumioxazin (105g ai/ha) & Pinoxaden	Spring & Post-Emergent	239 ^{AB}	41^{BC}	368 ^{DEC}
Triallate & Flumioxazin (70 g ai/ha)	Fall & Spring	147 ^{AB}	28^{BC}	202 ^{E}
Triallate & Flumioxazin (105 g ai/ha)	Fall & Spring	73^{B}	21^{BC}	112 ^{E}
LSD (0.05)		*	***	***

*,**,*** significantly different than the control at the 0.05,0.01, and 0.001 probability levels
Different letters indicate significant differences between treatments

Crop Biomass

In Lethbridge 2017, malt barley production was not significantly influenced by herbicide treatments (P=0.206) but crop biomass tended to increase with applications of fall and spring glyphosate, fall flumioxazin at a low and high rate and fall flumioxazin at a low rate with pinoxaden. Malt barley biomass dropped by 5% with spring application of flumioxazin at a high rate with pinoxaden and by 13% when triallate and flumioxazin at a high rate in the spring were applied (Table 5).

In Scott 2017, there was a non-significant effect of herbicide treatments on malt barley production (P=0.0924). However, malt barley biomass tended to increase with fall applications of flumioxazin at both high and low application rates applied alone and in combination with pinoxaden and triallate. Spring applications had lower biomass particularly when flumioxazin and pinoxaden were used in combination (Table 5). The lowest biomass recorded occurred with the unsprayed check and when triallate and pinoxaden were used alone.

In Scott 2018, malt barley biomass was significantly influenced by herbicide application (P=0.0009) in which most herbicides increased crop biomass. The highest malt barley biomass was recorded with spring applications of flumioxazin at a low rate applied alone, with pinoxaden and triallate and to a less extent when applied at a high application rate. Fall applied herbicides tended to have lower crop biomass compared to their spring counterparts, especially when flumioxazin was combined with pinoxaden. There was on average a 44% and 23% less crop biomass when flumioxazin with pinoxaden and flumioxazin applied alone in the fall compared to their spring applications, respectively. Lastly, the lowest biomass occurred with the unsprayed check, pinoxaden and triallate applied alone.

In Scott 2019, the timing of herbicide application very significantly ($P<0.0001$) influenced malt barley biomass. Similar to the trends in 2018, the application of herbicides tended to increase crop biomass, however, in contrast to 2018, fall applications significantly increased crop biomass compared to spring applications. The fall applications of flumioxazin alone, flumioxazin with pinoxaden and with triallate increased malt barley biomass by 40%, 60% and 46% respectively to their spring counterpart. Additionally, the lowest biomass occurred with the unsprayed check, pinoxaden applied alone and triallate applied alone.

Table 5. Malt barley biomass (kg/ha) was collected at Lethbridge in 2017 and Scott, SK in 2017, 2018, and 2019.

Herbicide Product & Rate	Application Timing	Lethbridge 2017	Scott 2017	Scott 2018	Scott 2019
		Malt barley biomass (kg/ha)			
Unsprayed Check		207 A	3388 A	890 B	1373 D
Pinoxaden	Post-Emergent	220 A	3541 A	889 B	1590 D
Glyphosate	Fall	247 A	4759 A	1237 AB	3198 ABC
Flumioxazin (70 g ai/ha)	Fall	227 A	4616 A	980 AB	3345 ABC
Flumioxazin (105g ai/ha)	Fall	273 A	4492 A	952 B	3393 ABC
Flumioxazin (70 g ai/ha) & Pinoxaden	Fall & Post-Emergent	220 A	4426 A	710 B	3614 AB
Flumioxazin (105g ai/ha) & Pinoxaden	Fall & Post-Emergent	207 A	3900 A	952 B	3588 AB
Triallate	Fall	260 A	3045 A	999 B	1350 D
Triallate & Flumioxazin (70 g ai/ha)	Fall	247 A	4059 A	1260 AB	3731 A
Triallate & Flumioxazin (105 g ai/ha)	Fall	203 A	4243 A	1336 AB	3537 AB
Glyphosate	Spring	237 A	4115 A	1327 AB	1827 CD
Flumioxazin (70 g ai/ha)	Spring	247 A	3696 A	1301 AB	2128 BCD
Flumioxazin (105g ai/ha)	Spring	217 A	4092 A	1214 AB	1936 CD
Flumioxazin (70 g ai/ha) & Pinoxaden	Spring & Post-Emergent	227 A	3389 A	1654 A	1575 D
Flumioxazin (105g ai/ha) & Pinoxaden	Spring & Post-Emergent	197 A	2621 A	1328 AB	1299 D
Triallate & Flumioxazin (70 g ai/ha)	Fall & Spring	267 A	4427 A	1104 AB	1882 CD
Triallate & Flumioxazin (105 g ai/ha)	Fall & Spring	180 A	3971 A	1357 AB	2051 BCD
	LSD (0.05)	NS	NS	***	***

