Impact of Application Temperature on Broadleaf Herbicide Efficacy[1]

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Abstract

Cold air temperatures at the time of herbicide application are generally thought to decrease efficacy of systemic herbicides. Contact herbicides such as carfentrazone and sulfentrazone combined with systemic herbicides may provide an increased level of weed control when applied at cold air temperatures compared to products containing only systemic ones. Identical herbicide treatments were made at air temperatures of approximately 7 C (45 F) and 18 C (65 F) in four different trials. Control of ivyleaf speedwell, common chickweed, henbit, purple deadnettle, and white clover was evaluated. In general, warm temperature applications initially provided better weed control during the first week after treatment (WAT). By 2 to 3 WAT though, air temperature at the time of application generally did not affect overall weed control. In study 1, at 56 days after treatment (DAT) regardless of air temperature at application, all tested herbicides provided 86% or greater control of ivyleaf speedwell (*Veronica hederifolia* L.), and 98% or greater control of henbit (*Lamium amplexicaule* L.), with the exception of Trimec Classic, which did not provide acceptable control of henbit. Common chickweed (*Stellaria media* L.) control with combination treatments containing carfentrazone or sulfentrazone was similar at both temperature regimes, with control of 95% or greater, averaged across application air temperature. In study 2, after higher initial control with warm temperature treatments during the first WAT, Powerzone and Speedzone provided the highest level of control of ivyleaf speedwell and purple deadnettle at 35 DAT with no difference noted between air temperatures at application. Control of ivyleaf speedwell and purple deadnettle (*Lamium purpureum* L.) with Powerzone was 85 and 82%, respectively, averaged across temperature applications, while Speedzone controlled these two weed species 88 and 92%, respectively. In general, herbicides evaluated provided similar weed control at approximately 50 DAT when applied at warm or cold temperatures. Only for common chickweed control in trial 3 was there a significant interaction between temperature and herbicide treatment when evaluated 50 DAT. In that study, Speedzone and Trimec Classic gave greater control at warm compared to cold temperature application. Herbicides containing carfentrazone plus ester forms of 2,4-D or MCPA provided the highest levels of control.

Index words: cold temperature, herbicide temperature interaction, carfentrazone combinations, sulfentrazone combinations.

Chemicals used in this study: Carfentrazone (QuickSilver); carfentrazone plus 2,4-D plus MCPP plus dicamba (Speedzone); carfentrazone plus 2,4-D plus MCPP plus dicamba (Speedzone Southern); carfentrazone plus MCPA plus MCPP plus dicamba (Powerzone); 2,4-D plus MCPP plus dicamba (Trimec Classic); 2,4-D ester plus 2,4-DP ester plus dicamba (Super Trimec); sulfentrazone plus 2,4-D plus MCPP plus dicamba (Surge).

Species used in this study: ivyleaf speedwell (*Veronica hederifolia* L.); common chickweed (*Stellaria media* L.); henbit (*Lamium amplexicaule* L.); white clover (*Trifolium repens* L.); purple deadnettle (*Lamium purpureum* L.).

Significance to the Horticulture Industry

Winter weeds are a management concern for those maintaining cool- or warm-season turfgrass. The herbicides evaluated in this study generally provided quicker injury development in broadleaf weed species when applied at 18 C (65 F) compared to 7 C (45 F). If speed of control is important, the postemergence herbicides should be applied under warmer air temperatures. If time constraints or weather conditions require turf managers to treat winter weeds at lower temperatures, long-term control will generally be similar to applications under warmer temperatures for treatments containing carfentrazone or sulfentrazone plus systemic broadleaf herbicides. Products containing ester forms of the systemic broadleaf herbicides are preferred for winter weed control.

Introduction

Air temperature at the time of herbicide application plays a significant role in herbicide efficacy (Bayer 1987, Coupland 1983, Kudsk et al. 1990). Applications of herbicides during periods of cold temperatures are generally less effective than those applied during warm temperatures (Domaradzki and Kieloch 2003, Kells et al. 1984, Olson, et al. 2000). During cold temperatures, plant growth and metabolism rates are reduced. These reductions decrease herbicide absorption and translocation and may be related to herbicide efficacy (Legg 1983).

