Chapter 21
Sulfonylurea Herbicides[1,2]

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I. INTRODUCTION

History, uses, and formulation. Chlorsulfuron (2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl] benzenesulfonamide) was marketed initially for postemergence broadleaf weed control in wheat (*Triticum aestivum* L.) in 1982 and 1983 in the United States and Canada, respectively, under the trade name "Glean" (Figure 1). Chlorsulfuron is phytotoxic to some grasses, as well. It was first discovered by Dr. G. Levitt of E.I. du Pont de Nemours and Co., Inc., who patented it in 1978. Chlorsulfuron is the second commercial member of a new class of herbicides, the sulfonylurea herbicides. The analog sulfometurn (2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]benzoic acid) was marketed first as "Oust" for use on noncropland in the United States (Figure 1). Each sulfonylurea herbicide molecule consists of an aryl and heterocyclic component joined by a sulfonylurea bridge. Synthesis and structure-activity relations of this

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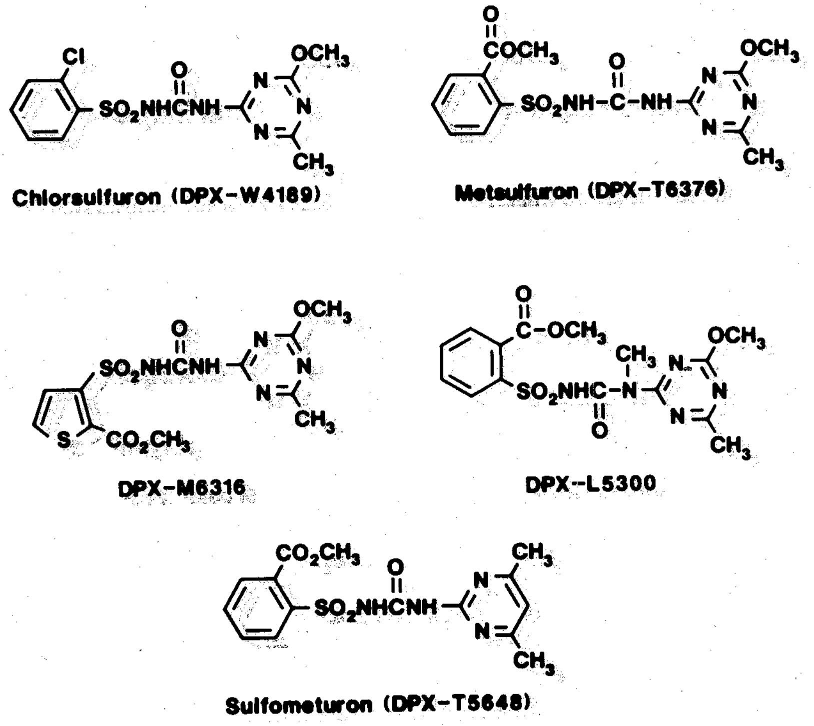

Chlorsulfuron (DPX-W4189)

Metsulfuron (DPX-T6376)

DPX-M6316

DPX-L5300

Sulfometuron (DPX-T5648)

Figure 1. The chemical structures of various sulfonylurea herbicides.

class of herbicides have been summarized (175, 303). Metsulfuron (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid), a slightly less persistent analog of chlorsulfuron, was marketed initially under the tradename “Ally” in the United States and Canada in 1986 and 1987, respectively (Figure 1). DuPont also is marketing “Finesse”, a mixture of chlorsulfuron and metsulfuron, in the Pacific Northwest. Other rapidly degraded sulfonylurea analogs being marketed or under development for broadleaf weed control in wheat include DPX-M6316 (methyl-2-[[(4-methoxy-6-methyl)-1,3,5-triazin-2-yl]aminocarbonyl] aminosulfonyl]-2-thiophenecarboxylate), trade name “Harmony” (325), and DPX-L5300 {methyl 2-[3-(4-methoxy-6-methyl-1,3,5-triazin-2-yl)-*N*-methylamino]carbonyl]amino]sulfonyl] benzoate}, trade name “Express” (108, 240) (Figure 1). “Matrix” is the proposed trade name for a mixture of Harmony and Express. The characteristics and constituents of these formulations are summarized in Tables 1 and 2. CIBA-GEIGY Corp. is developing a sulfonylurea analog, CGA 131036 {3-(6-methoxy-4-methyl-1,3,5-triazin-2-yl)-1-[2-(2-chloroethoxy)phenylsulfonyl]urea}, but relatively little information has been published on it (9, 46).

Chlorsulfuron was formulated as a wettable powder in its initial stages of field testing when it was designated as DPX-W4189. Currently, chlorsulfuron and its analogs are formulated as dry flowable granules (Table 2). Dry flowable formulations are easier to handle than wettable powders and resist caking due to moisture uptake from the atmosphere.

Chlorsulfuron, metsulfuron, and DPX-M6316 are registered for postemergence application at very low rates and control a wide range of broadleaf weeds in durum (*Triticum durum* Desf.), winter, and spring wheat (Tables 3, 4, and 5). Chlorsulfuron also is registered for preplant-incorporated, preplant surface, and preemergence applications. While this review will concern the use of sulfonylurea herbicides in wheat, their use in other cereals will be mentioned, where it is appropriate. These herbicides control or suppress some grass weeds (Table 5) and have limited preemergence herbicidal activity. While wheat is tolerant of chlorsulfuron and metsulfuron, the soil residual of these herbicides may restrict usage to areas producing these cereals predominately in the Great Plains, Pacific Northwest, and Prairie Provinces of Canada. While the soil residual may limit cropping options in rotation, herbicide carry-over may control or suppress some

Table 1. Selected physical characteristics of sulfonylurea herbicides.

	Herbicide			
Physical characteristic	Chlorsulfuron[a]	Metsulfuron[b]	DPX-M6316[c]	DPX-L5300[d]
Molecular weight	357.78	381.37	387.40	395.39
Water solubility (mg/ml at 25C)	0.125 at pH 4 0.30 at pH 5 27.90 at pH 7	0.270 at pH 5 1.75 at pH 6 5.80 at pH 7	24 at pH 4 260 at pH 5 2400 at pH 6	28 at pH 4 50 at pH 5 280 at pH 6
Vapor pressure (mm Hg at 25 C)	2.3×10^{-11}[g]	2.5×10^{-12}[g]	1.3×10^{-10}[g]	2.7×10^{-7}[g]
Melting point (C)	174-178	158	186	141
pK_a (at 25 C)	3.6[ef]	3.3[g]	4.0	5.0

[a] Herbicide Handbook, 1985.

[b] DuPont technical bulletin on Ally.

