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Control of winter cereals in the spring with glyphosate

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ABSTRACT

Poor survival of winter cereals due to winter conditions in Ontario can necessitate destruction of the stand in the spring to allow the subsequent seeding of an alternative crop. Winter cereals were seeded in the autumn of 2004 and 2005 at the Huron Research Station and at the University of Guelph Ridgetown Campus in Ontario to evaluate two formulations of glyphosate [potassium (K) vs diammonium (DA) salt] at different doses (225, 450, 675, 900, or 1350 g a.e. ha^{-1}) for the burn-off of soft white winter wheat (SWW), soft red winter wheat (SRW), hard red winter wheat (HRW) and autumn rye (AR) in either late April or early May. There was no difference between the glyphosate formulations for the control of winter cereals at 1, 2, 3, and 4 weeks after treatment (WAT). There was generally improved control with glyphosate applications made in early May compared to late April however results were not always statistically significant. Generally, control of winter cereals increased as the glyphosate dose was increased from 225 to 1350 g a.e. ha^{-1}. The minimum dose of glyphosate required for providing 90% or greater control of SWW, SRW, HRW, and AR was 675 g a.e. ha^{-1} at 4 WAT. Glyphosate applied at 675 g a.e. ha^{-1} caused a 98, 97, 98, and 99% reduction in shoot dry weight of SWW, SRW, HRW, and AR, respectively. Based on this study glyphosate (K or DA) applied in late April or early May can be used at doses as low as 675 g a.e. ha^{-1} to adequately control SWW, SRW, HRW, and AR in the spring.

1. Introduction

Winter cereals such as winter wheat (*Triticum aestivum* L.) and autumn rye (*Secale cereale* L.) are important crops in Ontario where nearly 1,235,000 tonnes are produced on approximately 261,000 hectares (Anonymous, 2008). In 2007, winter cereals had a farm-gate value of $306 million, ranking as the fourth largest field crop grown in Ontario after maize (*Zea mays* L.), soybean (*Glycine max* L.) and alfalfa (*Medicago sativa* L.) (Anonymous, 2008). Winter cereals are excellent crops to include in a rotation for the control of biennial and perennial weeds as they are planted in the autumn and in narrower rows allowing them to better compete with weeds. The fibrous roots system of winter cereals can also improve soil structure (Tottman, 1980). Winter cereals also play an important role in the protection of light soils against water and wind erosion as their establishment in the autumn helps to anchor the soil through roots and leaves. Winter cereal can provide a 20–30% yield advantage over the spring planted cereals if overwintered successfully (McLeod, 1980).

One of the major problems with winter cereals is that their survival is not dependable. Survival especially of winter wheat may be affected by cold temperatures in the winter, desiccation, flooding, ice crusting and diseases such as snow molds (*Microdocium nivale* L.) (McLeod, 1980). If there is poor survival, growers kill the winter cereal crop in the spring and replant to another crop. However, winter cereals are not easily killed with spring tillage and can cause significant losses of the subsequent crop if not adequately controlled (Boerboom and Doll, 2001).

Annually, in Ontario, a small percentage of winter cereals are sprayed-off the following spring with glyphosate due to poor winter survival. However, limited information exists on the effects of potassium (K) vs diammonium (DA) salt of glyphosate, application timing and application dose for the control of winter cereals in the spring under Ontario environmental conditions.

The objective of this research was to evaluate different formulations of glyphosate (K vs DA), at various doses for the control of soft white winter wheat (SWW), soft red winter wheat (SRW), hard red winter wheat (HRW) and autumn rye (AR) in the spring at two application timings.

2. Materials and methods

Field studies were seeded in the autumn of 2004 and 2005 at the Huron Research Station, Exeter, and at the University of Guelph, Ridgetown Campus, Ridgetown, Ontario, Canada. The soil at Exeter was a Brookston clay loam (Orthic Humic Gleysol) with 32% sand,

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Table 1
Significance of main effects and interactions for percent control and shoot dry weight of winter cereals. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at $P < 0.05$. Means for a main effect were separated only if there were no significant interactions involving that main effect.