Physiological plant responses to cold temperatures limit herbicide efficacy during periods of low temperatures. During cold stress, plant leaf epicuticular wax increases, thereby limiting herbicide penetration (Bayer and Lumb 1973). Also, the leaf wax results in hydrophobicity, leading to reduced herbicide spray leaf wetting (Hatterman-Valenti et al. 2006). The combination of herbicide penetration resistance and leaf hydrophobicity, along with limited herbicide translocation because of cold weather, can result in poor weed control during cold temperatures (Hamilton et al. 1982, Hull et al. 1982, Norris and Bukovac 1972).

Control of winter broadleaf weeds in turf is often necessary, especially in warm-season species like bermudagrass (*Cynodon dactylon* L.) that go dormant and thus are unable to compete with actively growing winter annual weeds. A combination of systemic herbicides is often used for broad spectrum winter weed control. Researchers have found that the addition of a contact herbicide to systemic herbicides such as 2,4-D or dicamba increases herbicide efficacy (Lyon et al. 2007). Carfentrazone and sulfentrazone are both contact herbicides that belong to the phenyl triazolinone class (Theodoridis et al. 1992). Both chemicals control broadleaf

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weeds primarily through the inhibition of the protoporphyrinogen oxidase enzyme, an important enzyme in chlorophyll production (Dayan et al. 1997). By combining one of these contact herbicides with systemic herbicides, cold weather weed control may be more effective.

The formulation of systemic herbicides may also influence weed control during cold temperatures. Some products contain herbicides formulated as amines because they are less volatile than ester formulations (Baskin and Walker 1953). While more volatile, especially in hot temperatures, ester formulations are more soluble in the plant's cuticle and therefore can be more readily absorbed by plants (Richardson 1977). This is especially important during cold weather applications when plant cuticles are thick. Air temperature also affects the rate of absorption of herbicides into the plant. The rate of absorption of foliar-applied herbicides tends to double with each 10 C increase in air temperature (Klingman and Ashton 1975, Leopold and Kriedemann 1975). Therefore, during cold temperatures, herbicide absorption is slowed, resulting in reduced initial weed injury. The increased penetration of ester formulations may help offset the slow absorption during cold temperatures and possibly provide better initial weed control.

Spray water temperature has also been shown to affect herbicide efficacy. Agostineto et al. (2015) observed that increasing the spray water temperature from 10 to 30 C (50 to 86 F) improved control of *Ipomoea hederifolia* L. and *Ipomoea quamclit* L. from carfentrazone. Glyphosate at 0.275 kg·ha^{-1} (0.25 lb·A^{-1}) plus dicamba at 0.137 kg·ha^{-1} (0.12 lb·A^{-1}) gave greater control of giant ragweed (*Ambrosia trifida* L.) and pitted morningglory (*Ipomoea lacunosa* L.) when the spray water temperature was 31 (88 F) compared to 5 C (41 F). However, in that study, control was not different between these two spray water temperatures in regards to horseweed and palmer amaranth control (Devkpota et al. 2016).

Several weed control products containing a combination of systemic and contact herbicides are being marketed as more effective in cold weather than traditional products. These products contain either carfentrazone or sulfentrazone mixed with various combinations of amine or ester forms of 2,4-D, mecoprop-p, dicamba, and MCPA. The objective of this study was to compare herbicide efficacy for treatments applied in both cold and warm air temperatures on common winter broadleaf weeds. Several systemic and contact herbicide combinations were evaluated to aid in determining the most effective chemicals for cold weather weed control.