[c] DuPont technical bulletin on Harmony.

[d] DuPont technical bulletin on Express.

[e] Levitt, et al. (176).

[f] Shea (322).

[g] DuPont, 1987, personal communication, (108).

Table 2. Formulation characteristics of sulfonylurea herbicides used in wheat.

	Formulated product					
Characteristic	Glean	Ally	Finesse	Harmony	Express	Matrix
DuPont code number	DPX-W4189	DPX-T6376	DPX-G8311	DPX-M6316	DPX-L5300	DPX-R9674
WSSA name	Chlorsulfuron	Metsulfuron	Chlorsulfuron plus metsulfuron	-	-	DPX-M6316 plus DPX-L5300
Ratio in formulation	-	-	5:1	-	-	2:1
Formulation[a]	75% d.f.	60% d.f.	75% d.f.	75% d.f.	75% d.f.	75% d.f.
(oz. product/A)	1/6 to 1/2	1/10	0.2 to 0.5	1/3 to 2/3	1/6 to 1/3	0.3 to 0.6

[a] d.f. = dry flowable.

weeds in the subsequent fallow or wheat crop in the year after treatment. Current registration labels for chlorsulfuron, metsulfuron, and other sulfonylurea herbicides should be consulted for up-to-date information. Information on the efficacy and limitations of these herbicides is rapidly expanding and changes in recommendations for use in wheat are expected. Because chlorsulfuron has been more thoroughly researched than other analogs, the discussion will concentrate on this herbicide.

Structure, chemistry, and physical characteristics. The chemical structure and physical characteristics of various sulfonylurea herbicides are presented in Figure 1 and Table 1, respectively. A knowledge of the chemistry of these herbicides is needed to better understand their use and behavior in the environment. For example, soil-applied chlorsulfuron does not require incorporation to prevent vapor losses because chlorsulfuron is nonvolatile, as are other analogs (Table 1).

Chlorsulfuron has a pKa of 3.58 ± 0.05 (322). The pKa of individual sulfonylurea herbicides describes the pH-dependent ionization of these herbicides and influences herbicide adsorption, leaching, and persistence in soil. The water solubility of chlorsulfuron and its analogs also is pH dependent (Table 1). Water solubility decreases as pH decreases. Chlorsulfuron has a water solubility of 10 and 100 ppm at pH 5 and 7, respectively, and exists chiefly in anionic form in most agricultural soils (322, 327). An acidic pKa is attributed to the sulfonamide nitrogen of the herbicide molecule. Like chlorsulfuron, sulfometuron is less water soluble at acidic pHs (137).

Chlorsulfuron stability in aqueous solution also depends upon pH. Chlorsulfuron had a half-life of 1 week and 1 month when incubated in aqueous solution at pH 4 and pH 7 to 9, respectively, at 20 C in darkness (19). It was rapidly hydrolyzed in 0.1 N acid to 2-chlorobenzenesulfonamide and 2-amino-4-methoxy-6-methyl-1,3,5-triazine (19) (Figure 2). These dark hydrolysis products were identical to those initially formed by photodecomposition in water (144) (Figure 2). Unidentified insoluble hydrolysis products were formed at pH 9 to 10.

Table 3. Weeds controlled or suppressed by various sulfonylurea herbicides in wheat according to the 1989 United States and Canadian registration or technical data sheets, 1986.

Weed Common name	Weed Scientific name	Chlorsulfuron (U.S.)	Metsulfuron	DPX-G8311	DPX-M6316	DPX-L5300	Chlorsulfuron (Canada)
Annual bluegrass	*Poa annua* L. # POAAN			X			
Annual sowthistle	*Sonchus oleraceus* L. # SONOL			X	X		
Bedstraw	*Galium* spp.	X		X			
Bittercress	*Cardamine* spp.		X				
Black mustard	*Cardamine nigra* (L.) W.J.D. Koch # BRSNI				X		
Blue Jacobsladder	*Polemonium caeruleum* L. # PMNCO			X			
Blue mustard	*Chorisora tenella* (Pallas) DC. # COBTE	X	X	X			
Bur beakchervil	*Anthriscus caucalis* Bieb. #ANRCAX	X		X	X		
Bur buttercup	*Ranunculus testiculatus* Crantz #CCFTE		X	X			
Buttercup	*Ranunculus* spp.	X					
Canada thistle	*Cirsium arvense* (L.) Scop. # CIRAR	X	X	X		X	X
Carolina geranium	*Geranium carolinianum* L. # GERCA				X		
Catchweed bedstraw (cleavers)	*Galium aparine* L. # GALAP				X		X
Chickweed	*Stellaria* spp.		X	X			X
Coast fiddleneck	*Amsinckia intermedia* Fisch. & Meg. # ABSIN				X		
Common chickweed	*Stellaria media* (L.) Vill. # STEME	X	X	X	X	X	X
Common groundsel	*Senecio vulgaris* L. # SENVU	X	X	X	X		
Common hempnettle	*Galeopsis tetrahit* L. # GAETE	X		X	X		X
Common lambsquarters	*Chenopodium album* L. # CHEAL	X	X	X	X	X	X
Common mallow	*Malva neglecta* Wallr. # MALNE				X		
Common purslane	*Portulaca oleracea* L. # POROL	X	X	X	X		
Common ragweed	*Ambrosia artemisiifolia* L. # AMBEL	X	X	X	X		
Common sunflower	*Helianthus annuus* L. # HELAN		X				
Cone catchfly	*Silene conoidea* L. # SILCO	X	X	X			
Corn cockle	*Agrostemma githago* L. # AGOGI		X				
Corn gromwell	*Lithospermum arvense* L. # LITAR	X	X	X		X	
Corn spurry	*Spergula arvensis* L. # SPRAR	X		X			
Cowcockle	*Vaccaria pyramidata* Medik. # VAAPY	X	X	X	X		X
Curly dock	*Rumex crispus* L. # RUMCR	X			X		
Dandelion	*Taraxacum officinale* Weber in Wiggers # TAROF						X
Dogfennel	*Eupatorium capillifolium* (Lam.) Small # EUPCP		X		X	X	
Dovefoot geranium	*Geranium molle* L. # GERMO			X			
Erect knotweed	*Polygonum erectum* L. # POLER					X	
False chamomile	*Matricaria maritima* L. # MATMA	X	X	X	X		
Falseflax	*Camelina* spp.	X					
Fiddleneck	*Amsinckia* spp.	X	X	X	X		
Field pennycress	*Thlaspi arvense* L. # THLAR	X	X	X	X	X	X
Filaree	*Erodium* spp.		X				
Flixweed	*Descurainia sophia* (L.) Webb. ex Prantl # DESSO	X	X	X	X	X	X

Table 3. Continued.

