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Research Article

Glyphosate-Resistant Canada Fleabane Control in Winter Wheat with Postemergence Herbicides

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In recent years, there has been a rapid increase in the number of herbicide-resistant weeds, including glyphosate-resistant (GR) biotypes in Ontario, Canada. A total of six field experiments were conducted over a two-year period (2018 and 2019) to determine the control of GR Canada fleabane (*Conyza canadensis* (L.) Cronq.) with currently available herbicides for winter wheat in Ontario. Winter wheat was not injured with any of the herbicides evaluated. Among herbicides evaluated, pyrasulfotole/bromoxynil (preformulated), 2,4-D ester, halauxifen, fluroxypyr/halauxifen (preformulated) + MCPA, pyrasulfotole/bromoxynil/fluroxypyr (preformulated), pyrasulfotole/bromoxynil/thiencarbazone (preformulated), pyrasulfotole/bromoxynil/thiencarbazone + MCPA, and fluroxypyr/halauxifen + pyroxsulam + MCPA controlled GR Canada fleabane 94–100% at 8 weeks after application (WAA) and reduced density 95–100% and biomass 97–100%. Reduced GR Canada fleabane interference with pyrasulfotole/bromoxynil/thiencarbazone + MCPA increased winter wheat yield 27% compared to the weedy control. GR Canada fleabane interference had no adverse effect on winter wheat yield with all other treatments. Based on these results, herbicide treatments that include 2,4-D, pyrasulfotole, or halauxifen can adequately control GR Canada fleabane in winter wheat.

1. Introduction

Winter wheat (*Triticum aestivum* L.) is a cereal crop in Ontario that growers often rotate with their soybean and corn crops. In 2019 in Ontario, over 2 million tonnes of winter wheat was harvested from 400 thousand hectares with a market value of approximately $500 million [1].

In recent years, there has been an expeditious rise in the number of herbicide-resistant weeds, including glyphosate-resistant (GR) biotypes, because of large-scale glyphosate use in glyphosate-resistant crops, the increased use of no-till practices and therefore the increased use of glyphosate as a burndown, reduced use of herbicides with an alternate mode-of-action, and greater movement of farm machinery and produce [2,3]. There has been movement of these herbicide-resistant weed biotypes from farm to farm, township to township, and county to county across Ontario. Glyphosate-resistant Canada fleabane (*Conyza canadensis* (L.) Cronq.) was initially confirmed in 2010 in one county (Essex) in Ontario [4]. It has spread rapidly to 30 counties across the province [5]. The challenge of managing herbicide-resistant weed biotypes has been exacerbated in recent years with the advent of multiple-resistant biotypes. Today, there is Group 2 and 9 resistant Canada fleabane in Ontario.

Winter wheat is sensitive to weed interference. In a meta-analysis from trials conducted across North America, Flessner et al. [6] reported an average of 22% winter wheat yield loss when Best Management Practices (BMP) were used and weeds were left uncontrolled. Weeds such as GR Canada fleabane competes with winter wheat for light, water, space, and nutrients and can cause significant yield losses in winter wheat [7]. Quinn et al. [8] found a 13% numeric yield decrease due to GR Canada fleabane interference in winter wheat.

The discovery of GR weeds in Ontario has provided a market opportunity for various agri-chemical companies that have herbicides with activity on these GR biotypes as

they may provide an efficacious, cost-effective weed management solution for the control of these yield robbing weed biotypes. Currently, the herbicide that is used most frequently for GR Canada fleabane control in winter wheat is pyrasulfotole/bromoxynil (preformulated). The overreliance on one herbicide can increase selection pressure for herbicide-resistant genotypes. Additional weed control options are necessary for long-term, sustainable crop production programs.