Materials and Methods

General conditions. The field studies were conducted in Virginia Beach, VA. Studies were conducted in December (Studies 1, 3 and 4) and March (Study 2). Study 1 was conducted in an established stand of 'Shenandoah' tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort, also listed as *Festuca arundinacea* Screb.], Studies 2 and 3 in dormant common bermudagrass [*Cynodon dactylon* (L.) Pers.], and study 4 was conducted in an established stand of 'Thermal Blue' hybrid bluegrass (*Poa pratensis* L. × Poa *arachnifera* Torr.). The soil was a Tetotum loam (fine-loamy, mixed, thermic Aquic Hapludults). A randomized complete block design containing four replications was used for all studies. Herbicides were applied using flat fan nozzles with a CO_2-pressurized backpack sprayer delivering 230 L·ha^{-1} (25 gal·A^{-1}). In each study, two identical herbicide applications were made at approximately 7 C (45 F) and 18 C (65 F). Weed control data was taken visually during the initial week after application along with data taken up to 9 WAT. Ratings were based on a scale of 0 to 100, with 0 = no injury and 100 = plant death.

All studies included the following treatments: carfentrazone (QuickSilver, FMC Corp., 1735 Market St., Philadelphia, PA) at 0.018 kg·ha^{-1}; carfentrazone plus 2,4-D plus MCPP plus dicamba (Speedzone, PBI/Gordon Corp., 1217 W. 12th St., Kansas City, MO) at 0.022 kg·ha^{-1}, 0.750 kg·ha^{-1}, 0.224 kg·ha^{-1}, and 0.067 kg·ha^{-1}, respectively; carfentrazone plus 2,4-D plus MCPP plus dicamba (Speedzone Southern, PBI/Gordon Corp.) at 0.022 kg·ha^{-1}, 0.291 kg·ha^{-1}, 0.112 kg·ha^{-1}, and 0.028 kg·ha^{-1}, respectively; carfentrazone plus MCPA plus MCPP plus dicamba (Powerzone, PBI/Gordon Corp.) at 0.020 kg·ha^{-1}, 1.08 kg·ha^{-1}, 0.213 kg·ha^{-1}, and 0.112 kg·ha^{-1}, respectively; sulfentrazone plus 2,4-D plus MCPP plus dicamba (Surge, PBI/Gordon Corp.) at 0.027 kg·ha^{-1}, 0.638 kg·ha^{-1}, 0.224 kg·ha^{-1}, and 0.101 kg·ha^{-1}, respectively; and 2,4-D plus MCPP plus dicamba (Trimec Classic, PBI/Gordon Corp.) at 0.896 kg·ha^{-1}, 0.246 kg·ha^{-1}, and 0.101 kg·ha^{-1}, respectively. Studies 3 and 4 also included 2,4-D ester plus 2,4-DP ester plus dicamba (Super Trimec, PBI/Gordon Corp.) at 0.672 kg·ha^{-1}, 0.336 kg·ha^{-1}, and 0.168 kg·ha^{-1}, respectively. In terms of application, these relate to Surge at 3.25 pt·A^{-1}, QuickSilver at 1.1 fl oz·A^{-1}, Speedzone Southern at 4 pt·A^{-1}, Powerzone at 3.5 pt·A^{-1}, Speedzone and Trimec Classic at 3.25 pt·A^{-1}, and Super Trimec at 2.5 pt·A^{-1}. Speedzone, Speedzone Southern, and Super Trimec contain an ester form of 2,4-D, while Powerzone contains an ester form of MCPA. Surge and Trimec Classic contain an amine form of 2,4-D.

Study 1. Broadleaf weeds included ivyleaf speedwell, common chickweed, and henbit. The warm weather applications were made on December 8, 2004, under the following conditions: 0% cloud cover, 19 C (66 F) air temperature, 12 C (54 F) soil temperature, 44% relative humidity, wind speed of 16 km·hr^{-1} (10 MPH) (west). Cold weather treatments were applied on December 16. Cloud cover was 5%, air temperature was 8 C (46 F), soil temperature was 4 C (39 F), relative humidity was 29%, wind speed was 13 km·hr^{-1} (8 MPH) (southwest). At the time of treatment, ivyleaf speedwell was 8 cm (3 in) tall, common chickweed was 6 cm (2 in) tall, and henbit was 10 cm (4 in) tall. Plot size was 1.8 by 6.1 m (6 × 20 ft).