Weed		Chlorsulfuron (U.S.)	Metsulfuron	DPX-G8311	DPX-M6316	DPX-L5300	Chlorsulfuron (Canada)
Common name	Scientific name						
Giant foxtail	*Setaria faberi* Herrm. # SETFA	X			-	-	
Green foxtail	*Setaria viridis* (L.) Beauv. # SETVI	X		X	-	-	X
Green smartweed	*Polygonum* spp.	X	X		X		X
Gromwell	*Lithospermum* spp.	X			X		
Haresear mustard	*Conringia orientalis* (L.) Dumort. # CNHOR	X	X		X	X	
Henbit	*Lamium amplexicaule* L. # LAMAM	X	X	X		X	
Italian ryegrass	*Lolium multiflorum* Lam. # LOLMU	X		X			
Knawel	*Scleranthus annuus* L. # SCRAN				X		
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	X	X	X	X	X	X
Ladysthumb	*Polygonum persicaria* L. # POLPE	X	X	X	X		X
Little bittercress	*Cardamine* spp.			X			
Little mallow	*Malva parviflora* L. # MALPA				X		
London rocket	*Sisymbrium irio* L. # SSYIR				X		
Mayweed chamomile	*Anthemis cotula* L. # ANTCO	X			X	X	
Miners lettuce	*Claytonia perfoliata* Donn ex Willd. # CLAPE	X	X	X	X	X	
Mouseear chickweed	*Cerastium vulgatum* L. # CERVU	X			X		
Mouseearcress	*Arabidopsis thaliana* (L.) Heynh. # ARBTH				X		
Pale smartweed	*Polygonum lapathifolium* L. # POLLA		X				
Pennsylvania smartweed	*Polygonum pensylvanicum* L. # POLPY	X		X	X		
Pineappleweed	*Matricaria matricarioides* (Less.) C. L. Porter # MATMT	X		X			
Plains coreopsis	*Coreopsis tinctoria* Nutt. # CRTLI		X				
Prickly lettuce	*Lactuca serriola* L. # LACSE	X	X	X		X	
Prostrate knotweed	*Polygonum aviculare* L. # POLAV	X	X	X	X		
Prostrate pigweed	*Amaranthus blitoides* S. Wats. # AMABL	X		X			
Rapeseed, volunteer	*Brassica napus* L.						X
Red maids	*Calandrinia ciliata* (Ruitz et Pav. DC) # CLNCI				X		
Redstem filaree	*Erodium cicutarium* (L.) L'Her. ex Ait. # EROCI	X		X			
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	X	X	X	X	X	X
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	X	X	X	X	X	X
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	X	X	X	X	X	
Slimleaf lambsquarters	*Chenopodium leptophyllum* (Mog.) Nutt. ex S. Wats. # CHELE		X				
Smallflower buttercup	*Ranunculus abortivus* L. # RANAB				X		
Smallseed falseflax	*Camelina microcarpa* Andrz. ex DC. # CMAMI		X			X	
Smooth pigweed	*Amaranthus hybridis* L. # AMACH	X	X	X			

Table 3. Continued.

Weed		Chlorsulfuron (U.S.)	Metsulfuron	DPX-G8311	DPX-M6316	DPX-L5300	Chlorsulfuron (Canada)
Common name	Scientific name						
Sowthistle	*Sonchus* spp.		X				
Speedwell	*Veronica* spp.	X		X	X		
Swamp smartweed	*Polygonum coccineum* Muhl. ex Willd. # POLCC				X		
Swinecress	*Coronopus didymus* (L.) Sm. # COPDI				X		
Sunflower, volunteer	*Helianthus annuus* L. # HELAN	X	X		X	X	
Tansymustard	*Descurainia* spp.	X	X	X	X	X	
Tarweed	*Madia* spp.	X	X	X	X	X	
Tumble mustard	*Sisymbrium altissimum* L. # SSYAL	X	X	X	X	X	
Tumble pigweed	*Amaranthus albus* L. # AMAAL		X				
Vetch	*Vicia* spp.			X			
Waterpod	*Ellisia nyctelea* L. # ELSNY	X	X				
White campion	*Silene alba* (Mill.) E.H.L. Krause # MELAL	X		X			
White cockle	*Lychnis alba* Mill.	X					
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	X	X	X	X	-	X
Wild carrot	*Daucus carota* L. # DAUCA	X		X			
Wild garlic	*Allium vineale* L. # ALLVI	X			X	-	
Wild mustard	*Sinapis arvensis* L. # SINAR	X	X	X	X	X	X
Wild onion	*Allium canadense* L. # ALLCA	X					
Wild radish	*Raphanus raphanistrum* L. # RAPRA	X		X			
Yellow foxtail	*Setaria glauca* (L.) Beauv. # SETLU	X			-	-	
Yellow starthistle	*Centaurea solstitialis* L. # CENSO	X					

Sulfometuron also hydrolyzed more rapidly under acidic than alkaline conditions (137). These observations have a direct bearing on chlorsulfuron persistence in soil (see below) and in the spray tank. According to the registration labels if chlorsulfuron, metsulfuron, or DPX-M6316 is left in the spray tank for more than 24 h, it may be inactivated by aqueous hydrolysis. Registration labels permit mixtures of these herbicides with liquid fertilizers having a pH greater than 3.0.

Chlorsulfuron photodecomposed with a half-life of 2 to 4 weeks in aqueous solution under artificial light (19). Although chlorsulfuron was stable on glass, it photodecomposed on dry soil or plant material with a half-life of 6 to 8 weeks. The photodecomposition products were identified after irradiation with a high-pressure mercury lamp (Figure 2) (144). The half-life for photodecomposition in distilled water was greater than in 'creek' water, 186 and 31 h, respectively. It was suggested that humic substances in creek water interacted with light and oxygen in the water to form singlet oxygen, hydroxy radicals, and alkoxyradicals which catalyzed herbicide degradation. Half-lives for photodegradation on silica and montmorillonite clay were 136 h and 115 h, respectively (144).

Chlorsulfuron hydrolyzes when stored in methanol, ethanol, acetone, or *N,N*-dimethylformamide (19). Chlorsulfuron was stable for at least 1 month when stored in darkness in either dichloromethane or anhydrous tetrahydrofuran.

Chemical assays, immunoassays, and bioassays for quantifying sulfonylurea residues have been summarized briefly (46). Extraction schemes and purification of chlorsulfuron by high-pressure liquid chromatography have been described for analytical grade herbicide (346), plant material (44, 326), and soil (388). Extraction and purification procedures for sulfometuron and chlorsulfuron from soil and plant material were similar (389, 390). Thin-layer

Table 4. Broadleaf weeds controlled or suppressed by sulfonylurea herbicides.

