

Tolerance of Winter Wheat to Co-application of Postemergence Broadleaf Herbicides Using Urea Ammonium Nitrate as the Carrier

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Abstract: Spring application of post-emergence (POST) broadleaf herbicides in a urea ammonium nitrate (UAN) as the carrier may provide winter wheat growers with a one-pass option for weed control and nitrogen application. Winter wheat tolerance to bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine or pyrasulfotole/bromoxynil applied using 28% UAN at various carrier volumes (0, 100, 200, 300 and 400 L ha⁻¹) was evaluated in field experiments planted in the fall of 2008, 2009 and 2010 at Exeter and Ridgetown Ontario, Canada. Generally, winter wheat injury was greater as the carrier volume of UAN increased. Injury due to bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine and pyrasulfotole/bromoxynil was as much as 8, 11, 18 and 9% at 7 days after treatment (DAT); the injury observed was transient and was 1, 2, 4 and 1% at 28 DAT, respectively. Winter wheat height and yield were not reduced by the herbicides evaluated, excepting bromoxynil/MCPA which reduced yield by 2%, and thifensulfuron/tribenuron + MCPA amine, which reduced height 3% and yield 2%. The establishment of underseeded red clover was decreased by at least 50% for all herbicide treatments assessed, except bromoxynil/MCPA. Based on this study, there is potential for spring co-application of UAN and bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine or pyrasulfotole/bromoxynil in winter wheat. However, growers that underseed red clover may not fully benefit as carrier UAN significantly reduced clover establishment.

Keywords: Red clover, urea ammonium nitrate, winter wheat.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is one of Canada's major cereal crops, comprising over 700,000 hectares [1]. High yields, competitive pricing and adaptability to various soil types have made this cereal crop the choice of many Canadian growers [2]. Unlike spring-planted cultivars, winter wheat is seeded in the autumn, overwinters as a seedling and reaches maturity in mid-summer of the following calendar year. Its prolonged growing season and influx of early spring moisture can contribute to yields that are up to 30% higher than spring wheat [2, 3]. In central Canada, winter wheat is typically grown following soybean [*Glycine max* (L.) Merr.]. As part of a sustainable approach, some growers underseed red clover (*Trifolium pretense* L.) in their winter wheat crop to fix soil nitrogen and to help offset the large nitrogen demand of the succeeding corn (*Zea mays* L.) crop in the rotation [4, 5]. Winter wheat exhibits vigorous spring growth therefore crop inputs and intensive management are most effective prior to canopy closure.

Spring management of nitrogen fertility and weed infestations are important considerations in profitable winter wheat production. A healthy winter wheat crop will resume growth early in the spring and require application of nitrogen to boost yield. Urea ammonium nitrate (UAN) is a liquid nitrogen fertilizer that is resistant to volatilization losses and is often applied in winter wheat crops [1, 6]. Broadleaf

post-emergence (POST) weed control in winter wheat has traditionally included bromoxynil/MCPA, dichlorprop/2,4-D and thifensulfuron/tribenuron + MCPA however, new chemistries including pyrasulfotole/bromoxynil have recently become commercially available [7]. Spring broadleaf weed control applications should be done prior to canopy closure and may coincide with nitrogen applications. As a result, sequential application of fertilizer and herbicide can be costly in terms of time and resources for winter wheat producers.

Co-application of a POST herbicide in UAN as the carrier has potential to optimize efficiency of field operations in winter wheat cultivation. Typically, UAN is applied with streamer nozzles that minimize leaf injury. Delivery of a foliar herbicide using streamer nozzles will not provide adequate coverage of target weeds, therefore a successful one-pass system requires application via flat fan or flood nozzles to ensure maximum herbicide efficacy. Edwards *et al.* [6] previously reported that low rates of UAN could be effectively applied with flood nozzles. However, Stahlman *et al.* [8] found that utilisation of UAN as a herbicide carrier caused greater damage than application of UAN alone. At this time, more research is needed to assess the feasibility of using UAN as the carrier for winter wheat herbicide applications.

The objective of this study was to determine if spring co-application of bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine or pyrasulfotole/bromoxynil with UAN as the herbicide carrier in winter wheat would limit establishment of underseeded red clover or result in increased wheat injury, or reduced plant height and yield.

