The Influence of Application Factors on the Phytotoxicity of Several Postemergence Herbicides[1]

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ABSTRACT

Phytotoxicity of fluazifop ((±)-2[4-[[5-(trifluoromethyl)2-pyridinyl]oxy]phenoxy]propanoic acid) increased as spray volume increased when applied with hollow cone nozzles at 1720 kPa, but was unchanged or decreased as spray volume increased when applied with flat fan nozzles at 276 kPa. Fluazifop was most phytotoxic when applied with hollow cone nozzles. Phytotoxicity of desmedipham(ethyl[3[[(phenylamino) carbonyl]oxy]phenyl]-carbamate) plus phenmedipham (3-[(methoxycarbonyl)- amino]phenyl(3-methylphenyl) carbamate) increased as spray volume increased when applied with flat fan nozzles at 276 kPa, hollow cone nozzles at 1720 kPa, and the controlled droplet applicator (CDA). Desmedipham plus phenmedipham was most phytotoxic when applied with hollow cone nozzles. Fluazifop was more phytotoxic when applied in a petroleum oil spray carrier with the CDA than in a soybean (*Glycine max*) oil spray carrier with the CDA, or in a water plus 1% (v/v) petroleum oil with 17% AtPlus 411F emulsifier (OC) spray carrier with the CDA or flat fan nozzles. Sethoxydim (2-[1-(ethoxyimino)butyl]-5-(2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one) was more phytotoxic when applied in a petroleum oil or soybean oil spray carrier with the CDA than when applied in a water plus 1% (v/v) OC spray carrier with flat fan nozzles. Application of several herbicides to the upper side, under side, and both sides of leaves of several plant species produced mixed results as to the optimum site of herbicide application.

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Additional Key Words: *Beta vulgaris*, spray carrier, spray volume, spray pressure, application site, application equipment, fluazifop, acifluorfen, desmedipham, phenmedipham, sethoxydim.

Desmedipham plus phenmedipham is the most widely used postemergence herbicide for weed control in sugarbeets (*Beta vulgaris*) grown in North Dakota and Minnesota (14). Fluazifop and sethoxydim are postemergence herbicides for grass control in broadleaf crops. Sethoxydim was applied to 50% of the sugarbeet acreage in North Dakota and Minnesota in 1985 (14). Fluazifop will be used in sugarbeets pending EPA registration. Previous research indicates that the phytotoxicity of postemergence herbicides may be influenced by such factors as application equipment (1, 9, 10, 22, 27), spray volume (6, 7, 8, 18, 24), spray carrier (9, 11, 26), and site of spray deposition (8, 13, 15, 17, 19, 25). Application equipment can affect spray droplet size, which also has been shown to influence the phytotoxicity of postemergence herbicides (1, 2, 4, 8, 16, 21, 23). However, results of previous research on the influence of application factors on postemergence herbicide phytotoxicity has been inconsistent, suggesting that application technique often interacts significantly with environment, herbicide tested, and plant species evaluated. Knowledge of the influence of application factors on the efficacy of fluazifop and desmedipham plus phenmedipham could be used by growers to select the most effective application techniques.

Objectives of this research were to: 1) determine the influence of application equipment and spray volume on the phytotoxicity of fluazifop and desmedipham plus phenmedipham, 2) evaluate the phytotoxicity of fluazifop and sethoxydim applied at a reduced spray volume in water plus petroleum oil additive, soybean oil, and petroleum oil spray carriers, and 3) determine the influence of site of spray deposition on the phytotoxicity of several postemergence herbicides.

MATERIALS AND METHODS

Method of application of fluazifop and desmedipham plus phenmedipham.

Field experiments were conducted at Crookston and Oklee, Minnesota, and Hunter, North Dakota in 1984. Plant species evaluated were planted in rows spaced 15 cm apart. Flat fan nozzles, hollow cone nozzles, and the CDA were mounted on modified bicycle wheel small plot sprayers. Spray volumes of 47 and 159 L/ha were applied at 276 kPa spray pressure with 800067 and 8002 flat fan nozzles, respectively, and at 1720 kPa with HC-1.25 and HC-4 hollow cone nozzles, respectively. The CDA was used to apply 9 and 47 L/ha spray volume using 2000 rpm with 4916-20 and 4916-48 orifices, respectively. Field plots were 3.4 by 7.6 m and herbicides were applied to the center 2 m of each plot. Plant injury was evaluated visually, with a rating of 0 indicating no injury and 100 indicating death. A randomized complete block design with four replications was used with combinations of application equipment, spray volume, herbicide rate, and plant growth stage in a factorial arrangement.