Weed		Rate	State	References
Common name	Scientific name	(g/ha)		
	Chlorsulfuron			
Annual polemonium	*Polemonium micranthum* Benth. # PMNMI	9 - 18	ID/WA	(120)
Blue mustard	*Chorispora tenella* (Pallas) DC. # COBTE	4 - 35	MT	(339)
		9	UT	(106)
		14	WA	(367)
Bur buttercup	*Ranunculus testiculatus* Crantz # CCFTE	170 - 500	UT	(60)
		9	UT	(106)
Catchweed bedstraw	*Galium aparine* L. # GALAP	2 - 5	ID	(305)
		19	ID	(308)
		9 - 18	ID	(311)
		18	ID	(314)
Chamomile	*Matricaria* spp.	18	ID	(200)
Coast fiddleneck	*Amsinckia intermedia* Fisch. Mey. # AMSIN	17 - 35	CA	(258)
		9 - 18	ID/WA	(120)
		9 - 18	ID	(311)
Common chickweed	*Stellaria media* (L.) Vill. # STEME	17 - 35	CA	(258)
		9 - 18	ID/WA	(120)
		10	VA	(116)
		9 - 18	VA	(117)
Common groundsel	*Senecio vulgaris* L. # SENVU	17 - 35	CA	(258)
Common lambsquarters	*Chenopodium album* L. # CHEAL	2 - 5	ID	(305)
		9 - 18	ID/WA	(120)
		9 - 18	ID	(309)
		14	ID	(199)
		9	ID	(202)
		9 - 35	KS	(174)
		11	MN	(29)
		22	MN	(35, 37)
		9	MN	(25)
		17 - 35	ND	(214, 215)
		8 - 47	WY	(150)
Common purslane	*Portulaca oleracea* L. # POROL	9 - 35	KS	(174)
Common ragweed	*Ambrosia artemisiifolia* L. # AMBEL	9	MN	(25)
Common speedwell	*Veronica officinalis* L. # VEROF	18	ID	(314)
Common tansy	*Tanacetum vulgate* L. # CHYVU	22 - 56	ID	(288)
		70	WY	(109)
Corn cockle	*Agrostemma githago* L. # AGOGI	9	ID	(353)
Corn chamomile	*Anthemis arvensis* L. # ANTCO	10	VA	(132)
Cornflower	*Centaurea cyanus* L. # CENCY	10	VA	(116)
Corn gromwell	*Lithospermum arvense* L. # LITAR	18	ID	(314)
		35	MT	(339)
Corn spurry	*Spergula arvense* L. # SPRAR	17 - 35	CA	(258)
		9 - 18	PEI^a	(154)
Cowcockle	*Vaccaria pyramidata* Medik. # VAAPY	5	Canada	(152)
Curly dock	*Rumex crispus* L. # RUMCR	36	AR	(164)
Cutleaf eveningprimrose	*Oenothera laciniata* Hill. # OEOLA	9	OK	(168)
False chamomile	*Matricaria maritima* L. # MATMA	30	ND	(145)
Fiddleneck	*Amsinckia* spp.	6 - 18	ID	(307)
		18	ID	(308)
		9 - 18	ID	(309)
Field pennycress	*Thlaspi arvense* L. # THLAR	7 - 14	ID	(229)
		14 - 56	ID	(300)
		9 - 35	ID	(237)
		2 - 5	ID	(305)
		9 - 18	ID/WA	(120)
		9 - 18	ID	(309)
		9 - 18	ID	(311)
		18	ID	(314)
		18	ID	(200)
		14	ID	(201)
		9	ID	(202)

Table 4. Continued.

Weed		Rate		
Common name	Scientific name	(g/ha)	State	References
Flixweed	*Descurainia sophia* (L.) Webb. ex Prantl # DESSO	35	ID	(319)
		6 - 18	ID	(308)
		9 - 18	ID	(311)
		18	ID	(313)
		14	ID	(201)
		9	OK	(168)
		9	UT	(106)
Forget-me-not	*Myosotis* spp.	9	ID	(230)
Hemp parsley	*Alchemilla* spp.	6 - 18	ID	(308)
		9	ID	(353)
Henbit	*Lamium amplexicaule* L. # LAMAM	2 - 5	ID	(305)
		9	ID	(230)
		6 - 19	ID	(307)
		9 - 18	ID/WA	(120)
		9 - 18	ID	(311)
		18	ID	(314)
		4 - 35	MT	(339)
		9 - 18	OK	(168)
		10	VA	(116)
		9 - 18	VA	(120)
Ivyleaf speedwell	*Veronica hederifolia* L. # VERHE	9 - 18	ID/WA	(120)
		18	ID	(313)
Jagged chickweed	*Holosteum umbellatum* L. # HLOUM	9 - 18	ID/WA	(120)
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	9 - 18	ID	(309)
		67	KS	(330)
		13-26-67	KS	(259, 260, 261)
		34	ND	(126)
		34 - 67	ND	(212)
		34 - 67	ND	(213)
		17 - 35	ND	(214, 215)
Mayweed chamomile	*Anthemis cotula* L. # ANTCO	24 - 140	ID	(229)
		9 - 35	ID	(237)
		9 - 35	ID	(353)
		2 - 5	ID	(305)
		9	ID	(230)
		9 - 18	ID/WA	(120)
		18	ID	(121)
		9 - 18	ID	(309)
		9 - 18	ID	(311)
		18	ID	(313)
		14	ID	(199)
		18	ID	(200, 314)
		9	ID	(202)
		10	VA	(116)
		9 - 18	VA	(117)
Miner's lettuce	*Claytonia perfoliata* Donn ex Willd # CLAPE	9 - 18	ID	(311)
Narrowleaf montia	*Montia linearis* (Dougl.) Green	18	ID	(121)
Nightflowering catchfly	*Silene noctiflora* L. # MELNO	6 - 18	ID	(307)
Pennsylvania smartweed	*Polygonum pensylvanicum* L. # POLPY	22	MN	(35, 37)
		9	MN	(25)
Pinnate tansymustard	*Descurainia pinnata* (Walt.) Britt. # DESPI	4	-	(364)
		20 - 70	ID	(323)
		67	KS	(330)
		17 - 35	KS	(334)
		34 - 67	ND	(213)
		17 - 35	ND	(214, 215)
		4	WY	(219)
Pineappleweed	*Matricaria matricarioides* (Less.) C.L. Porter # MATMT	9	ID	(202)
Popcorn-flower	*Allocarya figurata* Piper # ALMFI	18	ID	(200)

Table 4. Continued.