Study 2. Control of ivyleaf speedwell, common chickweed, and purple deadnettle was determined. The cold weather treatments were applied on March 4, 2005. Cloud cover was 5%, air temperature was 7 C (45 F), soil temperature was 7 C (45 F), relative humidity was 49%, wind speed was 14 km·hr^{-1} (9 MPH) (northeast). The warm weather applications were made on March 7 under the following conditions: 10% cloud cover, 18 C (64 F) air temperature, 9 C (48 F) soil temperature, 40% relative humidity, wind speed of 14 km·hr^{-1} (9 MPH) (southwest). At the time of treatment, ivyleaf speedwell and common chickweed were 10 cm (4 in) tall, and purple deadnettle was 13 cm (5 in) tall. Plot size was 1.8 by 6.1 m (6 × 20 ft).

Studies 3 and 4. Weeds included white clover, ivyleaf speedwell, common chickweed, and purple deadnettle. The

Table 1. Percent ivyleaf speedwell control at 5. 7, 17, and 56 days after treatment (DAT) in study 1 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	5 DAT		7 DAT		17 DAT	56 DAT
		Warm	Cold	Warm	Cold		
		% control					
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	76	26	85	70	94	98
Carfentrazone (QuickSilver)	0.018	85	20	90	78	94	100
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	76	21	90	80	95	99
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	79	21	86	77	96	100
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	78	31	91	76	95	99
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	8	6	11	14	34	86
LSD (0.05)		6		8		6	5
Temperatures effects averaged over herbicide							
Warm		67		75		85	97
Cold		21		66		84	97
LSD (0.05)		3		3		NS	NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

warm weather applications were made on November 30, 2005. Cloud cover was 0%, air temperature was 17 C (62 F), soil temperature was 14 C (58 f), relative humidity was 71%, wind speed was 8–16 km·hr^{-1} (northeast). The cold weather treatments were applied on December 1. Cloud cover was 100%, air temperature was 7 C (44 F), soil temperature was 12 C (53 F), relative humidity was 73%, wind speed was 0–8 km·hr^{-1} (north). At the time of treatment, all weeds species were approximately 5 cm (2 in) tall. Plots size was 1.8 by 3 m (6 × 10 ft).

Results and Discussion

Study 1. Air temperature at the time of application affected ivyleaf speedwell control at both 5 and 7 DAT; however, by 17 DAT, application temperature did not affect control (Table 1). All herbicides with the exception of Trimec Classic provided acceptable control of ivyleaf speedwell at 5 DAT. Trimec Classic's lack of an inclusion of a contact herbicide most likely resulted in less initial weed control. Differences between warm and cold temperature applications were larger at 5 DAT than at 7 DAT. At 5 DAT, herbicides applied during warm weather showed approximately three times greater control of ivyleaf speedwell compared to applications made in cold weather. At 7 DAT, all herbicides except Trimec Classic provided good control for warm weather applications and acceptable control for cold weather applications. By 17 DAT, temperature at the time of application did not affect ivyleaf speedwell control, with all herbicides except Trimec Classic providing greater than 90% control. Trimec Classic did not provide effective control at early rating dates; however, by 56 DAT, good control was achieved.

Henbit control was also affected by air temperature at the time of application (Table 2). Slightly better control with

Table 2. Percent henbit control at 5. 7, 17, and 56 days after treatment (DAT) in study 1 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	5 DAT		7 DAT		17 DAT		56 DAT
		Warm	Cold	Warm	Cold	Warm	Cold	
		% control						
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	48	35	60	73	85	91	100
Carfentrazone (QuickSilver)	0.018	39	30	50	73	82	86	98
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	48	33	60	81	87	94	99
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	41	30	51	73	90	93	100
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	55	45	63	73	84	89	99
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	5	6	10	18	18	25	61
LSD (0.05)		7		10		6		9
Temperatures effects averaged over herbicide								
Warm		39		49		74		92
Cold		30		65		80		94
LSD (0.05)		4		6		4		NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