Main effects	Winter cereal control				Shoot dry weight[a]
	1 WAT (%)	2 WAT (%)	3 WAT (%)	4 WAT (%)	
Glyphosate formulation	NS	NS	NS	NS	NS
K salt	30	64	77	78	16
DA salt	29	61	76	77	18
SE	1	1	1	1	1
Application timing[b]	NS	NS	NS	*	NS
Early	30	61	74	73	19
Late	28	65	80	82	14
SE	1	1	1	1	1
Type of winter cereal	**	***	**	**	NS
Soft white wheat	26 b	59	74	76	17
Soft red wheat	28 b	61	75	76	19
Hard red wheat	33 a	64	78	77	16
Rye	34 a	68	80	81	14
SE	1	2	2	2	2
Glyphosate dose (g a.e. ha^{-1})	***	***	***	***	***
225	7	18	24	24	67
450	23	57	74	75	13
675	35	73	91	92	2
900	41	81	96	97	0
1350	46	85	99	99	0
SE	1	1	1	1	1
Interactions					
F × A	*	NS	NS	NS	NS
F × T	NS	NS	NS	NS	NS
F × R	NS	NS	NS	NS	NS
A × T	NS	*	**	*	*
A × R	***	*	**	***	NS
T × R	NS	**	**	**	*
F × A × T	NS	NS	NS	NS	NS
F × A × R	NS	NS	NS	NS	NS
A × T × R	NS	NS	NS	NS	NS
F × A × T × R	NS	NS	NS	NS	NS

WAT, weeks after treatment; F, glyphosate formulation; A, application timing; T, type of winter cereal; R, glyphosate dose; NS, not significant at $P = 0.05$ level. Significance at $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels denoted by *, ** and ***, respectively.
[a] Calculated as a percent of the untreated check.
[b] Early, late April; late, early May.

41% silt, 27% clay, 4.8% organic matter and pH of 7.6 in 2005, and 39% sand, 33% silt, 28% clay, 4.7% organic matter and pH of 7.9 in 2006. The soil at Ridgetown was a Watford (Grey to Brown Brunisolic)-Brady (Gleyed Brunisolic Grey to Brown Luvisol, mixed) sandy loam with 48% sand, 28% silt, 24% clay, 6.7% organic matter and pH of 6.6 in 2005, and 43% sand, 35% silt, 22% clay, 7.9% organic matter and pH of 7.5 in 2006.

The study was established as a four-way factorial in a randomized complete block design with four replications. Factor one was type of winter cereal (SWW, SRW, HRW and AR), factor 2 was dose of glyphosate (225, 450, 675, 900 and 1350 g a.e. ha^{-1}), factor 3 was application timing (late April and early May with 2 week interval) and factor 4 was glyphosate formulation (K and DA). Treatments included a non-treated check. Plots were 2 m wide by 10 m long at Exeter and 2 m wide by 8 m long at Ridgetown. SWW Pioneer 25W41, SRW Pioneer 25R47, HRW AC Morley and AR were seeded with a double disc drill at 145 kg ha^{-1} in rows 17.5 cm apart at a depth of 4 cm in mid-October.

Herbicides were applied in late April or early May (with 2 week interval) of the following spring. Herbicides were applied with a CO_2 pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} at 241 kPa. The boom was 1.5 m long with four 8002 flat-fan nozzles tips (Spraying Systems Co., Wheaton, IL) spaced 50 cm apart.

Control was rated visually on a scale of 0 to 100% (0, no control; 100, plant death) at 1, 2, 3 and 4 weeks after treatment (WAT). A 1 m^2 section was hand harvested from each plot at 6 WAT and dried to a constant weight at 60 °C and the shoot dry weight was recorded.

All data were subjected to analysis of variance, and analyzed using the PROC MIXED procedure of SAS (Statistical Analysis Systems (SAS) software, Version 9e. Statistical Analysis Systems Institute Inc., PO Box 8000, Cary, NC 25712-8000). Variances were partitioned into the random effects of environment (comprising years and locations), blocks within environment, and the interactions with fixed effects (cereal types, application timings, doses and formulations). To meet assumptions of normality, injury 4 WAT and shoot dry weight (as a percent of the check) were square-root transformed. Means were converted back to the original scale for presentation of results. Means were separated using Fisher's protected LSD at $P = 0.05$.

3. Results and discussion

Data were combined over years and analyzed using the MIXED procedure of SAS. When there was no statistical interaction, data were pooled and averaged over cereal types, application timings, doses and formulations.