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MATERIALS AND METHODS

In the fall of 2008, 2009 and 2010, field experiments were planted near Exeter, at the Huron Research Station and in the fall of 2010 at the University of Guelph, Ridgetown Campus, near Ridgetown, Ontario, Canada. Soil characteristics are summarised in (Table 1).

The experimental design was a two-way factorial arranged in a randomized complete block, with four replications. Factor one was herbicide treatment and factor two was UAN carrier volume. Herbicide treatments included a untreated check, bromoxynil/MCPA (560 g a.i. ha⁻¹), dichlorprop/2,4-D (1017 g a.i. ha⁻¹), thifensulfuron/tribenuron (15 g a.i. ha⁻¹) plus MCPA amine (550 g a.i. ha⁻¹) and non-ionic surfactant (Agral 90[®], 0.2% vol/vol), and pyrasulfotole/bromoxynil (213 g a.i. ha⁻¹) plus ammonium sulfate (1.0 L ha⁻¹); UAN was applied at 0, 100, 200, 300 and 400 L ha⁻¹. Dry nitrogen fertilizer (46-0-0) was applied to each plot so that the total amount of nitrogen was 112 kg ha⁻¹ across the entire experimental area. Plot dimensions were 10 by 2 m at Exeter and 8 by 2 m at Ridgetown. Soft red winter wheat (SRWW) 'Pioneer 25R47' was planted at a 4 cm depth using a double disc drill at 150 kg ha⁻¹ with 17.5 cm row spacing, from mid-September to late October; common red clover was broadcasted at a rate of 11 kg ha⁻¹ the subsequent March to April. Herbicide/UAN treatments were applied late April to early May. Treatments were applied using a CO₂-pressurized backpack sprayer (Bellspray, Inc. Opelousas, USA) with four ultra-low drift nozzle tips (ULD 120-04;Hypro, New Brighton, USA), spaced 50 cm apart. The sprayer was adjusted to deliver 400 L ha⁻¹ aqueous solution at 240 kPa. Plots were kept free of weeds by hoeing as needed.

Winter wheat injury was visually scored on a scale of 0 (no injury present) to 100% (complete plant death) at 7, 14, 21 and 28 days after treatment (DAT). Wheat height was measured for ten random plants per plot at 56 DAT and averaged. Wheat head distortion was visually assessed on a scale of 0 (no distortion present) to 100% (complete distortion) just prior to harvest. Plots were harvested with a small plot combine and moisture and weight were recorded; based on which yields were adjusted to 14% moisture. Clover establishment at 112 DAT was rated on a scale of 0 (bare ground) to 10 (equivalent to the untreated check). Clover dry weight was evaluated 112 DAT by excising plants at the soil surface from 0.5 m² per plot. Plants were dried to constant moisture at 60 °C and then weighed.

Data were analysed as a two-way factorial using *Proc Mixed* in SAS 9.2 [9]. The two treatment factors, herbicide treatment and UAN carrier volume, as well as their interaction were considered fixed effects, while environment (year-location combinations), interactions between environment and the fixed effects, and replicate nested within environment were considered random effects. Environments were combined for all variables. Fixed effect significance and random effects were established using *F*-tests and a *Z*-test of the variance estimate, respectively. The *Univariate* procedure was used to test data for normality and homogeneity of variance. To satisfy the assumptions of the variance analyses, injury 7 and 14 DAT and clover establishment were square-root-transformed, injury 21 DAT and clover dry weight were log transformed. Treatment comparisons were made using Fisher's Protected LSD test. All statistical comparisons were made using a Type I error of 0.05. All data transformations made to facilitate comparison were transformed back to their original scale for tabular presentation.

RESULTS AND DISCUSSION

The amount of precipitation received at all trial sites was generally at or above the 30-yr average, for April and May (Table 2). When applied post-seeding, the efficacy of UAN is highly dependent upon receipt of some precipitation post-application to ensure that the product moves into the soil [10]. Moreover, there was no significant dose by environment interaction and thus no trial site required individual analysis.

No wheat head distortion was observed just prior to harvest for any of the herbicide or UAN combinations (data not shown). Analysis of the main effects indicated that winter wheat injury caused by bromoxynil/MCPA, dichlorprop/2, 4-D, thifensulfuron/tribenuron + MCPA amine and pyrasulfotole/bromoxynil was highly significant at 7, 14, 21 and 28 DAT (Table 3). Initially, winter wheat injury, attributed to herbicide treatment, was moderate ranging from 5 to 10% at 7 DAT (Table 3). However, injury was temporary and decreased to less than, 7, 3 and 3% at 14, 21 and 28 DAT, respectively (Table 3).