*,**,*** significantly different than the control at the 0.05,0.01, and 0.001 probability levels, NS= not significant; Different letters indicate significant differences between treatments

Grain Yield & Grain Quality

In Lethbridge 2017, yield was very low among all treatments (630 kg/ha to 937 kg/ha) and a significant effect was not observed (P=0.6482). Yields tended to increase with fall applied flumioxazin at both 70 and 105 g ai/ha, however, strong trends in general were difficult to determine due to the very low yields.

In Scott 2017, malt barley yield was significantly influenced by herbicide application (P=0.0452). The application timing of flumioxazin played a large role on malt barley yield. The highest yield of 3875 kg/ha was achieved with a fall application of flumioxazin (105 g ai/ha) with pinoxaden. Fall applications of flumioxazin applied alone and with pinoxaden resulted in the highest and most consistent yields with an average increase of 38% in yield compared to the unsprayed check, 15% higher than pinoxaden applied alone and 7% higher than glyphosate applied in the fall and spring. Fall applications of flumioxazin applied alone and with pinoxaden also resulted in a 6% higher yield compared to its spring counterparts. Spring applications of flumioxazin (applied alone, with pinoxaden, and triallate) were still relatively successful with a 36% increase in yield compared to the unsprayed check, however, yields were less consistent than the fall applications. Single herbicide applications of triallate and pinoxaden were unsuccessful as yield declined by 31% and 13% when flumioxazin was not used. The lowest yields occurred with the unsprayed check (2330 kg/ha), triallate alone (2500 kg/ha), pinoxaden alone (3231 kg/ha) (Table 6).

In Scott 2018, spring applied flumioxazin alone, with pinoxaden and triallate resulted in the highest yields ranging between 3212 kg/ha and 3431 kg/ha. Fall applied flumioxazin alone, with pinoxaden and with triallate resulted in consistently lower yields on average by 24% compared to their spring counterpart. There was very little difference between flumioxazin applied alone and when used in combination. In contrast, triallate and pinoxaden resulted in a 29% and 36% yield reduction when applied alone compared to the flumioxazin combinations. The lowest yields occurred with the unsprayed check of 1604 kg/ha.

In contrast, the results from Scott 2019 indicated that fall applications of flumioxazin applied alone, with pinoxaden and with triallate resulted in the highest and most consistent yields. The highest yield of 4883 kg/ha occurred with flumioxazin at 105 g ai/ha with pinoxaden while its spring counterpart resulted in a yield of 4112kg/ha. On average, spring applied herbicides resulted in a 7% yield loss compared to the fall applications. Triallate and pinoxaden applied alone resulted in a 29% yield loss compared to when flumioxazin was used in combination (Table 6).

Although there were significant yield differences recorded in each year at Scott, there was very little differences in thousand seed weight and test weight amongst all herbicide treatments. In all three years at Scott, the lowest thousand kernel weight typically occurred with the lowest yielding treatments of pinoxaden and triallate applied alone and the unsprayed check. However, differences between the highest and lowest thousand kernel weight was less than 3 grams total. The test weights also exhibited a similar trend as there were very little differences between the highest and lowest bushel weight was 1.5% (data not shown). Similarly, there were no differences detected for test weight (P= 0.3465) or thousand kernel weight (P= 0.1264) at Lethbridge in 2017. Both quality parameters at this location had very low values and no trends were observed among the treatments (data not shown).

Table 6. Malt barley yield (kg/ha) at Lethbridge in 2017 and Scott, SK in 2017, 2018, and 2019.