Desmedipham plus phenmedipham (formulated as equal parts of each herbicide) was applied at 0.28, 0.56, and 1.12 kg ai/ha with the CDA at 9 and 47 L/ha and with flat fan and hollow cone nozzles at 47 and 159 L/ha. Desmedipham plus phenmedipham was applied to flax (*Linum usitatissimum* L. 'Flor') and tame mustard (*Brassica hirta* L. 'Yellow #2') at two growth stages. Tame mustard height was 8 and 30 cm at Crookston and Oklee, and 18 and 45 cm at Hunter. Flax height was 4 and 13 cm at Crookston, 5 and 15 cm at Oklee, and 10 and 25 cm at Hunter.

Fluazifop was applied at 0.07, 0.14, and 0.28 kg ai/ha with the CDA at 9 and 47 L/ha, and with flat fan and hollow cone nozzles at 47 and 159 L/ha. Fluazifop was applied to wheat (*Triticum aestivum* L. 'Era'), oats (*Avena sativa* L. 'Lyon'), and foxtail millet (*Setaria italica* L. Beauv.) at the 3- and 5-leaf stage for all species at all locations. Petroleum oil with 17% AtPlus 411F (BASF Corp.) emulsifier (OC) was used at 1% (v/v) with all fluazifop treatments.

Spray carriers with fluazifop and sethoxydim.

Field experiments were conducted at Oklee, Minnesota and Hunter, North Dakota in 1984. Era wheat, Lyon oats, and foxtail millet were planted in rows 15 cm apart. Fluazifop and sethoxydim were applied with 650017 flat fan nozzles at 276 kPa in water plus 1% (v/v) OC. Fluazifop was applied at 0.08, 0.16, and 0.28 kg/ha with the CDA at 2000 rpm in water plus OC, petroleum oil, or soybean oil as spray carriers. Sethoxydim was applied with the CDA at 2000 rpm at 0.11 and 0.22 kg ai/ha with petroleum oil and soybean oil as spray carriers. The spray volume was 14 L/ha for all treatments. The soybean oil spray carrier was once refined soybean oil with no emulsifier added. The petroleum oil spray carrier was Sun Oil Company 11N petroleum oil with no emulsifier added. No other agents such as water, emulsifier, or surfactant were added when soybean oil or petroleum oil was specified as the spray carrier. Wheat, oats, and foxtail millet were treated at the 3- and 5-leaf stages. The CDA and flat fan nozzles were mounted on a bicycle wheel small plot sprayer. Plant injury was evaluated visually with 0 indicating no injury and 100 indicating complete control of plants. The design was a randomized complete block with four replications.

Herbicide application site.

Greenhouse experiments were conducted in 1984 and 1985. Corn (*Zea mays* L. 'Funks 6-4171'), was seeded in a sandy loam soil contained in 1.0 L plastic pots. Wild oats (*Avena fatua* L.), sunflower (*Helianthus annuus* L. 'Seedtec 315'), and redroot pigweed (*Amaranthus retroflexus* L.) were seeded in a sandy loam soil contained in 0.5 L plastic pots. All pots were fertilized with 112 kg/ha N, 41 kg/ha P, and 69 kg/ha K. Plants were selected for uniformity and thinned to one plant per pot before treatment. All pots were surface watered as needed. Supplemental lighting with fluorescent lamps maintained a daylength of 16 h. Herbicide was applied to the upper side of leaves, to the under side of leaves, or in equal amounts to both sides of leaves.

Fluazifop at 0.014, 0.035, 0.07, 0.11, and 0.14 kg/ha was applied in 1 microliter droplets to all leaves of 3-leaf corn plants; total volume was 187 L/ha. Corn was harvested 18 days after treatment and fresh and dry weights of shoots were determined.