Winter wheat injury, due to UAN treatment, was highly significant at 7, 14 and 21 DAT (Table 3). Similar to herbicide treatment, injury was highest immediately following application but declined as DAT increased, ranging from 4 to 10, 2 to 7, 1 to 3 and 1 to 2% for 7, 14, 21 and 28 DAT, respectively (Table 3). Likewise, Soltani *et al.* [11] reported 5% winter wheat injury 7 DAT when 28% UAN

Table 1. Location and soil information for experiments conducted during 2008 to 2010.

Year	Location	Soil texture	Sand	Silt	Clay	OM	pH
			%				
2008	Exeter	Brookston clay loam	28	38	34	4.1	7.9
2009	Exeter	Brookston clay loam	35	43	22	3.8	7.7
2010	Exeter	Brookston clay loam	17	47	36	3.6	7.9
2010	Ridgetown	Loam	49	31	20	6.0	6.5

Table 2. Mean and 30-yr average precipitation data for McGregor and Windsor in 2012 and McGregor, Harrow, and Tilbury in 2013, in Ontario from May to August^a.

Environment		April		May		June		July	
Year	Location	Mean	30-yr avg.	Mean	30-yr avg.	Mean	30-yr avg.	Mean	30-yr avg.
		mm							
2009	Exeter	80	-	93	94	68	62	50	61
2010	Exeter	29	-	69	94	185	62	88	61
2011	Exeter	93	-	135	94	88	62	34	61
2011	Ridgetown	155	78	180	75	83	83	155	86

^a30-yr average precipitation and data from Farmzone 2014.**Table 3.** Winter wheat percent injury, height and yield as well as red clover establishment and dry weight, treated with four different postemergence herbicides using UAN at different carrier volumes. Within each column, means followed by the same letter (a-d) do not significantly differ according to Fisher's Protected LSD at $P < 0.05$.^{ab}

Main Effects ^c	Winter Wheat Injury								Red Clover Injury ^d				
	Days After Treatment				Height	Yield	Establishment [‡]	Dry Weight					
	7	14	21	28									
	% Injury				Cm	MT ha ⁻¹	g						
Herbicide treatment [§]	**	**	**	**	*	*	**	**					
No herbicide	2.9	1.6	0.5	a	0.6	79	a	6.8	a	9	a	22.4	a
Bromoxynil/MCPA	4.6	2.6	0.8	b	0.8	79	a	6.7	bc	7	a	9.5	b
Dichlorprop/2,4-D	5.9	3.9	1.4	c	0.9	79	a	6.8	ab	2	b	1.4	cd
Thifensulfuron/tribenuron + MCPA amine	9.7	6.5	2.7	d	2.4	77	b	6.7	c	3	b	2.1	c
Pyrasulfotole/bromoxynil	4.6	3.0	0.9	bc	0.9	79	a	6.8	ab	1	c	0.5	d
SE	0.2	0.2	0.1		0.1	0		0.1		0		1.0	
UAN treatment	**	**	**	NS	NS	NS	NS	NS	**	**			
No UAN	0.7	0.2	0.1	a	0.2	79		6.8		5	a	7.2	a
100 L UAN	3.9	2.4	0.7	b	0.7	79		6.9		4	b	3.7	b
200 L UAN	6.9	3.8	1.3	bc	1.1	79		6.9		4	b	3.2	b
300 L UAN	8.1	5.6	1.9	cd	1.7	78		6.6		4	b	3.2	b
400 L UAN	10.0	6.8	2.6	d	1.9	78		6.7		4	b	3.0	b
SE	0.2	0.2	0.1		0.1	0		0.1		0		1.0	
Interaction													
Herbicide x UAN	*	*	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS

^a Abbreviations: UAN, urea ammonium nitrate^b Means presented have been transformed back to the original scale. Main effects were separated only where no significant interaction concerning that main effect was present.^c Significance at $P < 0.05$ and $P < 0.01$ levels represented by * and **, respectively. Non-ionic surfactant added to thifensulfuron/tribenuron + MCPA amine (0.2% v/v); ammonium sulfate added to pyrasulfotole/bromoxynil (1.0 L ha⁻¹)^d Clover establishment was rated on a scale of 0 to 10; where 0 was bare ground and 10 was equivalent to the untreated check. Cover dry weight corresponds to a 0.5 m² harvested area.