The aim of this study was to assess pyrasulfotole/bromoxynil, 2,4-D ester, thifensulfuron-ethyl/tribenuron-methyl (preformulated) + fluroxypyr + MCPA ester, halauxifen-methyl, fluroxypyr/halauxifen-methyl (preformulated) + MCPA EHE, pyroxsulam, pyrasulfotole/bromoxynil/fluroxypyr (preformulated), pyrasulfotole/bromoxynil/thiencarbazone-methyl (preformulated), pyrasulfotole/bromoxynil/thiencarbazone-methyl + MCPA ester, tribenuron-methyl- + thiencarbazone-methyl, tribenuron-methyl + thiencarbazone-methyl + MCPA ester, fluroxypyr/bromoxynil/MCPA (preformulated), tolpyralate, and fluroxypyr/halauxifen-methyl + pyroxsulam + MCPA for the control GR Canada fleabane in winter wheat. To our knowledge, no study has compared the efficacy of these herbicide options for the control of GR Canada fleabane in winter wheat in Ontario. Using ineffective herbicide options can decrease winter wheat yield, reduce net profit, and result in a needless application of pesticides into the environment. Additionally, it is critical for cereal producers to know which herbicide/herbicide tank-mixtures provide the most efficacious GR Canada fleabane control in winter wheat. As a result, only effective herbicides will be applied which in turn will minimize the environmental loading of pesticides, improve weed control efficacy, and increase net returns to producers.

2. Materials and Methods

A total of six experiments were conducted over a two-year period (2018, 2019) in winter wheat fields infested with GR Canada fleabane. Field trials were located near Ridgetown (42.458138, −81.882041), Blenheim (42.330170, −82.029603), and Ridgetown (42.504121, −81.915343) in 2018 and near Ridgetown (42.460798, −81.884509), Botany (42.486860, −81.992258) and Morpeth (42.413690, −81.800850) in 2019.

Experiments were arranged in a randomized complete block design with four replications. There were 16 treatments consisting of weed-free control, weedy control, pyrasulfotole/bromoxynil (205 g ai ha^{-1}), 2,4-D ester (850 g ai ha^{-1}), thifensulfuron-ethyl/tribenuron-methyl + fluroxypyr + MCPA ester (15 + 70 + 280 g ai ha^{-1}), halauxifen-methyl (5 g ai ha^{-1}), fluroxypyr/halauxifen-methyl + MCPA EHE (82 + 372 g ai ha^{-1}), pyroxsulam (15 g ai ha^{-1}), pyrasulfotole/bromoxynil/fluroxypyr (277 g ai ha^{-1}), pyrasulfotole/bromoxynil/thiencarbazone-methyl (211 g ai ha^{-1}), pyrasulfotole/bromoxynil/thiencarbazone-methyl + MCPA ester (211 + 280 g ai ha^{-1}), tribenuron-methyl + thiencarbazone-methyl (7.5 + 5 g ai ha^{-1}), tribenuron-methyl + thiencarbazone-methyl + MCPA ester (7.5 + 5 + 280 g ai ha^{-1}), fluroxypyr/bromoxynil/MCPA (600 g ai ha^{-1}), tolpyralate (40 g ai ha^{-1}), and fluroxypyr/halauxifen-methyl + pyroxsulam + MCPA EHE (82 + 15 + 372 g ai ha^{-1}). Adjuvants used were based on the herbicide manufacturers' recommendations and are listed in Table 1.

Plots were 2 m wide by 8 m long. Winter wheat '25R40' (DuPont Pioneer, Mississauga, ON) was seeded with a double-disc drill at 140–150 kg ha^{-1} in rows spaced 19 cm apart at a depth of 3 cm in early October of 2017 and 2018. Plots were not irrigated throughout the growing season.

Herbicides were applied (when GR Canada fleabane was less than 10 cm in height) with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L of spray solution ha^{-1}. The sprayer was equipped with a 1.5 m wide handheld boom with four ULD nozzles (Hypro, New Brighton, MN) which produced a 2.0 m spray width.