Applications of fluazifop to wild oats, acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxy)-2-nitrobenzoic acid) to sunflower, and desmedipham plus phenmedipham to redroot pigweed were made with a greenhouse micro sprayer which delivered 200 micron droplets in a total spray volume of 187 L/ha. Leaves of plants were treated by holding them under the micro sprayer for a period of time required to give the desired volume of solution. The specifications and operation of the micro sprayer were outlined by Coggins and Baker (12).

Fluazifop at 0.035, 0.07, 0.14, and 0.28 kg/ha was applied to the first leaf of two leaf wild oat plants. Acifluorfen at 0.1, 0.2, 0.4, and 0.8 kg ai/ha was applied to both leaves of 2-leaf sunflower plants. Desmedipham plus phenmedipham (1:1) at 0.11, 0.22, 0.45, and 0.9 kg/ha was applied to the first leaf of 1.5-leaf redroot pigweed plants. Fluazifop was applied with 1% (v/v) OC, while acifluorfen and desmedipham plus phenmedipham were applied with 0.5% (v/v) Ortho X-77 nonionic surfactant (Chevron Chemical Co.). Wild oats, sunflower, and redroot pigweed were harvested 17, 22, and 20 days after treatment, respectively, and fresh and dry weights of shoots were determined. Experiments were conducted with a completely random design with four repetitions. Each experiment was conducted twice and data were combined.

RESULTS AND DISCUSSION

Method of application of fluazifop and desmedipham plus phenmedipham.

Injury to wheat, oats, and foxtail millet from fluazifop applied with hollow cone nozzles at 1720 kPa increased when spray volume was increased (Table 1). Injury to 3-leaf wheat, and 3- and 5-leaf oats from fluazifop applied with flat fan nozzles at 276 kPa decreased when spray volume was increased. Spray volume did not affect injury from fluazifop applied with the CDA at 2000 rpm.

Buhler and Burnside (8) found that increasing spray volume

Table 1. Injury to wheat, oats, and foxtail millet from fluazifop applied with various application methods, spray volumes, and leaf stages averaged over three rates and three locations.

		Leaf stage					
		Wheat		Oats		Foxtail millet	
Application method	Spray volume	3	5	3	5	3	5
	(L/ha)	(Injury rating)					
CDA at 2000 rpm	9	80	64	82	67	58	53
CDA at 2000 rpm	47	85	65	83	71	62	55
Flat fan at 276 kPa	47	87	68	88	73	67	62
Flat fan at 276 kPa	159	66	68	60	66	61	63
Hollow cone at 1720 kPa	47	92	50	90	65	64	58
Hollow cone at 1720 kPa	159	98	68	98	76	81	71
LSD (0.05)		6		6		7	

through flat fan nozzles at 200 kPa gave reduced fluazifop phytotoxicity. Froseth and Arnold (18) reported that weed control was similar when fluazifop was applied in 23, 47, 94, 187, or 374 L/ha. The volume median diameter ($D_{V0.5}$) of droplets produced by 8002 flat fan nozzles at 276 kPa is 390 microns with 10% of the volume in droplets larger than 550 microns (3). The $D_{V0.5}$ of droplets produced by hollow cone nozzles at 1720 kPa is 75 microns with no droplets larger than 150 microns (3). The $D_{V0.5}$ of droplets produced by the CDA at 2000 rpm is approximately 200 microns with few droplets being significantly larger or smaller (5). Increasing spray volume with flat fan nozzles may have reduced phytotoxicity by causing increased run off of relatively large spray droplets produced by flat fan nozzles, as compared to smaller droplets produced by hollow cone nozzles at 1720 kPa and the CDA at 2000 rpm. Buchholtz observed this phenomenon (6). Also, small spray droplets improve coverage by increasing droplet number per area, which has been shown to increase herbicide phytotoxicity (4, 8, 23). Buhler and Burnside (8) and McKinlay et al. (23) suggested that absorption of small droplets may be greater than absorption of large droplets. Greater uptake of small compared to large spray droplets may have been a factor in this experiment also.