Table 4. Percent injury 7, 14 and 28 DAT of winter wheat with five carrier volumes of UAN and four postemergence herbicides. Within each column (a-d) and row (W-Z), means followed by the same letter, in each section, do not significantly differ according to Fisher's Protected LSD at $P < 0.05$.^a

Herbicide Treatment ^b	UAN Carrier Volume															SE
	0			100			200			300			400			
	(L ha ⁻¹)															
<i>Injury 7 DAT</i>																
No herbicide	0.0	a	Z	2.0	a	Y	3.8	a	X	4.9	a	WX	5.9	a	W	0.3
Bromoxynil/MCPA	0.6	b	Z	3.4	b	Y	5.9	b	X	7.1	b	WX	8.3	b	W	0.3
Dichlorprop/2,4-D	1.4	c	Z	3.8	b	Y	7.8	c	X	8.2	b	X	10.7	c	W	0.4
Thifensulfuron/tribenuron + MCPA amine	1.6	c	Z	8.1	c	Y	11.7	d	X	14.2	c	X	17.8	d	W	0.7
Pyrasulfotole/bromoxynil	0.3	ab	Z	3.2	b	Y	6.2	bc	X	7.4	b	X	9.2	bc	W	0.4
SE	0.1			0.3			0.4			0.4			0.5			
<i>Injury 14 DAT</i>																
No herbicide	0.0	a	Z	0.8	a	Y	1.4	a	Y	3.0	a	X	4.1	a	X	0.2
Bromoxynil/MCPA	0.0	a	Z	1.7	ab	Y	3.2	b	X	4.4	b	WX	5.8	b	W	0.3
Dichlorprop/2,4-D	0.5	ab	Z	2.8	c	Y	4.7	c	X	6.0	c	WX	7.3	b	W	0.4
Thifensulfuron/tribenuron + MCPA amine	0.8	b	Z	5.7	d	Y	7.8	d	X	10.0	d	W	11.5	c	W	0.5
Pyrasulfotole/bromoxynil	0.0	a	Z	2.2	bc	Y	3.4	b	Y	5.5	bc	X	6.3	b	X	0.3
SE	0.1			0.3			0.3			0.4			0.3			
<i>Injury 28 DAT</i>																
No herbicide	0.0	a	Z	0.3	a	Z	0.6	a	Z	1.1	a	Z	0.9	a	Z	0.2
Bromoxynil/MCPA	0.0	a	Z	0.4	a	Z	0.8	a	Z	1.3	a	Z	1.4	a	Z	0.2
Dichlorprop/2,4-D	0.4	a	Z	0.6	a	Z	0.9	a	Z	1.4	a	Z	1.5	a	Z	0.2
Thifensulfuron/tribenuron + MCPA amine	0.4	a	Z	1.9	b	YZ	2.2	b	YZ	3.6	b	XY	4.1	b	X	0.3
Pyrasulfotole/bromoxynil	0.0	a	Z	0.5	a	Z	1.0	a	Z	1.4	a	Z	1.4	a	Z	0.2
SE	0.1			0.2			0.2			0.3			0.3			

^a Abbreviations: DAT, days after treatment; UAN, urea ammonium nitrate

^b Non-ionic surfactant added to thifensulfuron/tribenuron + MCPA amine (0.2 % v/v); ammonium sulfate added to pyrasulfotole/bromoxynil (1.0 L ha⁻¹).

was applied at 200 L ha⁻¹ using flat fan nozzles. Edwards *et al.* [7] similarly found that flood nozzles could be effectively used to apply UAN at up to 120 L ha⁻¹.

Generally, winter wheat injury increased as the UAN carrier volume increased (Table 4). UAN alone, without any herbicide, caused 2, 4, 5 and 6% visible crop injury 7 DAT at 100, 200, 300 and 400 L carrier volume ha⁻¹, respectively (Table 4). With herbicide, injury 7 DAT ranged from 3 to 8, 6 to 12, 7 to 14 and 8 to 18% for carrier volumes of 100, 200, 300 and 400 L ha⁻¹, respectively (Table 4). Although winter wheat injury due to herbicide application with a UAN carrier was additive, the extent of damage diminished over time. At 28 DAT, the addition of a herbicide to the UAN

carrier did not increase the level of winter wheat injury, except for thifensulfuron/tribenuron + MCPA amine at 100, 200, 300 and 400 L ha⁻¹ (Table 4). In similar studies, Litcher and Mahler [12] found significant winter wheat injury when bromoxynil/MCPA was applied using UAN as the carrier. Soltani *et al.* [11] reported that winter wheat injury of 4, 5 and 5% at 7 DAT decreased to 0.2, 1 and 4% by 28 DAT, when bromoxynil/MCPA, dichlorprop/2,4-D and thifensulfuron/tribenuron were applied with 100 L ha⁻¹ 28% UAN, respectively.