Table 3. Percent common chickweed control at 5. 7, 17, and 56 days after treatment (DAT) in study 1 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	5 DAT		7 DAT	17 DAT	56 DAT
		Warm	Cold			
		% control				
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	43	13	50	78	99
Carfentrazone (QuickSilver)	0.018	26	9	33	53	48
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	33	11	49	76	97
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	30	14	53	76	100
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	49	13	49	72	98
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	21	9	31	56	95
LSD (0.05)		6		12	13	9
Temperatures effects averaged over herbicide						
Warm		34		43	68	90
Cold		11		45	69	89
LSD (0.05)		2		NS	NS	NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

warm temperature applications was observed at 5 DAT; however, at 7 DAT, cold weather applications provided a higher level of control. Reasons for better performance by cold weather treatments at 7 DAT were unclear, but the same effect was observed at 17 DAT. By 56 DAT, temperature at the time of application did not affect henbit control. All herbicides with the exception of Trimec Classic provided good to excellent control by 17 DAT. Trimec Classic did not provide acceptable control of henbit at any rating date.

Control of common chickweed was greater for warm weather treatments at 5 DAT, but air temperature at application did not affect control on any other rating date (Table 3). At 5 DAT, warm weather application control was approximately three times greater than cold weather applications. By 7 DAT, common chickweed control was the same for both warm and cold weather applications for a given herbicide. Overall, the rate of common chickweed injury was slower than the other three weeds evaluated in this experiment. While most herbicides provided excellent control by 56 DAT, QuickSilver applied alone provided unacceptable control at each rating date. Because this product only contains carfentrazone, a contact herbicide, the contact injury provided was not enough to effectively control common chickweed.

Study 2. Study 2 was conducted in early spring, and, as a result, the winter annual weeds evaluated were larger and more mature than in Study 1. In Study 2, warm weather applications of herbicides provided better control of ivyleaf speedwell at 7 DAT than cold weather applications; however, by 14 DAT, application temperature had no effect on control (Table 4). Throughout the evaluation period, carfentrazone applied alone did not provide acceptable control of ivyleaf

Table 4. Percent ivyleaf speedwell control at 7, 14, 21, and 35 days after treatment (DAT) in study 2 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	7 DAT		14 DAT	21 DAT	35 DAT
		Warm	Cold			
		% control				
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	15	10	44	42	49
Carfentrazone (QuickSilver)	0.018	26	16	30	18	11
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	21	15	52	55	75
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	23	14	59	64	84
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	25	16	58	66	88
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	6	0	42	33	46
LSD (0.05)		5		7	8	13
Temperatures effects averaged over herbicide						
Warm		19		49	48	59
Cold		12		46	45	59
LSD (0.05)		3		NS	NS	NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

Table 5. Percent purple deadnettle control at 7, 14, 21, and 35 days after treatment (DAT) in study 2 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	7 DAT	14 DAT		21 DAT		35 DAT
			Warm	Cold	Warm	Cold	
		% control					
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	14	26	45	16	43	16
Carfentrazone (QuickSilver)	0.018	19	33	20	46	10	3
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	18	54	46	74	64	69
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	18	64	44	87	78	82
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	20	68	46	91	86	92
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	4	20	14	9	13	13
LSD (0.05)		5	10		11		14
Temperatures effects averaged over herbicide							
Warm		17	44		54		46
Cold		14	36		49		46
LSD (0.05)		NS	4		4		NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

speedwell. However, herbicides containing a combination of carfentrazone and systemic herbicides (Speedzone Southern Powerzone, and Speedzone) provided acceptable control by 35 DAT. These combination products provided better control than the product containing only systemic herbicides, Trimec Classic. Therefore, a synergistic effect appeared to result from combining carfentrazone and systemic herbicides; however, increased efficacy with Speedzone and Powerzone may also have been the result of containing ester forms of systemic herbicides.

