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Tolerance of Winter Wheat (*Triticum aestivum* L.) and Under Seeded Red Clover (*Trifolium pretense* L.) to Fall Applied Post-Emergent Broadleaf Herbicides

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Abstract

The fall application of post-emergent (POST) herbicides on winter wheat provided effective control of emerged winter annual, biennial, and perennial broadleaf weeds. In recent years, wheat producers have seen a shift to these weeds, due in part, to the adoption of reduced-and no-tillage practices and the use of non-residual herbicides such as glyphosate in the preceding soybean and corn crops. The tolerance of winter wheat to ten herbicides, applied POST in the fall, was evaluated between 2008 and 2011 at Exeter and Ridgetown, Ontario. Winter wheat yield was not reduced by applications of MCPA ester, dicamba/MCPA/mecoprop, clopyralid, bromoxynil/MCPA, thifensulfuron/tribenuron+MCPA ester, fluroxypyr+MCPA ester, and pyrasulfotole/bromoxynil. In contrast, 2,4-D ester and dichlorprop/2,4-D, caused visible injury in June and July of the following year and consistently decreased winter wheat yield by at least 10%. Applications of 100 g a.i. ha^{-1} saflufenacil also decreased winter wheat yield in two of the four harvest years examined. None of the herbicide options examined were safe on red clover when it was under seeded the spring following winter wheat planting. All herbicides significantly decreased red clover dry biomass one month after wheat harvest.

Keywords

2,4-D; Clopyralid; Pyrasulfotole; Saflufenacil; Winter Wheat

1. Introduction

Winter wheat (*Triticum aestivum* L.) agronomic practices have changed in recent years as the economic value of

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the crop has increased. Typically in Ontario, winter wheat is no-till planted in the fall, following a soybean crop. Since 2001, the price of winter wheat in Ontario has nearly doubled from $138 to $231 per metric tonne [1]. The timely application of fertilizers, fungicides, and herbicideshas contributed to such yield increases and net returns. Traditionally, producers in Ontario have relied on spring-applied herbicides such 2,4-D, MCPA, dicamba, and dichlorprop [2] [3] to provide effective control of broadleaf weeds. However, the adoption of reduced- and no-tillage systems and the use of non-residual herbicides such as glyphosate in the preceding soybean and corn crops have shifted the weed spectrum towards winter annual, biennial, and perennial weeds [4], increasing the advantages of fall-applied herbicides. Winter annuals, such as common chickweed (*Stellaria media* (L.) Vill.) and shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), are more easily controlled in the autumn than early spring due to warmer temperatures and the translocation of plant resources from shoots to roots. Controlling these weeds in the fall may limit weed seed return and improve wheat establishment by eliminating dense weed stands [5]. Since common chickweed begins to grow and flower at temperatures above 2˚C [6], it is able to quickly outcompete the slower-growing winter wheat in the spring. As an additional incentive for wheat producers, fall-applied winter wheat herbicide programs eliminate the stress of timing spring applications around wet soil conditions that could delay field access, thus allowing producers to focus on planting other crops. Many Ontario winter wheat producers also under seed their crop to red clover (*Trifolium pretense* L.) in the spring following planting. Red clover may help to improve soil structure [7] and will reduce corn (*Zeamays* L.) nitrogen requirements if corn is planted the year following winter wheat harvest [8]. Typically, under seeded red clover does not negatively impact winter wheat yield [9]-[11]. Use of fall-applied winter wheat herbicides may also help to reduce early season weed competition with red clover and improve its stand, provided that the herbicide does not injure the clover. Currently, Ontario producers have a limited number of winter wheat herbicides registered for fall application: MCPA, bromoxynil, bromoxynil/MCPA, pyrasulfotole/bromoxynil, thifensulfuron/tribenuron, and saflufenacil [3]. Bromoxynil/MCPA is the only herbicide registered for use in winter wheat under seeded to red clover, but only when used as a spring application after red clover emergence.

The purpose of this study was to examine winter wheat and red clover tolerance to several fall applied, post-emergent herbicides in an attempt to provide producers with better herbicide options to control fall-emerged broadleaf weeds. If broadleaf weeds were controlled in the fall, then fewer weeds would compete with the winter wheat crop in early spring. The tolerance of red clover, under seeded the following spring, to the applied herbicides was also evaluated.