Winter wheat height did not decrease in response to application of bromoxynil/MCPA, dichlorprop/2,4-D, pyrasulfotole/bromoxynil (Table 3). In contrast, the application

of thifensulfuron/tribenuron + MCPA amine caused a decrease of 3% in winter wheat height (Table 3). Soltani *et al.* [11] reported that application of bromoxynil/MCPA, dichlorprop/2,4-D and thifensulfuron/tribenuron using UAN as the carrier at a volume of 100 L ha⁻¹ did not decrease winter wheat height. In experiments where water was used as a carrier, fall application of dichlorprop +2,4-D reduced winter wheat height by 8% [13] while spring application of bromoxynil + MCPA dichlorprop + 2,4-D did not reduce wheat height [14].

Bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine and pyrasulfotole/bromoxynil reduced red clover dry weight by 58, 94, 91 and 98% relative to the untreated control, respectively (Table 3). In studies conducted where UAN was used as the carrier solution, bromoxynil/MCPA, thifensulfuron/tribenuron, dichlorprop/2,4-D and 2,4-D caused no yield reduction [8, 11] while bromoxynil + MCPA resulted in a yield decrease [12]. Bradley and Conley [15] also found that the addition of 2,4-D or 20% UAN to imazamox reduced yields in imidazolinone-resistant wheat, relative to application of imazamox alone. Moreover, application of broadleaf herbicides including 2,4-D, bromoxynil, MCPA and dichlorprop in a water carrier has shown no negative impact on wheat yields when applied at the recommended rate [14, 16].

This study examined SRWW tolerance to POST spring-applied herbicide with a UAN carrier. In other research, Sikkema *et al.* [17] demonstrated excellent SRWW tolerance to spring-applied 2, 4-D amine, bromoxynil + MCPA and dichlorprop + 2,4-D, while Brown and Sikkema [14] similarly concluded that crop safety was adequate for spring-applied fluroxypyr + MCPA ester. In the two latter studies, SRWW tolerance was generally matched by that of hard red winter wheat and soft white winter wheat. It is therefore likely that hard red and soft white winter wheat would show similar tolerance to bromoxynil/MCPA and dichlorprop/2,4-D applications in a UAN carrier, however, substantiating research is required for confirmation.

Dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine and pyrasulfotole/bromoxynil reduced red clover establishment (Table 3). Bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine and pyrasulfotole/bromoxynil reduced red clover dry weight by 58, 94, 91 and 98% relative to the untreated control, respectively (Table 3). Ivany *et al.* [18] similarly reported high red clover injury due to bromoxynil/MCPA, thifensulfuron/tribenuron and 2,4-D mixtures when applied to barley (*Hordeumvulgare* L.) under sown to red clover. UAN treatment reduced clover establishment by more than 50%.

CONCLUSION

Results of this study indicate that application of bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine or pyrasulfotole/bromoxynil in 28% UAN carrier will cause injury in winter wheat initially, however, injury is transient with minimal to no impact on wheat height, head distortion and yield. Where present, thifensulfuron/tribenuron + MCPA amine caused more injury than bromoxynil/MCPA, dichlorprop/2, 4-D and pyra-

sulfotole/bromoxynil. Herbicide injury when applied in UAN as the carrier was additive and increased as rate of UAN increased. Establishment of red clover was decreased by dichlorprop/2,4-D, thifensulfuron/tribenuron + MCPA amine and pyrasulfotole/bromoxynil. This research suggests that UAN has potential to be used as a herbicide carrier for bromoxynil/MCPA, dichlorprop/2,4-D, thifensulfuron/tribenuron +MCPA amine and bromoxynil/pyrasulfotole for spring POST application in winter wheat. However, it is not recommended for growers who opt to under seed red clover as this practice can reduce legume establishment.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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