Herbicide Product & Rate	Application Timing	Lethbridge 2017	Scott 2017	Scott 2018	Scott 2019
Unsprayed Check		787^{A}	2320^{C}	1604^{E}	2501^{E}
Pinoxaden	Post-Emergent	714^{A}	3231^{AB}	2089DE	3007DE
Glyphosate	Fall	753^{A}	3568^{A}	2232^{CDE}	4189^{AB}
Flumioxazin (70 g ai/ha)	Fall	938^{A}	3812^{A}	2281^{CDE}	4337^{AB}
Flumioxazin (105g ai/ha)	Fall	870^{A}	3711^{A}	2283^{CDE}	4488^{AB}
Flumioxazin (70 g ai/ha) & Pinoxaden	Fall & Post-Emergent	790^{A}	3769^{A}	2414^{BCDE}	4230^{AB}
Flumioxazin (105g ai/ha) & Pinoxaden	Fall & Post-Emergent	756^{A}	3875^{A}	2599^{ABCD}	4883^{A}
Triallate	Fall	772^{A}	2500^{BC}	1967DE	3040^{CDE}
Triallate & Flumioxazin (70 g ai/ha)	Fall	749^{A}	3496^{A}	2788^{ABCD}	4333^{AB}
Triallate & Flumioxazin (105 g ai/ha)	Fall	698^{A}	3585^{A}	2858^{ABCD}	4316^{AB}
Glyphosate	Spring	781^{A}	3514^{A}	3049^{ABC}	3586^{BCD}
Flumioxazin (70 g ai/ha)	Spring	764^{A}	3377^{AB}	3212^{AB}	3969^{B}
Flumioxazin (105g ai/ha)	Spring	630^{A}	3783^{A}	3284^{AB}	4161^{AB}
Flumioxazin (70 g ai/ha) & Pinoxaden	Spring & Post-Emergent	718^{A}	3550^{A}	3431^{A}	3917^{BC}
Flumioxazin (105g ai/ha) & Pinoxaden	Spring & Post-Emergent	806^{A}	3603^{A}	3366^{A}	4112^{AB}
Triallate & Flumioxazin (70 g ai/ha)	Fall & Spring	774^{A}	3804^{A}	3343^{A}	4270^{AB}
Triallate & Flumioxazin (105 g ai/ha)	Fall & Spring	790^{A}	3618^{A}	3346^{A}	4284^{AB}
	LSD (0.05)	NS	*	***	***

*,**,*** significantly different than the control at the 0.05,0.01, and 0.001 probability levels, NS= not significant; Different letters indicate significant differences between treatments

Discussion

Single herbicide applications were less effective in controlling Japanese brome than when used in combination. Fall glyphosate, triallate, and post- emergent pinoxaden applications were very ineffective in controlling Japanese brome and ultimately resulted in low yields and to some degree poorer seed quality. Spring applied glyphosate provided great early season weed control with little crop damage, however, Japanese brome regrowth did occur and ultimately resulted in a slightly lower yield compared to applications with a residual component.

Single applications of residual herbicides such as flumioxazin resulted in slightly better weed control than the non-residual (glyphosate and pinoxaden) applications. Spring applied flumioxazin, averaged over three years at Scott, resulted in a 70% and 58% reduction in Japanese brome compared to fall applications of glyphosate and post- emergent pinoxaden, respectively. Spring applications of glyphosate were comparable to fall flumioxazin and were slightly less effective than spring applied flumioxazin.

Application timing of flumioxazin played a very important role in its efficacy and degree of crop injury. In 2017 and 2019, spring applications of flumioxazin had a slight increase in efficacy (up to 21%) for Japanese brome control compared to fall applications. Spring applications in 2018 were much more effective with a 96% reduction in Japanese brome biomass compared to the fall applications. Although spring applied herbicides provided more effective weed control in all four site-years, crop biomass and yield was higher with fall applications compared to the spring applications in three site-years. The exception occurred in 2018, as fall applications were much less effective in controlling Japanese brome and therefore had a greater crop- weed competition and ultimately less crop biomass. In 2019, crop injury was excessive and deemed unacceptable (>10% injury) with spring applications and ultimately resulted in a yield reduction of 7% compared to fall applications. Applying multiple herbicides in the spring also increased the risk of crop injury. Spring applied flumioxazin at the high rate in combination with a post-emergent application of pinoxaden typically resulted in a slight yield decline. This likely occurred because the crop was slightly damaged by the flumioxazin application and then the post-emergence application under stress conditions resulted in further crop damage. These results indicate that although weed control is superior with spring applications, there is a risk of crop damage at both low and high spring application rates.