Weed		Rate	State	References
Common name	Scientific name	(g/ha)		
Prickly lettuce	*Lactuca serriola* L. # LACSE	7 - 14	ID	(229)
		14 - 56	ID	(300)
		6 - 18	ID	(307)
		17 - 70	ID	(188)
		9 - 18	ID	(311)
		18	ID	(313)
		18	ID	(236)
		14	ID	(199)
		9 - 35	KS	(174)
Prostrate knotweed	*Polygonum aviculare* L. # POLAV	9 - 18	ID/WA	(120)
Puncturevine	*Tribulus terrestris* L. # TRBTE	35	CO	(10)
Rapeseed	*Brassica napus* L.	3	Canada	(62)
Redstem filaree	*Erodium cicutarium* (L.) L'Her. ex Ait. # EROCI	17 - 35	CA	(258)
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	35	CO	(10)
		22	MN	(37)
Russian knapweed	*Centaurea repens* L. # CENRE	70 - 140	WY	(156)
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	17 - 70	ID	(188)
		67	KS	(330)
		13-26-67	KS	(259, 260, 261)
		34 - 67	ND	(212, 213)
		17 - 35	ND	(214, 215)
		17 - 70	UT	(386)
		8 - 47	WY	(150)
Scouringrush	*Equisetum hyemale* L. # EQUHY	35 - 140	MN	(112)
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	9	ID	(230)
		9 - 18	ID/WA	(120)
		9 - 18	ID	(311)
		18	ID	(313)
Smallflower collinsia	*Collinsia parviflora* Dougl. # CLCPA	9 - 18	UT	(61)
Smallseed falseflax	*Camelina microcarpa* Andrz. ex DC. # CMAMI	9	UT	(106)
Smooth pigweed	*Amaranthus hybridus* L. # AMACH	9 - 35	KS	(174)
Spikeweed	*Hemizonia pungens* (Hook. and Arn.) T. and G. # HEZPU	53 - 210	OR	(368, 369)
Sunflower	*Helianthus annuus*. L. # HELAN	17 - 35	CO	(11)
		35	CO	(10)
		2 - 9	ND	(249)
		7 - 70	ND	(355)
Tansymustard	*Descurainia* spp.	9 - 18	ID	(309)
Tansy ragwort	*Senecio jacobaea* L. # SENJA	100 - 210	OR	(376)
		53 - 210	OR	(377)
Tarweed fiddleneck	*Amsinckia lycopsoides* (Lehm.) Lehm. # AMSLY	4 - 8	-	(78)
Tumble mustard	*Sisymbrium altissimum* L. # SSYAC	4	-	(78, 364)
		7 - 14	ID	(229)
Tumble pigweed	*Amaranthus albus* L. # AMAAL	4	-	(364)
Velvetleaf	*Abutilon theophrasti* Medik. # ABUTH	22	MN	(23)
Weed beet	*Beta vulgaris* L.	10	ND	(77)
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	11	MN	(29)
		4 - 9	MN	(25)
		34	ND	(126)
		17 - 35	ND	(214, 215)
		9 - 18	OK	(168)
		36	PEI	(154)
Wild carrot	*Daucus carota* L. # DAUCA	20 - 70	ID	(323)
Wild geranium	*Geranium maculatum* L.	10	VA	(116)
Wild mustard	*Sinapis arvensis* L. # SINAR	11	MN	(29)
		22	MN	(35)
		34 - 67	ND	(212)
Willowweed spp.	*Epilobium* spp.	14 - 56	ID	(300)
Yarrow	*Achilles millefolium* L. # ACHMI	80	-	(48)
		17 - 35	CA	(258)
Yellow starthistle	*Centaurea solstitialis* L. # CENSO	140	OR	(370)
Yellow woodsorrel	*Oxalis stricta* L. # OXAST	26 - 35	KS	(174)
	Metsulfuron			
Annual polemonium	*Polemonium micranthum* Benth. # PMNMI	9 - 18	ID/WA	(120)
Bittercress	*Cardamine* sp.	5	-	(364)

Table 4. Continued.

Weed		Rate		
Common name	Scientific name	(g/ha)	State	References
Blue mustard	*Chorispora tenella* (Pallas) DC. # COBTE	5	-	(364)
Broadleaf dock	*Rumex obtusifolius* L. # RUMOB	4 - 8	-	(78)
Bur buttercup	*Ranunculus testiculatus* Crantz # CCFTE	4	UT	(106)
Burning nettle	*Urtica urens* L. # URTUR	4 - 8	-	(78)
Bushy wallflower	*Erysimum repandum* L. # ERYRE	4 - 8	-	(78)
Catchweed bedstraw	*Galium aparine* L. # GALAP	4 - 7	ID	(305)
		6 - 18	ID	(308)
Chervil	*Anthriscus* spp.	4 - 8	-	(78)
Chickweed	*Stellaria* spp.	9 - 18	ID/WA	(120)
Coast fiddleneck	*Amsinckia intermedia* Fisch. and Mey. # AMSIN	9 - 18	ID/WA	(120)
Common chickweed	*Stellaria media* (L.) Vill. # STEME	4	-	(364)
		-	-	(78)
		4 - 8	-	(344)
		9 - 18	VA	(117)
Common groundsel	*Senecio vulgaris* L.# SENVU	4 - 8	-	(78, 344)
Common hempnettle	*Galeopsis tetrahit* L. # GAETE	4 - 8	-	(78, 344)
Common lambsquarters	*Chenopodium album* L. # CHEAL	4 - 7	ID	(314)
		9 - 18	ID/WA	(120)
		22	MN	(23, 35, 37)
		4 - 9	MN	(25)
		17 - 35	ND	(215)
		4 - 9	UT	(105)
		9 - 53	WY	(150)
		4	WY	(219)
Common mallow	*Malva neglecta* Wallr. # MALNE	35	ID	(74)
Common purslane	*Portulaca oleracea* L. # POROL	4	-	(364)
Common tansy	*Tanacetum vulgate* L. # CHYVU	70 - 140	WY	(109)
		22 - 56	ID	(288)
Cone catchfly	*Silene conoida* L. # SILCO	4	-	(364)
Corn chamomile	*Anthemis arvensis* L. # ANTCO	10	VA	(132)
Corn gromwell	*Lithospermum arvense* L. # LITAR	4	-	(78, 364)
Corn marigold	*Chrysanthemum segetum* L. # CHYSE	4 - 8	-	(78)
		6	-	(344)
Corn poppy	*Papaver rhoeas* L. # PAPRH	4 - 8	-	(78)
Corn spurry	*Spergula arvensis* L.	6 - 18	PEI	(155)
Corncockle	*Agrostemma githago* L. # AGOGI	4	-	(364)
Cornflower	*Centaurea cyanus* L. # CENCY	10	VA	(116)
Cowcockle	*Vaccaria pyramidata* Medik. # VAAPY	4	-	(364)
Creeping buttercup	*Ranunculus repens* L. # RANRE	13 - 50	OR	(373)
Dogfennel	*Eupatorium capillifolium* (Lam.) Small # EUPCP	4 - 8	-	(78)
		4	-	(364)
False chamomile	*Matricaria maritima* # MATMA	4	-	(364)
Fiddleneck	*Amsinckia* spp.	18	ID	(308)
		9 - 18	ID	(309)
		4	-	(364)
Field bindweed	*Convolvulus arvensis* L. # CONAR	112	OR	(372)
Field forget-me-not	*Myosotis arvensis* (L.) Hill # MYOAR	4 - 8	-	(78)
		8	-	(344)
Field violet	*Viola arvensis* Murr. # VIOAR	4 - 8	-	(78, 344)
Field pennycress	*Thlaspi arvense* L. # THLAR	4 - 7	ID	(305)
		9 - 18	ID/WA	(120, 309)
		34 - 67	ND	(216)
		4	-	(364)
		4 - 8	-	(78)
Field poppy	*Papaver rhoeas* L. # PAPRH	6	-	(344)
Filaree	*Erodium* sp.	4	-	(364)
Flixweed	*Descurainia sophia* (L.) Webb. ex Prantl # DESSO	6 - 18	ID	(308)
		4	UT	(106)
		4	-	(364)
Forget-me-not	*Myosotis* spp.	9 - 18	ID	(230)
Hairy buttercup	*Ranunculus sardous* Crantz # RANSA	4 - 8	-	(78)
Hemp parsley	*Alchemilla* spp.	6 - 18	ID	(308)