Visible winter wheat injury was evaluated 1, 2, and 4 weeks after applicaiton (WAA) and GR Canada fleabane control was evaluated at 2, 4, and 8 WAA on a scale of 0 to 100% (0 = no visible injury/no control and 100 = plant death/total control). Density was determined at 4 WAA by counting the number of GR Canada fleabane plants within two 0.25 m^2 quadrats randomly placed in each plot. Biomass was then determined by harvesting the aboveground section of GR Canada fleabane plants within each quadrat and drying them in a paper bag at 60°C for a minimum of 48 hours. At maturity, a small plot combine was used to harvest winter wheat, and grain moisture content and weight were recorded. Yield data were adjusted to 14% moisture content.

The GLIMMIX procedure in SAS [9] was utilized for data analysis. The fixed effect consisted of herbicide treatment, and random effects were environment (year-location combinations), treatment by environment interaction, and replicate within environment. The assumptions for analysis and distributions within GLIMMIX were checked by plotting studentized residuals against predicted, environment, treatment, and replicate for each variable, as well as using the Shapiro-Wilk statistic [9]. To meet normality assumptions, visual estimates of GR Canada fleabane control 4 and 8 WAA were arcsine square-root transformed prior to analysis, while control 2 WAA and wheat yield needed no transformation. The lognormal distribution was utilized for GR Canada fleabane density and dry biomass. Means for all variables were separated at $P \leq 0.05$ on the model scale using Tukey's HSD. Any treatments with assigned values, and therefore having no variance, were excluded from the analysis. However, in the case of GR Canada fleabane control for the weedy control and density and dry biomass for the weed-free control, all assigned to be 0, comparisons with the value zero were still possible using the P-value from the LSMEAN output.

3. Results and Discussion

At 1, 2, and 4 WAA, there was no visible winter wheat injury from any of the herbicides evaluated. Previous research has similarly shown no significant visible injury with herbicides such as 2,4-D, pyrasulfotole, bromoxynil, thifensulfuron, tribenuron, prosulfuron, fluroxypyr, or MCPA mixtures at comparable rates in winter wheat [10–12]. However,

Table 1: Glyphosate-resistant Canada fleabane (GRCF) control 2, 4, and 8 weeks after herbicide application (WAA), GRCF density, and dry biomass 4 WAA and winter wheat yield for herbicides applied postemergence from 6 sites in southwestern Ontario in 2018–2019.

Herbicide treatment	Rate (g ai ha^{-1})	GRCF Control (%) 2 WAA	4 WAA	8 WAA	GRCF density (plants m^{-2})	GRCF dry biomass (g m^{-2})	Winter wheat yield (T ha^{-1})
Weed-free control		100	100	100	0 a	0 a	4.13 ab
Weedy control		0 f	0 e	0 e	142.1 h	10.8 e	3.58 b
Pyrasulfotole/bromoxynil + AMSa (1 L ha^{-1})	205	89 ab	97 ab	98 ab	0.7 abc	0.25 abc	4.31 ab
2,4-D ester	850	76 abc	93 ab	94 ab	6.4 bcde	0.37 abc	4.09 ab
Thifensulfuron-ethyl/tribenuron-methyl + fluroxypyr + MCPA ester + NISb (0.2% v/v)	15 + 70 + 280	62 bcd	74 bc	71 bc	17.1 def	1.46 bc	3.96 ab
Halauxifen-methyl + MSOc (1% v/v)	5	76 abc	98 ab	99 ab	0.8 abc	0.08 ab	4.36 ab
Fluroxypyr/halauxifen-methyl + MCPA EHE	82 + 372	78 abc	97 ab	98 ab	1.9 abcd	0.20 abc	4.19 ab
Pyroxsulam + NIS (0.25% v/v) + UANd (2 L ha^{-1})	15	19 e	8 d	7 d	49.9 fg	8.58 de	3.96 ab
Pyrasulfotole/bromoxynil/fluroxypyr	277	91 ab	98 ab	98 ab	2.3 abcd	0.20 abc	4.16 ab
Pyrasulfotole/bromoxynil/thiencarbazone-methyl + AMS (1 L ha-1)	211	94 a	100 a	100 a	0.1 ab	0.02 ab	4.56 a
Pyrasulfotole/bromoxynil/thiencarbazone-methyl + MCPA ester + AMS (1 L ha^{-1})	211 + 280	95 a	100 a	100 a	0.8 abc	0.02 ab	4.15 ab
Tribenuron-methyl + thiencarbazone-methyl + AMS (1 L ha-1)	7.5 + 5	11 ef	5 de	4 de	55.1 gh	7.17 de	4.02 ab
Tribenuron-methyl + thiencarbazone-methyl + MCPA ester + AMS (1 L ha^{-1})	7.5 + 5 + 280	38 de	38 cd	33 cd	28.4 efg	3.12 cd	3.93 ab
Fluroxypyr/bromoxynil/MCPA	600	67 abcd	81 abc	84 ab	13.7 cdef	0.94 bc	3.67 ab
Tolpyralate + MSO (0.5% v/v) + UAN (2.5% v/v)	40	57 cd	73 bc	78 ab	6.9 bcdef	0.52 abc	4.22 ab
Fluroxypyr/halauxifen-methyl + pyroxsulam + MCPA EHE + NIS (0.25% v/v)	82 + 15 + 372	79 ab	96 ab	96 ab	1.8 abcd	0.23 abc	3.92 ab

Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at $P \leq 0.05$ Ammonium sulfate. [b]Nonionic surfactant. [c]Methylated seed oil. [d]28% urea ammonium nitrate.

Reddy et al. [13] observed as much as 4% winter wheat injury with pyrasulfotole applied alone or in combination with metsulfuron, bromoxynil, dicamba, or MCPA.

At 2 WAA, pyrasulfotole/bromoxynil, 2,4-D ester, halauxifen, fluroxypyr/halauxifen + MCPA, pyrasulfotole/bromoxynil/fluroxypyr, pyrasulfotole/bromoxynil/thiencarbazone, pyrasulfotole/bromoxynil/thiencarbazone + MCPA, and fluroxypyr/halauxifen + pyroxsulam + MCPA controlled GR Canada fleabane 76–95%. Thifensulfuron/tribenuron + fluroxypyr + MCPA, fluroxypyr/bromoxynil/MCPA, and tolpyralate provided 57–67% control, and pyroxsulam, tribenuron + thiencarbazone, and tribenuron + thiencarbazone + MCPA provided only 11–38% control (Table 1).

GR Canada fleabane control generally increased over time. At 4 WAA, pyrasulfotole/bromoxynil, 2,4-D ester, halauxifen, fluroxypyr/halauxifen + MCPA, pyrasulfotole/bromoxynil/fluroxypyr, pyrasulfotole/bromoxynil/thiencarbazone, pyrasulfotole/bromoxynil/thiencarbazone + MCPA, and fluroxypyr/halauxifen + pyroxsulam + MCPA controlled GR Canada fleabane 93–100%. Thifensulfuron/tribenuron + fluroxypyr + MCPA, fluroxypyr/bromoxynil/MCPA, and tolpyralate provided 73–81% control, and pyroxsulam, tribenuron + thiencarbazone, and tribenuron + thiencarbazone + MCPA provided minimal control (5–38%) of GR Canada fleabane in winter wheat (Table 1).

GR Canada fleabane control was generally the highest at 8 WAA which can be attributed to the competitiveness of a vigorous winter wheat crop. Pyrasulfotole/bromoxynil, 2,4-D ester, halauxifen, fluroxypyr/halauxifen + MCPA, pyrasulfotole/bromoxynil/fluroxypyr, pyrasulfotole/bromoxynil/thiencarbazone, pyrasulfotole/bromoxynil/thiencarbazone + MCPA, and fluroxypyr/halauxifen + pyroxsulam + MCPA provided excellent control (94–100%) of GR Canada fleabane in winter wheat. However, thifensulfuron/tribenuron + fluroxypyr + MCPA, fluroxypyr/bromoxynil/MCPA, and tolpyralate provided fair control (71–84%) of GR Canada fleabane at 8 WAA in winter wheat (Table 1).Other herbicides evaluated including pyroxsulam, tribenuron + thiencarbazone, and tribenuron + thiencarbazone + MCPA provided poor control (4–33%) of GR Canada fleabane at 8WAA in winter wheat (Table 1). Results are similar to Mahoney et al. [12] who found 89, 67, 91, 83, 96, 60, 74, 87, 97, and 56% control of GR Canada fleabane with 2,4-D, MCPA, dicamba/MCPA/mecoprop, dichlorprop/2,4-D, clopyralid, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA, fluroxypyr + MCPA, pyrasulfotole/bromoxynil, and prosulfuron + bromoxynil at 8 WAA, respectively. Other studies have found 90–100% control of GR Canada fleabane with 2,4-D and dichlorprop/2,4-D [14–16]. Kumar et al. [17] also reported 97, 82–94, 85–100, 91–97, 83–85, and 85–92% control of GR Canada fleabane with pyrasulfotole/