Injury to wheat and oats was greater when fluazifop was applied at the 3-leaf stage than at the 5-leaf stage with all application methods except flat fan nozzles at 276 kPa and 159 L/ha (Table 1). Injury to foxtail millet followed this same trend. Injury to 3-leaf plants was greatest when fluazifop was applied with hollow cone nozzles at 1720 kPa and 159 L/ha, while all application equipment gave similar injury of 5-leaf plants. The relatively small droplets produced by hollow cone nozzles at 1720 kPa may have given better coverage of 3-leaf plants than the larger droplets from flat fan nozzles at 276 kPa, resulting in greater phytotoxicity

(4, 8, 23). However, all droplet sizes gave similar results when applied to 5-leaf plants. The small droplets may have lost their advantage over larger droplets due to superior penetration of the canopy of 5-leaf plants by large droplets as compared to small droplets. Maximum fluazifop phytotoxicity to wheat, oats, and foxtail millet was achieved when fluazifop was applied with hollow cone nozzles at 1720 kPa, 159 L/ha, and at the 3-leaf stage (Table 1).

Injury to tame mustard and flax from desmedipham plus phenmedipham increased as spray volume increased with all application methods when averaged over growth stages, herbicide rates, and locations (Table 2). Translocation of these herbicides is almost entirely acropetal (20), which suggests that complete coverage of plants with spray may be especially important for optimum phytotoxicity. Increasing spray volume likely improved coverage of both species with spray solution. Fluazifop phytotoxicity to grass species was increased by increasing spray volume when applied with hollow cone nozzles at 1720 kPa, but phytotoxicity was unaffected or reduced by increasing spray volume when applied with flat fan nozzles (Table 1). A possible explanation for the difference in response to changing volume between fluazifop and desmedipham plus phenmedipham could be greater retention of the large spray droplets from the flat fan nozzles at 276 kPa on broadleaf species compared to grass species.

Spray carriers with fluazifop and sethoxydim.

Significant transportation and handling cost savings can be obtained by reducing spray volume. Fluazifop was most phytotoxic to wheat, oats, and foxtail millet when applied in 14 L/ha of petroleum oil spray carrier with the CDA (Table 3). Fluazifop phytotoxicity was similar when applied in a soybean oil or water plus OC spray carrier with the CDA, or in a water

Table 2. Injury to flax and tame mustard from desmedipham plus phenmedipham applied with various application methods and spray volumes averaged over two growth stages, three herbicide rates, and three locations.

Application method	Spray volume	Injury rating: Flax	Injury rating: Tame mustard
	(L/ha)		
CDA at 2000 rpm	9	19	37
CDA at 2000 rpm	47	32	50
Flat fan at 276 kPa	47	38	54
Flat fan at 276 kPa	159	43	62
Hollow cone at 1720 kPa	47	52	62
Hollow cone at 1720 kPa	159	56	69
LSD (0.05)		4	4

Table 3. Injury to wheat, oats, and foxtail millet from fluazifop and sethoxydim applied with various application equipment and spray carriers averaged over application at two growth stages, two locations, three rates with fluazifop, and two rates with sethoxydim.

				Injury rating		
Application method	Herbicide	Spray carrier	Spray volume	Wheat	Oats	Foxtail millet
			(L/ha)			
CDA at 2000 rpm	Fluazifop	Water[*]	14	73	79	61
CDA at 2000 rpm	Fluazifop	Pet. Oil[†]	14	92	90	73
CDA at 2000 rpm	Fluazifop	Soy. Oil[‡]	14	72	76	60
Flat fan at 276 kPa	Fluazifop	Water	14	75	78	59
CDA at 2000 rpm	Sethoxydim	Pet. Oil	14	86	91	96
CDA at 2000 rpm	Sethoxydim	Soy. Oil	14	86	93	93
Flat fan at 276 kPa	Sethoxydim	Water	14	77	83	91
LSD (0.05)				5	4	6

[*] Water plus 1% (v/v) AtPlus 411F oil concentrate.
[†] Sun Oil Company 11N petroleum oil.
[‡] Once refined soybean oil.

plus OC spray carrier with flat fan nozzles. The superiority of the petroleum oil spray carrier was likely due to increased uptake of fluazifop in this spray carrier compared to the other two spray carriers tested.