2. Materials and Methods

2.1. Field Sites

The field trials were conducted at four sites; three were situated at the Huron Research Station (HRS), Exeter, Ontario (43˚19'N, 81˚30'W) and the fourth site was located at the University of Guelph, Ridgetown Campus (RC), Ridgetown, Ontario (42˚26'N, 81˚53'W). Experiments were initiated in the fall of 2008, 2009, and 2010 at Exeter and the fall of 2010 at Ridgetown. Soil characteristics, seeding, herbicide application, and emergence dates are listed in **Table 1**. The soil at Exeter and Ridgetown was a Brookston clay loam and a Watford/Brady series, respectively. Pioneer "25R47" winter wheat cultivar was planted in rows, spaced 18 cm apart, using a double disk drill at both locations. At HRS, plots were seeded at 170 kg ha^{-1} and were 2 m wide and 10 m long, while plots at RC were 2 m wide and 8 m long and were seeded at 140 kg ha^{-1}.According to wheat management practices in Ontario, nitrogen was applied in the spring following seeding at a rate of 110 kg N ha^{-1}, while phosphorous and potassium requirements were determined based on soil P-K levels using the rates outlined by the Ontario Ministry of Agriculture Food publication 811 [12]. Winter wheat trial sites were not irrigated, as per Ontario practice. Double-cut red clover "Common No. 1" was under seeded in the spring at a rate of 11 kg ha^{-1} using a Herd Broadcaster (Herd Seeder Company Inc., Logansport, Indiana, 46947) at all locations.

2.2. Experimental Design

A randomized complete block design, with four replications was used for all field trials. Treatments included a non-treated check, 2,4-D Ester at 550 g a.e. ha^{-1} (2,4-D Ester 700® 660 EC, Nufarm Agriculture Inc., Calgary, AB), MCPA Ester at 850 g a.i. ha^{-1} (MCPA Ester 500®, 500 SN, Nufarm Agriculture Inc.), dichlorprop/2,4-D at 1017 g a.i. ha^{-1} (Dichlorprop D®, 582 EC, IPCO Agri Products, Winnipeg, MB), dicamba/MCPA/mecoprop

Table 1. Soil characteristics and winter wheat planting, emergence, and spray dates for Huron Research Station and Ridgetown Campus fall-applied herbicides to winter wheat (2008 to 2011).

Location	Planting Date	Emergence Date	Spray Date	Sand (%)	Silt (%)	Clay (%)	OM (%)	pH	CEC
HRS-2008	September 24	September 30	October 23	33	35	32	3.4	7.9	31
HRS-2009	September 14	September 25	October 27	35	43	22	3.8	7.7	28.2
HRS-2010	September 21	September 29	October 19	17	47	36	3.6	7.9	36
RC-2010	October 23	November 5	November 24	56	27	17	5.4	6.7	18

Abbreviations: HRS = Huron Research Station, Exeter, ON, Canada; RC = Ridgetown Campus, University of Guelph, Ridgetown, ON, Canada; CEC= cation exchange capacity; OM = organic matter.

600 g a.i. ha^{-1} (Target®, 400 SN, Syngenta Crop Protection Canada, Plattsville, ON), clopyralid 200 g a.i. ha^{-1} (Lontrel 360®, 360 SN, Dow Agrosciences, Guelph, ON), bromoxynil/MCPA 560 g a.i. ha^{-1} (Buctril M®, 560 EC, Bayer, Guelph, ON), thifensulfuron/tribenuron + MCPA Ester + non-ionic surfactant at 15 g a.i. ha^{-1} + 550 g a.i. ha^{-1} + 0.2% v v^{-1}, respectively (Refine SG®, 50 SG, Dupont Canada Inc., Mississauga, ON), fluroxypyr + MCPA Ester at 108 g a.i. ha^{-1} + 562.5 g a.i. ha^{-1}, respectively (Trophy A®, 180 EC, Nufarm Agriculture Inc.), pyrasulfotole/bromoxynil + UAN 28% at 213 g a.i. ha^{-1} + 1.0 L ha^{-1}, respectively (Infinity®, 256 EC, Bayer), and saflufenacil + surfactant/solvent at 100 g a.i. ha^{-1} + 1.0 v v^{-1}, respectively (Eragon®, 70 SG, BASF, Mississauga, ON). Herbicides were applied using a backpack CO_2-pressurized sprayer (R&D, Opelousas, LA) when winter wheat was at the two to five leaf stage (Zadoks 12 - 15). The sprayer was calibrated at 241 kPa (HRS) and 207 kPa (RC) for an output of 200 L ha^{-1} using Hypro Ultra-Lo Drift 120 - 02 nozzles (Hypro® ULD 120 - 02 nozzle, New Brighton, MN).