bromoxynil, 2,4-D, bromoxynil + fluroxypyr, bromoxynil/MCPA, fluroxypyr, and halauxifen + florasulam, respectively. In another study, GR Canada fleabane was controlled 90% with halauxifen and 71% with 2,4-D in soybean [18,19]. However, McCauley et al. [20] reported only 65–80% control of GR Canada fleabane with halauxifen in noncropped fields.

Herbicide treatments that were rated the highest for visible GR Canada fleabane control also caused the greatest GR Canada fleabane density and biomass reduction in winter wheat (Table 1). Pyrasulfotole/bromoxynil, 2,4-D ester, halauxifen, fluroxypyr/halauxifen + MCPA, pyrasulfotole/bromoxynil/fluroxypyr, pyrasulfotole/bromoxynil/thiencarbazone, pyrasulfotole/bromoxynil/thiencarbazone + MCPA, and fluroxypyr/halauxifen + pyroxsulam + MCPA reduced GR Canada fleabane density 95–100% and biomass 97–100% in winter wheat. Thifensulfuron/tribenuron + fluroxypyr + MCPA, fluroxypyr/bromoxynil/MCPA, and tolpyralate reduced GR Canada fleabane density 88–95% and biomass 86–95%. Pyroxsulam, tribenuron + thiencarbazone, and tribenuron + thiencarbazone + MCPA reduced GR Canada fleabane density 61–80% and biomass 21–71% (Table 1).

Similar to the findings in this study, Mahoney et al. [12] reported 98, 87, 94, 77, 92, 94, and 99% density reduction and 97, 90, 96, 88, 96, 96, and 100% biomass reduction in GR Canada fleabane with 2,4-D, MCPA, dichlorprop/2,4-D, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA, fluroxypyr + MCPA, and pyrasulfotole/bromoxynil in winter wheat, respectively. Kumar et al. [17] also reported 89–90, 78–87, 80–87, 78–87, 88–90, and 78–86% reduction in shoot biomass of GR Canada fleabane with pyrasulfotole/bromoxynil, 2,4-D, bromoxynil + fluroxypyr, bromoxynil/MCPA, fluroxypyr, and halauxifen + florasulam, respectively. In another study, GR Canada fleabane density was reduced 75% with halauxifen and 60% with 2,4-D [18,19].

Winter wheat yield was comparable for all herbicides evaluated. Reduced GR Canada fleabane interference with pyrasulfotole/bromoxynil/thiencarbazone + MCPA resulted in a winter yield increase of 27% relative to the weedy control. Reduced GR Canada fleabane interference with all of the herbicide treatments evaluated resulted in winter wheat yield that was similar to the weed-free control (Table 1).

4. Conclusions

Based on these results, all herbicide treatments that included 2,4-D, pyrasulfotole or halauxifen provide excellent control of GR Canada fleabane in winter wheat. Additionally, there is potential for the control of GR Canada fleabane with thifensulfuron/tribenuron + fluroxypyr + MCPA, fluroxypyr/bromoxynil/MCPA, and tolpyralate in winter wheat. However, pyroxsulam, tribenuron + thiencarbazone and tribenuron + thiencarbazone + MCPA do not provide adequate control of GR Canada fleabane in winter wheat.

Data Availability

The data used to support the findings are presented in the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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