Table 4. Continued.

Weed		Rate		
Common name	Scientific name	(g/ha)	State	References
Henbit	*Lamium amplexicaule* L. # LAMAM	4 - 7	ID	(305)
		9 - 18	ID	(230)
		9 - 18	ID/WA	(120)
		10	VA	(116)
		9 - 18	VA	(117)
		4	-	(364)
		4 - 8	-	(344)
Hoary plantain	*Plantago media* L. # PLAME	4 - 8	-	(78)
Ivyleaf speedwell	*Veronica hederifolia* L. # VERHE	9 - 18	ID/WA	(120)
Jagged chickweed	*Holosteum umbellatum* L. # HLOUM	9 - 18	ID/WA	(120)
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	17 - 35	ND	(215)
		34 - 67	ND	(216)
		2 - 4	ND	(252)
		9 - 53	WY	(150)
Ladysthumb	*Polygonum persicaria* L. # POLPE	4 - 8	-	(78)
Low cudweed	*Gnaphalium uliginosum* L.	6 - 18	PEI	(155)
Mayweed chamomile	*Anthemis cotula* L. # ANTCO	4 - 7	ID	(305)
		9 - 18	ID	(230)
		9 - 18	ID/WA	(120)
		9 - 18	ID	(309)
		18	ID	(198, 199, 313)
		10	VA	(116)
		9 - 18	VA	(117)
		4	-	(78, 364)
Miner's lettuce	*Claytonia perfoliata* Donn ex Willd. # CLAPE	4	-	(364)
Mousearcress	*Arabidopsis thaliana* (L.) Heynh. # ARBTH	4 - 8	-	(78)
Nipplewort	*Lapsana communis* L. # LAPCO	4 - 8	-	(78)
Pale smartweed	*Polygonum lapathifolium* L. # POLLA	4 - 8	-	(78)
Pansy	*Viola tricolor* L. # VIOTR	4 - 8	-	(78)
Parsley	*Caucalis* spp.	4 - 8	-	(78)
Pennsylvania smartweed	*Polygonum pensylvanicum* L. # POLPY	22	MN	(23, 35, 37)
		4 - 9	MN	(25)
Persian speedwell	*Veronica persica* Poir. # VERPE	4 - 8	-	(78, 344)
Pinnate tansy mustard	*Descurainia pinnata* (Walt.) Britt. # DESPI	4 - 8	-	(78)
		17 - 35	KS	(334)
		17 - 35	ND	(215)
		34 - 67	ND	(216)
		4	WY	(219)
		4	-	(364)
Prickly lettuce	*Lactuca serriola* L. # LACSE	4	-	(364)
		4 - 8	-	(78)
Prostrate knotweed	*Polygonum aviculare* L. # POLAV	9 - 18	ID/WA	(120)
		4	-	(363)
		8	-	(344)
Purple deadnettle	*Lamium purpureum* L. # LAMPU	4 - 8	-	(78)
Rapeseed	*Brassica napus* L.	4 - 8	-	(78)
Redroot pigweed	*Amaranthus retroflexus* # AMARE	22	MN	(23, 37)
		4 - 9	UT	(105)
		4	-	(364)
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	17 - 35	KS	(332)
		17 - 35	ND	(215)
		34 - 67	ND	(216)
		9 - 53	WY	(150)
		4	-	(364)
Scarlet pimpernel	*Anagallis arvensis* L. # ANGAR	4 - 8	-	(78)
Shepherdpurse	*Capsella bursa-pastoris* (L.) Medik # CAPBP	9 - 18	ID	(230)
		9 - 18	ID/WA	(120)
		4 - 8	-	(78)
		6 - 18	PEI	(155)
Silverweed cinquefoil	*Potentilla anserina* L. # PTLAN	4 - 8	-	(78)
Slimleaf lambsquarters	*Chenopodium leptophyllum* (Moq.) Nutt. ex S. Wats # CHELE	4	-	(364)
Smallseed falseflax	*Camelina microcarpa* Andrz. ex DC. # CMAMI	4	-	(364)

Table 4. Continued.