3.1. Control

There was no difference between the potassium salt (K) and the diammonium (DA) salt of glyphosate for the control of winter cereals at 1, 2, 3 and 4 WAT (Table 1).

Table 2
Percent control of winter cereals at two glyphosate application timings as a function of glyphosate dose. Means followed by the same letter within a column (a–d) or row (Y–Z) are not significantly different according to Fisher's protected LSD at $P < 0.05$.

Glyphosate dose (g a.e. ha^{-1}) by variable	Application timing[a]		SE
	Early (%)	Late (%)	
Control 1 WAT			
225	3 a Z	11 a Z	1
450	19 b Z	26 b Z	1
675	37 c Z	33 c Z	1
900	43 c Z	39 cd Z	1
1350	51 d Z	41 d Z	1
SE	1	1	
Control 2 WAT			
225	10 a Z	26 a Z	1
450	54 b Z	60 b Z	1
675	73 c Z	74 c Z	1
900	81 c Z	81 c Z	1
1350	85 c Z	85 c Z	1
SE	1	1	
Control 3 WAT			
225	14 a Y	35 a Z	2
450	72 b Z	76 b Z	1
675	90 c Z	91 c Z	1
900	94 c Z	97 c Z	1
1350	98 c Z	99 c Z	1
SE	1	1	
Control 4 WAT			
225	12 a Y	36 a Z	2
450	71 b Z	79 b Z	1
675	90 bc Z	94 bc Z	1
900	96 c Z	99 c Z	1
1350	99 c Z	100 c Z	1
SE	1	1	

WAT, weeks after treatment.
[a] Early, late April; late, early May.

Table 3
Percent control and shoot dry weight of four types of winter cereals as a function of glyphosate dose. Means followed by the same letter within a column (a–d) or row (W–Z) are not significantly different according to Fisher's protected LSD at $P < 0.05$.

Glyphosate dose (g a.e. ha^{-1}) by variable	Type of winter cereal				SE
	SWW (%)	SRW (%)	HRW (%)	AR (%)	
Control 2 WAT					
225	15 a X	14 a X	19 a Y	25 a Z	1
450	50 b W	54 b X	59 b Y	66 b Z	1
675	69 c X	71 c XY	75 c YZ	78 c Z	1
900	78 cd Y	80 cd YZ	82 c YZ	84 c Z	1
1350	83 d Z	84 d Z	86 c Z	86 c Z	1
SE	2	2	2	2	
Control 3 WAT					
225	19 a X	20 a X	25 a Y	33 a Z	2
450	69 b Y	71 b Y	76 b Z	80 b Z	1
675	89 c Z	90 c Z	92 c Z	92 c Z	1
900	94 c Z	96 c Z	96 c Z	96 c Z	1
1350	98 c Z	99 c Z	99 c Z	99 c Z	1
SE	2	2	2	2	
Control 4 WAT					
225	19 a X	20 a XY	23 a Y	33 a Z	2
450	73 b YZ	71 b Y	75 b YZ	81 b Z	1
675	90 bc Z	91 c Z	92 bc Z	94 b Z	1
900	96 c Z	97 c Z	98 c Z	98 b Z	1
1350	99 c Z	99 c Z	100 c Z	100 b Z	1
SE	2	2	2	2	
Shoot dry weight[a]					
225	73 a YZ	76 a Z	63 a XY	58 a X	2
450	12 b Y	17 b Z	13 b Y	11 b Y	1
675	2 c Y	3 c Z	2 c Y	1 c Y	1
900	0 c Z	0 c Z	0 c Z	0 c Z	1
1350	0 c Z	0 c Z	0 c Z	0 c Z	1
SE	2	2	2	2	

WAT, weeks after treatment; SWW, soft white winter wheat; SRW, soft red winter wheat; HRW, hard red winter wheat (HRW); AR, autumn rye.
[a] Calculated as a percent of the untreated check.

Table 4
Percent control and shoot dry weight of four types of winter cereals as a function of glyphosate application timing. Means followed by the same letter within a column (a–d) or row (Y–Z) are not significantly different according to Fisher's protected LSD at $P < 0.05$.