2.3. Data Collection

Initial visible crop injury ratings were taken in the fall of planting at 7 and 28 days after herbicide application (DAA), when possible. At HRS in 2008 and RC in 2010 snow fell prior to the 28 DAA injury rating, blanketing the winter wheat and making it impossible to complete the assessment. After winter wheat began to grow the following spring, visible injury ratings were also conducted at the beginning of May, June, and July. Injury was rated on a scale of 0 to 100%, where zero represented no crop injury and 100% represented complete crop death. Crop height was measured once wheat heads had fully emerged in July of 2010 and 2011. Winter wheat was harvested at maturity using a plot combine and yield adjusted to 14% moisture. At Exeter winter wheat was harvested on July 22, 2009, July 7, 2010, and July 20, 2011, while in Ridgetown the crop was harvested July 18, 2011. Dry biomass measurements of the under seeded red clover were collected at HRS and RC, 28 days after harvest only in 2011. Biomass samples were collected from two randomly placed 0.5 m^{-2} quadrants in each plot.

2.4. Statistical Analysis

Data were subjected to an analysis of variance and analyzed using PROC MIXED in SAS 9.2 (SAS Institute Inc., Cary, NC). Environment (year-location combinations), the interaction between environments and herbicide treatment, and replicates nested within environments were deemed random effects; significance of random effects were identified using a Z-test of the variance estimate. Herbicide treatments were identified as fixed effects and an F-test was used to identify significance. Generally, for each evaluation parameter examined, data collected from trials planted in 2008 and 2009 could be combined, while data from the two trials initiated in 2010 were combined; the exceptions being the 28 DAA injury rating (combined the HRS trial planted in 2009 with the RC location) and the height rating parameter where data from the three sites could all be combined based on no site-year interactions. Data was transformed to meet normality assumptions; injury data at 7 and 28 DAA and June were square root transformed, the May injury rating was natural log transformed, and the July injury rating, height, and red clover dry biomass data were arcsine square root transformed. No transformation was required for yield data. Transformed data were back-transformed for the purpose of reporting and all treatment comparisons were made using a Fisher's Protected LSD, significance was determined at $P < 0.05$.

3. Results and Discussion

3.1. Visible Injury

Winter wheat injury was minimal (less than 3%) at the 7 DAA rating for all treatments except the saflufenacil treatment across all sites. Depending on year, the POST application of saflufenacil caused 16 and 31% injury to winter wheat (**Table 2**) at the early injury rating. Injury symptoms consisted of chlorosis, necrosis, and plant stunting. Injury caused by saflufenacil decreased over time and by the 28 DAA rating only 11% injury was observed. Frihauf *et al*. [13] reported a similar trend when saflufenacil was fall-applied POST; up to 30% injury was observed 3 to 6 DAA and injury diminished over time. The remaining herbicide treatments examined in this study did not cause noticeable injury at the 28 DAA rating compared to the non-treated check (**Table 2**).

Beginning in May of the following spring, winter wheat injury ratings were conducted on a monthly basis at the beginning of each month until harvest. Similar to fall injury ratings, the May rating indicated that, with the exception of saflufenacil, the herbicides applied caused minimal crop injury regardless of year (**Table 3**). Saflufenacil, applied post-emergent in the fall caused 9 or 19% visible injury, depending on year. Despite minimal injury symptoms observed at earlier ratings, applications of 2,4-D ester and dichlorprop/2,4-D caused 32% injury in June of 2009 and 2010 (**Table 3**). Injury symptoms included decreased plant growth, delayed maturity, and severe head distortion. The saflufenacil treatment also resulted in winter wheat injury in June in 2009 and 2010; generally the wheat appeared stunted and was delayed in development. Although no treatment at either location showed increased injury compared to the non-treated check for the June of 2011 evaluations (**Table 3**), there was a trend towards greater injury when 2,4-D ester, dichlorprop/2,4-D, or saflufenacil were applied. Injury evaluations conducted at the beginning of July showed the same trend as the June ratings; in 2009 and 2010 there was injury when wheat was treated with either 2,4-D ester, dichlorprop/2,4-D, or saflufenacil and there was a trend towards increased injury when wheat was sprayed with 2,4-Dester or dichlorprop/2,4-D for the July 2011 evaluations. The stunting, delayed development, and head distortion observed when wheat was sprayed with 2,4-D in the fall was anticipated as several researchers have observed similar injury patterns [4] [14] [15]. When the height evaluation was conducted in July, just after head emergence, no significant difference in height was observed between wheat treated with any herbicide and the non-treated check; wheat height across all treatments ranged between 79 and 84 cm (data not shown).