Single herbicide applications, regardless of application timing, were generally less effective than herbicides applied in combination. Applications of triallate applied alone over a three-year average resulted in 30% less weed control than when used in combination with flumioxazin and to a lesser extent (26%) when flumioxazin combined with pinoxaden. As application timing of flumioxazin was critical to its efficacy, spring applied flumioxazin with triallate over three years reduced weed biomass by 87% and by 51% when flumioxazin and pinoxaden were combined compared to their fall counterpart application. The application of triallate and flumioxazin applied in the spring appear to provide an additive effect as Japanese brome was strongly controlled with this combination in both 2017, 2018, and 2019 and to some degree at Lethbridge in 2017. Although this combination was very effective in controlling Japanese brome, it also caused notable crop injury.

Overall ranking of these products will be based on overall consistency of weed control and degree of crop injury. Spring applied glyphosate provided effective yet slightly inconsistent weed control that resulted in weed regrowth and slightly less yields compared to spring applied flumioxazin (high and low) with triallate and pinoxaden. Spring applied flumioxazin with triallate and with pinoxaden provided the most consistent weed control when averaged over all years. However, flumioxazin applied at a high rate with triallate and pinoxaden tended to cause greater crop injury compared to a low rate of flumioxazin with triallate and pinoxaden. Although these two combinations were the most effective in controlling Japanese brome, the risk of crop injury remains a prominent concern with both spring and fall applications. For this reason, registration of flumioxazin remains unlikely due to crop injury concerns, regardless of application rate or timing. The most practical and safe practice would be to spray glyphosate in the spring prior to seeding combined with an in-crop herbicide application.

APPENDIX A1:

Agronomic Information

Table A1: Selected agronomic information for Japanese brome weed control in malt barley at two locations in Western Canada in 2017- 2019.

Activity	**Lethbridge, 2017**	**Scott, 2017**	**Scott, 2018**	**Scott, 2019**
Broadcasting J. brome	October 06, 2016	None	None	None
Fall application (glyphosate + flumioxazin)	October 22, 2016	October 21, 2016	October 19th, 2017	October 24, 2019
Fall application (triallate)	October 22, 2016	October 22, 2016	October 19th, 2017	October 24, 2019
Seeding date	May 10, 2017	May 10, 2017		May 21, 2019
Spring application (glyphosate + flumioxazin)	April 19, 2017	May 9, 2017	May 18th, 2018	May 14, 2019
Post-emergence application (pinoxaden)	June 6, 2017	June 15, 2017	June 8th, 2018	June 17, 2019
Fungicide application	N/A	July 14, 2017 (metconazole)	N/A	NA
Harvest date	August 17, 2017	August 28, 2017	August 29th, 2018	September 16, 2019

APPENDIX B1:

Table B1: Visual assessment scale (0-100) to evaluate herbicide efficacy for weed control and crop tolerance.

Description of Visual 0-100 Rating Scale

A) Evaluation of Herbicidal Action

The assessment of herbicide action of a product is based on the comparison of the treated plot with the untreated check plot. The aim is to assess as accurately as possible the decrease in biomass (ie. Number of plants, height, number of leaves, etc.) per weed species as compared to the check. The decrease in biomass is attributed to the action of the product. This reduction can be expressed by means of a linear scale.

Activity Range	Description of Control	Suggested Interval size
91-100%	Very Good to Excellent	2%
81-90%	Good to Very Good	5%
80%	Just Acceptable	
70-79%	Suppression	5%
60-69%	Not Acceptable	5%
< 60%	Poor	10%

- 80% or better is considered acceptable control

Without an exact count there are limits to the accuracy of assessment even for the practiced eye. It has therefore been found useful to aim for a differentiation of approximately 2% exactitude in the very good to excellent action range, but below that to estimate to not more than 5% or 10 % accuracy.

The evaluation is always based on the direct comparison between treated and untreated plots.

The use of the 0-100% assessment is no more or less subjective than using any other scale (0-9 or 0-10), and the researcher's judgement still can be incorporated into the assessment. We must recognize this assessment as not representing an actual count since it does not.

B) Evaluation of Crop Tolerance

The same basic principals apply. The evaluation should again be done with a comparison to the untreated check.. In most cases, however, the untreated check suffer from the competition of the weeds and therefore one should include hand weeded check plots.