Weed		Rate		
Common name	Scientific name	(g/ha)	State	References
Smooth pigweed	*Amaranthus hybridus* L. # AMACH	4	-	(364)
Sowthistle	*Sonchus* spp.	4	-	(364)
Speedwell	*Veronica* spp.	40	VA	(116)
Spikeweed	*Hemizonia pungens* (Hook. and Arn.) T. and G. # HEZPU	53 - 210	OR	(369)
Sunflower	*Helianthus annuus* L. # HELAN	2 - 4	ND	(249)
		4	-	(364)
Tansymustard	*Descurainia* spp.	9 - 18	ID	(309)
Tansy ragwort	*Senecio jacobaea* L. # SENJA	100 - 210	OR	(376)
		53 - 210	OR	(377)
Tarweed fiddleneck	*Amsinckia lycopsoides* (Lehm.) Lehm. # AMSLY	4 - 8	-	(78)
Tumble mustard	*Sisymbrium altissimum* L. # SSYAL	4	-	(78, 364)
Tumble pigweed	*Amaranthus albus* L. # AMAAL	4	-	(364)
Velvetleaf	*Abutilon theophrasti* Medik. # ABUTH	22	MN	(23)
Venus-comb	*Scandix pecten-veneris* L. # SCAPV	4 - 8	-	(78)
Waterpod	*Ellisia nyctelea* L. # ELSNY	4	-	(364)
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	4 - 7	ID	(364)
		9 - 18	ID	(309)
		22	MN	(23)
		4 - 9	MN	(25)
		17 - 35	ND	(215)
		4	-	(364)
		4 - 8	-	(78)
Wild geranium	*Geranium maculatum* L.	10	VA	(116)
Wild mustard	*Sinapis arvensis* L. # SINAR	22	MN	(23, 35)
		2 - 4	ND	(249)
		4	-	(364)
		4 - 8	-	(78)
Wild radish	*Raphanus raphanistrum* L. # RAPRA	4 - 8	-	(78)
	DPX-M6316			
Blue mustard	*Chorispora tenella* (Pallas) DC. # COBTE	36	WA	(367)
California hedge-parsley	*Torilis* spp.	9	ID	(315)
Catchweed bedstraw	*Galium aparine* L. # GALAP	9	ID	(315)
		9 - 35	ID	(393)
		60	-	(325)
Coast fiddleneck	*Amsinckia intermedia* Fisch. and Mey. # AMSIN	18 - 35	ID	(347)
Common chickweed	*Stellaria media* L. # STEME	45 - 60	-	(325)
Common lambsquarters	*Chenopodium album* L. # CHEAL	18	ID	(198)
		9 - 35	ID	(393)
		18	ID	(199)
		9 - 35	MN	(91, 93)
		18	MN	(90)
		34 - 67	WY	(221, 222)
		34 - 67	WY	(220)
		8 - 17	WY	(219)
		17 - 26	WY	(218)
Common sunflower	*Helianthus annuus* L. # HELAN	5 - 15	CO	(15)
Corn poppy	*Papaver rhoeas* L. # PAPRH	60	-	(325)
Corn speedwell	*Veronica arvensis* L. # VERAR	60	-	(325)
Field forget-me-not	*Myositis arvensis* (L.) Hill # MYOAR	60	-	(325)
Field speedwell	*Veronica agrestis* L. # VERAG	60	-	(325)
Field pennycress	*Thlaspi arvense* L. # THLAR	9	ID	(315)
		18 - 35	ID	(347)
		35	ID	(200)
		18	ID	(199, 201)
Flixweed	*Descurainia sophia* (L.) Webb. ex Prantl # DESSO	18	ID	(201, 343)
Henbit	*Lamium amplexicaule* L. # LAMAM	18 - 35	ID	(347)
Ivyleaf speedwell	*Veronica hederifolia* L. # VERHE	18	ID	(343)
		60	-	(335)

Table 4. Continued.

Weed		Rate		
Common name	Scientific name	(g/ha)	State	References
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	8 - 70	ND	(242)
		8 - 35	ND	(249)
		8 - 16	ND	(252)
		67	WY	(222)
		34 - 67	WY	(220, 221)
		17 - 26	WY	(218)
Ladysthumb	*Polygonum persicaria* L. # POLPE	60	-	(325)
Mayweed chamomile	*Anthemis cotula* L. # ANTCO	18	ID	(198, 199, 313)
Parsley-piert	*Alchemilla arvensis* (L.) Scop. # APHAR	60	-	(325)
Pennsylvania smartweed	*Polygonum pensylvanicum* L. # POLPY	9 - 35	MN	(91, 93)
		4 - 16	IL	(162)
Prickly lettuce	*Lactuca serriola* L. # LACSE	18	ID	(313)
		9	ID	(315)
Prostrate knotweed	*Polygonum aviculare* L. # POLAV	45	-	(325)
Purple deadnettle	*Lamium purpureum* L. # LAMPU	60	-	(325)
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	18	MN	(90)
		9 - 34	MN	(91)
		8 - 70	ND	(242)
		4 - 16	IL	(162)
		34 - 67	WY	(220, 221, 222)
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	18	ID	(198, 343)
		60	-	(325)
Sunflower	*Helianthus annuus* L. # HELAN	8 - 35	ND	(249)
Tansymustard	*Descurainia* spp.	9	ID	(315)
		34 - 67	WY	(220, 221)
		4 - 67	WY	(222)
		8 - 17	WY	(219)
Tumble mustard	*Sisymbrium altissimum* L. # SSYAL	18 - 35	ID	(347)
Velvetleaf	*Abutilon theophrasti* Medik. # ABUTH	4 - 16	IL	(162)
		9 - 35	MN	(91, 93)
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	18	ID	(198)
		18	MN	(90)
		9 - 34	MN	(91)
		34 - 67	WY	(220, 221, 222)
Wild chamomile	*Matricaria chamomilla* L. # MATCH	60	-	(325)
Wild garlic	*Allium vineale* L. # ALLVI	8 - 35	TN	(268)
Wild mustard	*Sinapis arvensis* L. # SINAR	9 - 35	MN	(91)
		18	MN	(90)
		8 - 70	ND	(242)
		8 - 35	ND	(249)
		60	-	(325)
	DPX-L5300			
Black knapweed	*Centaurea nigra* L. # CENNI	10 - 20	-	(108)
Black mustard	*Brassica nigra* (L.) W.J.D. Koch # BRSNI	10 - 20	-	(108)
Bushy wallflower	*Erysimum repandum* L. # ERYRE	10 - 20	-	(108)
Catfly species	*Silene* spp.	8 - 10	-	(240)
Chamomile species	*Anthemis* spp.	8 - 10	-	(240)
Catchweed bedstraw	*Galium aparine* L. # GALAP	9 - 35	ID	(393)
Coast fiddleneck	*Amsinckia intermedia* Fisch. and May. # AMSIN	18 - 32	ID	(347)
		10 - 20	-	(108)
Common chickweed	*Stellaria media* (L.) Vill. # STEME	5 - 10	-	(108)
		10 - 20	-	(108)
Common hempnettle	*Galeopsis tetrahit* L. # GAETE	10 - 20	-	(108)
Common lambsquarters	*Chenopodium album* L. # CHEAL	35 - 70	CA	(228)
		9 - 35	ID	(393)
		18	MN	(90)
		9 - 35	MN	(91)
		17 - 34	WY	(218)
		4 - 17	WY	(219)
		10	-	(240)
		10 - 20	-	(108)
Corn buttercup	*Ranunculus arvensis* L. # RANAR	5 - 10	-	(240)
Corn cockle	*Agrostemma githago* L. # AGOGI	10 - 20	-	(108)

Table 4. Continued.