3.2. Winter Wheat Yield

Winter wheat yield reductions resulting from fall-applied post-emergent herbicide applications mirrored visible injury results. Generally, winter wheat treated with 2,4-D, dichlorprop/2,4-D, or saflufenacil had significantly decreased yield compared to the untreated check, while the remaining treatments examined did not affect yield. Depending on year applied, plots receiving treatments containing 2,4-D had yield reductions of 10 to 34% compared to the non-treated check (**Table 4**), a loss of between $23.10 and $78.54 per metric tonne, based on aver-

Table 2. Percent visible winter wheat injury 7 and 28 days after fall-applied post-emergent herbicide applications at Exeter, ON (2008 to 2010) and Ridgetown, ON (2010).

Herbicide Treatment	Rate	Visible Injury (%)		
		7 DAA		28 DAA
	(g ae/ai ha^{-1})	2008/2009	2010	2009/RC-2010
Non-treated check		0c	0b	0b
2,4-D Ester	550	1b	0b	0b
MCPA Ester	850	0c	0b	0b
Dichlorprop/2,4-D	1017	1b	0b	0b
Dicamba/MCPA/mecoprop	600	3b	0b	0b
Clopyralid	200	0c	0b	0b
Bromoxynil/MCPA	560	0c	0b	0b
Thifensulfuron/tribenuron + MCPA Ester[a]	15 + 550	0c	0b	0b
Fluroxypyr + MCPA Ester	108 + 562.5	0c	1b	0b
Pyrasulfotole/bromoxynil[a]	213	1b	0b	0b
Saflufenacil[a]	100	31a	16a	11a
SE		1.2	0.5	0.4

Abbreviations: DAA = days after herbicide application; RC = University of Guelph, Ridgetown Campus; SE = standard error. [a]A non-ionic surfactant (Agral 90) (0.2% v v^{-1}) included with thifensulfuron/tribenuron + MCPA Ester treatment; 28% UAN (1.0 L ha^{-1}) included with pyrasulfotole/bromoxynil treatment; a surfactant/solvent (1.0% v v^{-1}) included with saflufenacil treatment. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

Table 3. Percent visible winter wheat injury in the spring following fall-applied post-emergent herbicide applications at Exeter, ON (2008 to 2010) and Ridgetown, ON (2010).

Herbicide Treatment	Rate	Visible Injury (%)					
		May		June		July	
	(g ae/ai ha^{-1})	2009/2010	2011	2009/2010	2011	2009/2010	2011
Untreated check		0b	0b	0b	0	0b	0
2,4-D Ester	550	1b	0b	32a	2	24a	5
MCPA Ester	850	1b	0b	0b	1	1b	0
Dichlorprop/2,4-D	1017	1b	0b	32a	2	21a	5
Dicamba/MCPA/mecoprop	600	0b	0b	1b	1	2b	0
Clopyralid	200	0b	0b	0b	1	0b	0
Bromoxynil/MCPA	560	0b	0b	0b	1	0b	0
Thifensulfuron/tribenuron+MCPA Ester[a]	15 + 550	0b	0b	0b	1	0b	0
Fluroxypyr+MCPA Ester	108 + 562.5	1b	0b	0b	1	0b	0
Pyrasulfotole/bromoxynil[a]	213	0b	0b	0b	1	0b	0
Saflufenacil[a]	100	19a	9a	18a	2	16a	1
SE		1.6	0.5	1.8	0.5	1.3	0.6

Abbreviations: DAA = days after application; SE=standard error. [a]A non-ionic surfactant (Agral 90) (0.2% v v^{-1}) included with thifensulfuron/tribenuron + MCPA Ester treatment; 28% UAN (1.0 L ha^{-1}) included with pyrasulfotole/bromoxynil treatment; a surfactant/solvent (1.0% v v^{-1}) included with saflufenacil treatment. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P < 0.05). May, June, and July visible injury data was log, square root, and arcsine square root transformed, respectively.