Phytotoxicity Range	Assessment of Injury	Suggested Interval size
0-9%	Slight Discoloration and/or Stunting	2%
10%	Just acceptable	
11-30%	Not Acceptable	5%
< 30%	Severe	10%

- 10% or less is considered acceptable injury

Initial Damage of up to 10% will generally be outgrown and will disappear with time. The impact of these low levels of injury will not be reflected in yield losses.

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Extension & Acknowledgements

This demonstration was a formal stop during the Farmer Writers of Saskatchewan Tour at Scott Saskatchewan in 2017. The tour was well attended and signs were in place to acknowledge the support of Saskatchewan Barley Development Commission. A poster presentation was also conducted at Soils and Crops conference in Saskatoon, Saskatchewan in 2018. At the WARC annual conference, Crop Opportunity on March 13th, 2018 the trial was highlighted and presented in North Battleford, Saskatchewan where there was approximately 120 producers and agronomists in attendance. Eric Johnson presented a project update at the Scott Research Field Day in 2018 with approximately 95 attendees. The results in the form of a factsheet will also be made available on the WARC website. The Saskatchewan Barley Development Commission was acknowledged at all of the extension events.

10. Conclusions and Recommendations

Overall ranking of these products will be based on overall consistency of weed control and degree of crop injury. Spring applied glyphosate provided effective yet slightly inconsistent weed control that resulted in weed regrowth and slightly less yields compared to spring applied flumioxazin (high and low) with triallate and pinoxaden. Spring applied flumioxazin with triallate and with pinoxaden provided the most consistent weed control when averaged over all years. However, flumioxazin applied at a high rate with triallate and pinoxaden tended to cause greater crop injury compared to a low rate of flumioxazin with triallate and pinoxaden. Although these two combinations were the most effective in controlling Japanese brome, the risk of crop injury remains a prominent concern with both spring and fall applications. For this reason, registration of flumioxazin remains unlikely due to crop injury concerns, regardless of application rate or timing. The most practical and safe practice would be to spray glyphosate in the spring prior to seeding combined with an in-crop herbicide application.

Abstract

11. Abstract/Summary:

Japanese brome (*Bromus japonicus L.*) is difficult weed to control on the prairies, due to the limited and minimally effective herbicide options available malt barley growers. The objectives of this study were to evaluate malt barley tolerance to various herbicide combinations and application timings as well as determine the efficacy of these combinations for Japanese brome control. This study was initiated in Lethbridge in 2017 and Scott in 2017, 2018 and 2019. The treatments consisted of four herbicides (glyphosate, flumioxazin, pinoxaden, and triallate) applied alone and in-combination at two application timings (fall vs. spring). Flumioxazin was applied at two rates: 70 and 105 g ai/ha (low vs. high). There were 17 herbicide combinations in total. Single herbicide applications were less effective in controlling Japanese brome than when used in combination. Fall glyphosate, triallate, and post- emergent pinoxaden applications were very ineffective in controlling Japanese brome and ultimately resulted in low yields and to some degree poorer seed quality. Spring applied glyphosate provided great early season weed control with little crop damage, however, Japanese brome regrowth did occur and ultimately resulted in a slightly lower yield compared to applications with a residual component. Single applications of flumioxazin resulted in slightly better weed control than the non-residual (glyphosate and pinoxaden) applications. Spring applied flumioxazin, averaged over three years at Scott, resulted in a 70% and 58% reduction in Japanese brome compared to fall applications of glyphosate and post- emergent pinoxaden, respectively. Spring applications of glyphosate were comparable to fall flumioxazin and were slightly less effective than spring applied flumioxazin. The most effective herbicide combination for Japanese brome control was spring applied flumioxazin with pinoxaden and to a greater extend flumioxazin with triallate. The combination appeared to provide an additive effect as Japanese brome was strongly controlled with this combination in both 2017, 2018, and 2019 and to some degree at Lethbridge in 2017. Although this combination was the most effective in controlling Japanese brome, the risk of crop injury remains a prominent concern. For this reason, registration of flumioxazin remains unlikely due to crop injury concerns, regardless of application rate or timing. The most practical and safe practice would be to spray glyphosate in the spring prior to seeding combined with an in-crop herbicide application.