Sethoxydim was more phytotoxic to wheat and oats when applied in petroleum oil or soybean oil with the CDA than when applied in water plus OC with flat fan nozzles (Table 3). Sethoxydim, unlike fluazifop, gave similar results with petroleum oil or soybean oil as the spray carrier.

Herbicide application site.

Currier and Dybing (13) stated that the lower epidermis of plant leaves is usually more penetrable due to a thinner cuticle and more numerous stomata compared to the upper epidermis. Franke (17) suggested that absorption of substances may be greater through the under surface of leaves due to an abundance of ectodesmata associated with stomata, which are more numerous on the under surface of leaves. Dybing and Currier (15), and Gustafson (19) demonstrated that uptake was greater from the under side than from the upper side of leaves of certain species. Greenhouse experiments were conducted with several herbicides on several plant species to determine if herbicide application site influenced phytotoxicity.

Corn fresh weight reduction from fluazifop was similar for all sites of application at all rates except 0.014 kg/ha (Table 4). Corn fresh weight reduction from fluazifop at 0.014 kg/ha was greater when fluazifop was applied to the under side of leaves than when applied to both sides of leaves, while application to both sides of leaves reduced corn fresh weight more than appli-

Table 4. Fresh weight of four plant species treated on the upper side, under side, and both sides of leaves with various herbicides.

	Site of application on leaves		
Herbicide rate	Upper side	Under side	Both sides
(Kg/ha)		(g/plant)	
Fluazifop on corn			
0.0		11.2	
0.014	12.1	6.6	8.9
0.035	1.5	1.5	1.3
0.07	0.9	0.9	1.2
0.11	0.9	0.8	0.7
0.14	1.0	0.8	0.8
Mean	3.1	2.1	2.6
LSD (0.05) for rate x placement interaction = 2.1			
LSD (0.05) for placement mean = 1.1			
Fluazifop on wild oats			
0.0		1.30	
0.035	0.53	0.80	0.51
0.07	0.08	0.14	0.11
0.14	0.01	0.11	0.09
0.28	0.05	0.09	0.06
Mean	0.18	0.28	0.19
LSD (0.05) for rate x placement interaction = 0.29			
LSD (0.05) for placement mean = 0.14			
Acifluorfen on sunflower			
0.0		6.40	
0.10	6.9	6.6	6.4
0.20	6.7	5.8	6.4
0.40	5.6	4.9	5.5
0.80	3.7	3.5	3.1
Mean	5.7	5.2	5.4
LSD (0.05) for rate x placement interaction = 0.7			
LSD (0.05) for placement mean = 0.4			
Desmedipham plus phenmedipham on redroot pigweed			
0.0		1.10	
0.11	0.8	1.0	0.8
0.22	1.0	0.8	0.8
0.45	0.5	0.9	0.5
0.90	0.4	0.6	0.7
Mean	0.7	0.8	0.7
LSD (0.05) for rate x placement interactions = 0.5			
LSD (0.05) for placement mean = 0.2			

cation to the upper side of leaves. Although not statistically significant, fresh weight reduction of wild oats from fluazifop tended to be greater when fluazifop was applied to the upper side or to both sides of leaves then when applied only to the under side of leaves for all fluazifop rates tested (Table 4).

Fresh weight reduction of sunflower from acifluorfen at 0.20 and 0.40 kg/ha was greater when acifluorfen was applied to the under side of leaves than when applied to the upper side of leaves, and application to the under side of leaves tended to reduce fresh weight more than application to both sides of leaves (Table 4). Fresh weight reduction from acifluorfen averaged over rates was greater when applied to the under side of leaves than when applied to the upper side of leaves.

Reduction of redroot pigweed fresh weight from desmedipham plus phenmedipham was similar with all sites of application (Table 4).

In these experiments, application of herbicides to under sides of leaves increased, decreased, or had no effect on herbicide phytotoxicity (Table 4). The observed variation in optimum site of application of herbicide suggests that coverage of under sides of leaves with herbicides may increase the phytotoxicity of specific herbicides to specific plant species. However, no general improvement in weed control would be expected with various target species and herbicides.

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