Table 4. Winter wheat yield and percent under seeded red clover dry biomass relative to the non-treated check following fall-applied post-emergent herbicide applications at Exeter, ON (2008 to 2010) and Ridgetown, ON (2010).

Herbicide Treatment	Rate	Winter Wheat Yield		Relative Red Clover Biomass
		2009/2010	2011	
	(g ae/ai ha^{-1})	(T ha^{-1})		(%)
Untreated check		7.9a	6.2a	100b
2,4-D Ester	550	5.2c	5.5b	66a
MCPA Ester	850	7.6ab	6.1ab	51a
Dichlorprop/2,4-D	1017	5.2c	5.6b	63a
Dicamba/MCPA/mecoprop	600	7.5ab	6.5a	57a
Clopyralid	200	7.7ab	6.5a	61a
Bromoxynil/MCPA	560	8.0a	6.3a	69a
Thifensulfuron/tribenuron + MCPA Ester[a]	15 + 550	7.6ab	6.2a	63a
Fluroxypyr + MCPA Ester	108 + 562.5	7.9a	6.4a	63a
Pyrasulfotole/bromoxynil[a]	213	7.9a	6.3a	66a
Saflufenacil[a]	100	7.1b	6.0ab	57a
SE		0.1	0.1	17.5

Abbreviations: SE = standard error. [a]A non-ionic surfactant (Agral 90) (0.2% v v^{-1}) included with thifensulfuron/tribenuron + MCPA Ester treatment; 28% UAN (1.0 L ha^{-1}) included with pyrasulfotole/bromoxynil treatment; a surfactant/solvent (1.0% v v^{-1}) included with saflufenacil treatment. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P < 0.05).Percent red clover reduction data required an arcsine square root transformation; data were back-transformed for the purpose of reporting.

age 2011 Ontario winter wheat prices [1]. Post-emergent applications of saflufenacil also decreased yield in 2009 and 2010 by 10% (**Table 4**). Similar to visible injury data, there was no yield difference between plots sprayed with 100 g ai ha^{-1} saflufenacil and the non-treated check in 2011.

3.3. Red Clover Injury

All ten herbicide treatments tested in this study decreased the dry biomass of red clover at harvest, approximately one month after winter wheat harvest. Biomass was reduced by between 31 and 49% depending on treatment (**Table 4**). Of the herbicides tested only bromoxynil/MCPA is currently registered for use on winter wheat under seeded to red clover, but it is only registered as a spring application to be applied when red clover reaches the first to third trifoliate stage [3].

Based on the findings of this study, Ontario wheat producers would be able to spray a fall-applied POST application of MCPA ester, dicamba/MCPA/mecoprop, clopyralid, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA ester, fluroxypyr + MCPA ester, and pyrasulfotole/bromoxynil with minimal visual injury or yield reduction to the wheat. However, none of these applications would be advisable if the producer were to under seed the winter wheat to red clover the following spring. Many of these herbicide options would provide producers with good control of winter annual, biennial, and perennial broadleaf weeds, thus decreasing crop-weed competition in early spring. Bromoxynil/MCPA and fluroxypyr + MCPA ester offer good stinkweed (*Thlaspi arvense* L.) and shepherd's purse control, thifensulfuron/tribenuron + MCPA ester controls common chickweed and wild carrot (*Daucus carota* L.), and pyrasulfotole/bromoxynil could be used to control common chickweed and dandelion (*Taraxacum officinale* F.H. Wiggs.) problems [3]. Despite not being currently registered for use on winter wheat, clopyralid did not cause crop injury or reduce yield in this study, although it did decrease red clover biomass. Provided producers did not under seed the wheat crop, clopyralid would provide good Canada thistle control (*Cirsium arvense* (L.) Scop.) [3]. Although winter wheat yield was only reduced in 2009 and 2010 when 100 g ai ha^{-1} saflufenacil was applied post-emergent, based on visible injury observed and the potential for yield reductions,post-emergent applications of saflufenacil at this rate should be avoided. Similarly, fall-applied post-emergent herbicide applications containing 2, 4-D are not recommended, despite little visual injury observed in the fall. Spring injury ratings are unacceptable and yield reductions were significant.

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