Type of winter cereal by variable	Application timing[a]		SE
	Early (%)	Late (%)	
Control 2 WAT			
SWW	55 a Z	63 a Z	2
SRW	58 b Z	63 a Z	2
HRW	63 c Z	66 a Z	2
AR	67 d Z	69 b Z	2
SE	1	1	
Control 3 WAT			
SWW	69 a Y	79 a Z	2
SRW	71 a Y	79 a Z	2
HRW	75 b Z	80 a Z	2
AR	80 c Z	81 a Z	2
SE	1	1	
Control 4 WAT			
SWW	70 a Y	81 a Z	2
SRW	71 a Y	81 a Z	2
HRW	74 a Y	81 a Z	2
AR	79 b Z	83 a Z	2
SE	1	1	
Shoot dry weight[b]			
SWW	21 a Z	14 a Z	2
SRW	23 a Y	16 a Z	2
HRW	18 ab Z	13 a Z	2
AR	14 b Z	14 a Z	2
SE	1	1	

WAT, weeks after treatment; SWW, soft white winter wheat; SRW, soft red winter wheat; HRW, hard red winter wheat (HRW); AR, autumn rye.
[a] Early, late April; late, early May.
[b] Calculated as a percent of the untreated check.

Generally, there was improved control of winter cereals when glyphosate was applied in early May compared to late April however results were not always statistically significant (Table 2). Generally, control increased with time and as the glyphosate dose was increased from 225 to 1350 g a.e. ha^{-1} (Tables 2, 3). Glyphosate applied at 675 g a.e. ha^{-1} provided only 78% or less control of SWW, SRW, HRW and AR at 2 WAT (Table 3). However at 3 and 4 WAT, glyphosate applied at 675 g a.e. ha^{-1} provided 89% or greater control of SWW, SRW, HRW and AR (Table 3). Results are similar to Boerboom and Doll (2001) who reported that 627 g a.e. ha^{-1} is sufficient to adequately control volunteer winter wheat in corn grown under a no-tillage system in Wisconsin, USA. They also reported that glyphosate dosage can be reduced to 426 g a.e. ha^{-1} if the glyphosate application is followed with light tillage before planting corn. Wiese Chenault (1987) *reported adequate control of winter wheat with as little as 250* g a.e. ha^{-1} of glyphosate in Texas, USA.

3.2. Shoot dry weight

There was no difference between the K and DA salt of glyphosate for their effects on shoot dry weight of SWW, SRW, HRW, and AR (Table 1).

Shoot dry weight decreased as the dose of glyphosate increased (Table 1). Glyphosate applied at doses of 225, 450, 675, 900, and 1350 g a.e. ha^{-1} decreased shoot dry weight 33, 87, 98, 100, and 100%, respectively (Table 1). Winter cereals differed in their response to glyphosate, especially at lower doses (Table 3). Autumn rye shoot dry weight reduction was greater than other winter cereals however results were not always statistically significant (Table 4). Other studies have shown similar differential sensitivity to post-emergence herbicides with winter cereals (Derksen et al., 1989; Ivany et al., 1990; Rinella et al., 2001; Robison and Fenster, 1973; Schroeder and Banks, 1989; Swan, 1975; Tottman, 1980). Glyphosate applied at 225 and 450 g a.e. ha^{-1} provided less than adequate (24–89%) shoot dry weight reduction of winter cereals (Table 3). Glyphosate applied at 675 g a.e. ha^{-1} caused a 98, 97, 98, and 99% reduction in shoot dry weight of SWW, SRW, HRW and AR, respectively (Table 3). There was a 100% shoot dry weight reduction in all winter cereals evaluated with glyphosate at 900 and 1350 g a.e. ha^{-1}. There was generally a greater reduction in shoot dry weight of winter cereals, especially winter wheat, with glyphosate applications made in early May compared to late April however results were not always statistically significant (Table 4).

4. Conclusions

There was no difference between glyphosate formulations (K and DA salt) for the control of SWW, SRW, HRW, and AR in the spring. Control of winter cereals generally increased with time after glyphosate application and as the dose of glyphosate was increased. When there was a difference among winter cereals in their sensitivity to glyphosate, autumn rye was more sensitive to glyphosate than winter wheat. This study concludes that glyphosate (K or DA salt) applied in late April or early May can be used at doses as low as 675 g a.e. ha^{-1} to adequately control SWW, SRW, HRW, and AR in the spring.

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