Warm weather herbicide applications provided better purple deadnettle control on the 14 and 21 DAT ratings (Table 5) in trial 2. No temperature effect was observed on the 7 DAT rating. Control was less than 20% at this rating. Most herbicides applied during warm weather had higher levels of control than the cold weather applications at the 14 and 21 DAT rating; however, cold weather-applied Surge provided higher control than warm weather-applied Surge. Reasons for this difference were unclear. By 35 DAT, carfentrazone applied alone offered virtually no control of purple deadnettle. Combinations of carfentrazone and systemic herbicides provided acceptable to excellent control with no temperature effect on the results. Trimec Classic did not control purple deadnettle in this study.

Temperature at the time of application had little effect on common chickweed control (Table 6). On the 7 DAT rating, warm weather applications provided greater common chickweed control; however, differences were slight and of little practical significance, as overall control was less than 20%. By 14 DAT, control was not affected by temperature at the time of application. Combination products containing both carfentrazone and systemic herbicides provided the

Table 6. Percent common chickweed control at 7, 14, 21, and 35 days after treatment (DAT) in study 2 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	7 DAT		14 DAT		21 DAT	35 DAT
		Warm	Cold	Warm	Cold		
		% control					
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	10	14	30	44	45	50
Carfentrazone (QuickSilver)	0.018	11	19	21	14	9	0
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	13	16	53	26	43	20
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	13	15	66	43	69	100
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	14	18	59	28	62	70
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	5	0	38	19	47	30
LSD (0.05)		3		11		7	11
Temperatures effects averaged over herbicide							
Warm		11		44		44	30
Cold		5		29		46	40
LSD (0.05)		2		4		NS	NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

Table 7. Percent ivyleaf speedwell control at 6, 12, 21, and 50 days after treatment (DAT) in study 3 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	6 DAT	12 DAT	21 DAT	50 DAT
		% control			
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	25	49	43	69
Carfentrazone (QuickSilver)	0.018	29	62	38	51
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	38	59	46	61
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	34	69	51	79
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	34	62	43	71
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	11	23	26	61
2,4-D + 2,4-DP + dicamba[y] (Super Trimec)	1.18	10	22	31	55
LSD (0.05)		6	9	10	NS
Temperatures effects averaged over herbicide					
Warm		29	53	41	67
Cold		23	46	38	61
LSD (0.05)		3	5	NS	NS

[z]Contains an amine form of 2,4-D.
[y]Contains an ester form of 2,4-D or MCPA.

most effective control, with each providing acceptable common chickweed control by 35 DAT. Carfentrazone applied alone, Surge, and Trimec Classic did not effectively control common chickweed.

Study 3. There was no interaction between herbicide treatment and temperature at any rating date for ivyleaf speedwell control (Table 7). Averaged across herbicide treatment, there was greater ivyleaf speedwell control with warm weather application compared to cold weather treatment at 6 and 12 DAT but not at 21 and 50 DAT. Control ranged from 51 to 79% across the herbicide treatments.

There was no interaction between herbicide treatment and temperature at any rating date for purple deadnettle control (Table 8). Averaged across herbicide treatment, there was greater ivyleaf speedwell control at 6, but not at 12, 21 and 50 DAT for warm compared to cold temperature application. Surge and Powerzone gave approximately 70% purple deadnettle control at 50 DAT, with other treatments providing lower control.

There was no interaction between herbicide treatment and temperature at 6 and 21 DAT, but there was one at 12 and 50 DAT for common chickweed control (Table 9). At 12 DAT, control ranged from 15 to 29%, with certain herbicides performing slightly better at one of the temperatures, but the differences were of little practical importance. At 50 DAT, Powerzone and Super Trimec provided complete control of common chickweed at both application temperatures. Speedzone and Trimec Classic gave excellent control when applied under warm conditions, with lower control when applied under cold conditions.

Study 4. There was no interaction between herbicide treatment and temperature at 6, 12, 21, or 50 DAT for white

Table 8. Percent purple deadnettle control at 6, 12, 21, and 50 days after treatment (DAT) in study 3 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	6 DAT	12 DAT	21 DAT	50 DAT
		% control			
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	19	37	41	75
Carfentrazone (QuickSilver)	0.018	19	38	31	38
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	26	39	43	55
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	22	40	48	71
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	26	41	40	55
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	8	19	21	19
2,4-D + 2,4-DP + dicamba[y] (Super Trimec)	1.18	6	19	28	54
LSD (0.05)		6	6	9	18
Temperatures effects averaged over herbicide					
Warm		20	34	36	51
Cold		16	32	36	53
LSD (0.05)		3	NS	NS	NS

[z]Contains an amine form of 2,4-D.
[y]Contains an ester form of 2,4-D or MCPA.

Table 9. Percent common chickweed control at 6, 12, 21, and 50 days after treatment (DAT) in study 3 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	6 DAT	12 DAT		21 DAT	50 DAT	
			Warm	Cold		Warm	Cold
		% control					
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	8	29	23	35	100	95
Carfentrazone (QuickSilver)	0.018	5	11	20	18	8	35
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	8	21	24	33	78	75
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	6	20	28	36	100	100
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	8	20	20	28	93	53
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	8	20	15	29	100	83
2,4-D + 2,4-DP + dicamba[y] (Super Trimec)	1.18	8	20	15	28	100	100
LSD (0.05)		3	5		7	16	
Temperatures effects averaged over herbicide							
Warm		8	20		29	83	
Cold		6	21		30	77	
LSD (0.05)		NS	NS		NS	NS	

[z]Contains an amine form of 2,4-D.

[b]Contains an ester form of amine form of 2,4-D and/or MCPA.

clover control (Table 10). Averaged across herbicide treatments, control was greater under warm compared to cold conditions at 6 but not at 12, 21, or 50 DAT. Powerzone gave excellent control (96%) while Speedzone Southern and Speedzone gave good (84 and 89%, respectively) control of white clover.

Herbicide applications under warm 8 C (65 F) air temperatures generally caused faster injury symptom development in the broadleaf weed species tested compared to applications made at cold 7 C (45 F) air temperatures during the first week after application. Differences in control between warm and cold temperature applications generally disappeared by 3 WAT. Unless speed of control was important, application of these herbicides at what would be considered cold temperatures will still provide acceptable control by one to two months after application. Carfentrazone applied alone caused similar, but overall unacceptable control at both air temperatures. By combining carfentrazone with systemic herbicides such as 2,4-D, MCPP, and dicamba, effective winter broadleaf control can be achieved under cold weather applications. Utilizing ester formulations of systemic herbicides also may be a reason for the effective winter weed control seen with Speedzone and Powerzone.

Literature Cited

Agostineto, M.C., H.H. Ansolin, and L.B. de Carvalho. 2015. Spray temperature and spray volume influence on the efficacy of carfentrazone-ethyl and saflufenacil to control morning-glory. Commu. Plant Sci. 5(3–4):45–49.

Baskin, A.D. and E.A. Walker. 1953. The responses of tomato plants to vapors of 2,4-D and/or 2,4,5-T formulations at normal and higher temperatures. Weeds 2:280–287.

Table 10. Percent white clover control at 6, 12, 21, and 50 days after treatment (DAT) in study 3 as affected by either an 18 C (65 F) (warm) or a 7 C (45 F) (cold) application air temperature in a field trial.

Treatment	Rate kg ai·ha^{-1}	6 DAT	12 DAT	21 DAT	50 DAT
		% control			
Sulfentrazone + 2,4-D + MCPP + dicamba[z] (Surge)	0.99	6	14	29	60
Carfentrazone (QuickSilver)	0.018	1	5	14	25
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone Southern)	0.45	8	19	38	84
Carfentrazone + MCPA + MCPP + dicamba[y] (Powerzone)	1.43	9	20	58	96
Carfentrazone + 2,4-D + MCPP + dicamba[y] (Speedzone)	1.06	5	17	50	89
2,4-D + MCPP + dicamba[z] (Trimec Classic)	1.24	9	19	34	54
2,4-D + 2,4-DP + dicamba[y] (Super Trimec)	1.18	6	13	33	69
LSD (0.05)		2	6	9	13
Temperatures effects averaged over herbicide					
Warm		8	15	35	66
Cold		5	15	38	70
LSD (0.05)		1	NS	NS	NS

[z]Contains an amine form of 2,4-D.

[y]Contains an ester form of 2,4-D or MCPA.

Bayer, D.E. 1987. Temperature as a modifying environmental factor of herbicidal response. Proc. Calif. Weed Conf. 39:114–116.

Bayer, D.E. and J.M. Lumb. 1973. Penetration and translocation of herbicides. pp 387–440. *In*: W.V. Valkenburg, ed. Pesticide formulations, Marcel Dekker, Inc. New York, NY.

Coupland, D. 1983. Influence of light, temperature and humidity on the translocation and activity of glyphosate in *Elymus repens* (5*Agropyronrepens*). Weed Res. 23:347–355.

Dayan, F.E., S.O. Duke, J.D. Weete, and H.G. Hancock. 1997. Selectivity and mode of action of carfentrazone-ethyl, a novel phenyl triazolinone herbicide. Pestic. Sci. 51:65–73.

Devkota, P., F. Whitford, and W.G. Johnson. 2016. Influence of spray-solution temperature and holding duration on weed control with premixed glyphosate and dicamba formulation. Weed Technology 30:116–122.

Domaradzki, K. and R. Kieloch. 2003. The influence of weeds growth stage and climate conditions on optimizing dose of herbicides. J. Plant Protection Research 43:233–239.

Hamilton, R.J., A.W. McCann, P.A. Sewell, and G.T. Merrall. 1982. Foliar uptake of the wild oat herbicide flamprop-methyl by wheat. pp 303–313. *In*: D.F. Dutler, K.L. Alvin, and C.E. Price, eds. The Plant Cuticle. London: Academic.

Hatterman-Valenti, H.M., A. Pitty, and M.D.K. Owen. 2006. Effect of environment on giant foxtail (Setaria faberi) leaf wax and fluazifop-P absorption. Weed Sci. 54:607–614.

Hull, H.M., D.G. Davis, and G.E. Stolzenberg. 1982. Action of the adjuvants on plant surfaces. pp 26–67. *In*: R.H. Hodgsen, ed. Adjuvants for Herbicides. Champaign, IL: Weed Science Society of America.

Kells, J.J., W.F. Meggitt, and D. Penner. 1984. Absorption, translocation, and activity of fluazifop-butyl as influenced by plant growth stage and environment. Weed Sci. 32:143–149.

Klingman, G.C. and F.M. Ashton. 1991. Weed Science — Principles and Practices, Wiley, New York, NY.

Kudsk, P., T. Olsen, and K.E. Thonke. 1990. The influence of temperature, humidity and simulated rain on the performance of thiameturonmethyl. Weed Res. 30:261–269.

Legg, B.J. 1983. Micrometeorology and the influence of local variations of environment on plant growth and herbicide performance. Asp.Appl. Biol. 4:15–31.

Leopold, A.C. and P.E. Kriedemann. 1975. Plant Growth and Development. McGraw-Hill Book Co., New York, NY.

Lyon, D.J., A. Kniss, and S.D. Miller. 2007. Carfentrazone improves broadleaf weed control in proso and foxtail millets. Weed Tech. 21:84–87.

Norris, R.F. and M.J. Bukovac. 1972. Influence of cuticular waxes on penetration of pear leaf cuticle by 1-naphthalene-acetic acid. Pestic. Sci. 3:705–708.

Olson, B.L.S., K. Al-Khatib, P. Stahlman, and P.J. Isakson. 2000. Efficacy and metabolism of MON 37500 in *Triticum aestivum* and weedy grass species as affected by temperature and soil moisture. Weed Sci. 48:541–548.

Richardson, R.G. 1977. A review of foliar absorption and translocation of 2,4-D and 2,4,5-T. Weed Res. 17:259–272.

Theodoridis, G., J.S. Baum, F.W. Hotzman. 1992. Synthesis and herbicidal properties of aryltriazolinones. A new class of pre- and postemergence herbicides. Am. Chem. Soc. Symp. Ser. 504:135–146.