Weed		Rate	State	References
Common name	Scientific name	(g/ha)		
Corn gromwell	*Lithospermum arvense* L. # LITAR	10 - 20	-	(108)
Corn poppy	*Papaver rhoeas* L. # PAPRH	5 - 10	-	(240)
		10 - 20	-	(108)
Corn spurry	*Spergula arvensis* L. # SPRAR	10 - 20	-	(108)
Cutleaf geranium	*Geranium dissectum* L. # GERDI	5 - 10	-	(240)
Dogfennel	*Eupatorium capillifolium* (Lam.) Small # EUPCP	10 - 20	-	(108)
Erect knotweed	*Polygonum erectum* L. # POLER	10 - 20	-	(108)
Field pennycress	*Thlaspi arvense* L. # THLAR	18 - 32	ID	(347)
		5 - 10	-	(240)
Field violet	*Viola arvensis* Murr. # VIOAR	5 - 10	-	(240)
		10 - 20	-	(108)
Flixweed	*Descurania sophia* (L.) Webb. ex Prantl # DESSO	10 - 20	-	(108)
Fumitory	*Fumaria officinalis* L. # FUMOF	19	-	(240)
Hairy bittercress	*Cardamine hirsuta* L. # CARHI	5 - 10	-	(240)
Hairy buttercup	*Ranunculus sardous* Crantz # RANSA	5 - 10	-	(240)
Henbit	*Lamium amplexicaule* L. # LAMAM	18 - 32	ID	(347)
		10	-	(240)
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	10 - 20	-	(108)
		35 - 70	CA	(228)
		35	ND	(249)
		17 - 34	WY	(218)
		10 - 20	-	(108)
Ladysthumb	*Polygonum persicaria* L. # POLPE	10 - 20	-	(108)
London rocket	*Sisymbrium irio* L. # SSYIR	10 - 20	-	(108)
Mayweed chamomile	*Anthemis cotula* L. # ANTCO	10 - 20	-	(108)
Pansy	*Viola tricolor* L. # VIOTR	10	-	(240)
		10 - 20	-	(108)
Persian speedwell	*Veronica persica* Poir. # VERPE	10 - 20	-	(108)
Pinnate tansymustard	*Descurainia pinnata* (Walt.) # DESPI	4 - 17	WY	(219)
Prickly lettuce	*Lactuca serriola* L. # LACSE	10 - 20	-	(108)
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	18	MN	(90)
		9 - 34	MN	(91)
		10 - 20	-	(108)
Sand catchfly	*Silene conica* L. # SILCN	10 - 20	-	(108)
Scarlet pimpernel	*Anagallis arvensis* L. # ANGAR	10	-	(240)
Scentless chamomile	*Matricaria perforata* Merat # MATIN	10 - 20	-	(108)
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	5 - 10	-	(240)
		10 - 20	-	(108)
Spiny saltwort	*Salsola kali* L. # SASKA	10 - 20	-	(108)
Sunflower	*Helianthus annuus* L. # HELAN	8 - 35	ND	(249)
		10 - 20	-	(108)
Tarweed fiddleneck	*Amsinckia lycopsoides* (Lehm.) Lehm. # AMSLY	10 - 20	-	(108)
Tumble mustard	*Sisymbrium altissimum* L. # SSYAL	18 - 32	ID	(347)
		10 - 20	-	(108)
Turnipweed	*Raphistrum rugosum* (L.) All. # RASRU	5 - 10	-	(240)
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	18	MN	(90)
		9 - 34	MN	(91)
		10 - 20	-	(108)
Wild chamomile	*Matricaria chamomilla* L. # MATCH	5 - 10	-	(240)
Wild mustard	*Sinapis arvensis* L. # SINAR	18	MN	(90)
		9 - 34	MN	(91)
		8 - 35	ND	(249)
		42	ND	(250)
		5 - 10	-	(240)
		10 - 20	-	(108)
Wild radish	*Raphanus raphanistrum* L. # RAPRA	10 - 20	-	(108)
Woodsorrel species	*Oxalis* spp.	10 - 20	-	(108)
		CGA 131,036		
Catchweed bedstraw	*Galium aparine* L. # GALAP	15 - 20	-	(9)
Chamomile species	*Matricaria* spp.	10 - 20	-	(9)

Table 4. Continued.

Weed		Rate	State	References
Common name	Scientific name	(g/ha)		
Common chickweed	*Stellaria media* (L.) Vill. # STEME	10 - 20	-	(9)
Common hempnettle	*Galeopsis tetrahit* L. # GAETE	10 - 20	-	(9)
Cutleaf eveningprimrose	*Oenothera laciniata* Hill # OEOLA	9	OK	(168)
Field forget-me-not	*Myosotis arvensis* (L.) Hill # MYOAR	10 - 20	-	(9)
Flixweed	*Descurainia sophia* (L.) Webb. ex Prantl # DESSO	9	OK	(168)
Henbit	*Lamium amplexicaule* L. # LAMAM	15 - 20	-	(9)
Manyseeded goosefoot	*Chenopodium polyspermum* L. # CHEPO	10 - 20	-	(9)
Mouseearcress	*Arabidopsis thaliana* (L.) Heynh. # ARBTH	10 - 20	-	(9)
Pansy	*Viola tricolor* L. # VIOTR	10 - 20	-	(9)
Parsley-piert	*Alchemilla arvensis* (L.) Scop. # APHAR	10 - 20	-	(9)
Poppy species	*Papaver* spp.	10 - 20	-	(9)
Purple deadnettle	*Lamium purpureum* L. # LAMPU	15 - 20	-	(9)
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	10 - 20	-	(9)
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	10 - 20	-	(9)
		9 - 18	OK	(168)
Wild mustard	*Sinapis arvensis* L. # SINAR	10 - 20	-	(9)

[a] PEI = Prince Edward Island, Canada.

chromatography also can be used to purify this compound (19, 276) and separate it from soil metabolites (256, 327). An enzyme immunoassay with a sensitivity of 1.2 ppb was developed for quantifying chlorsulfuron in soil (163). Keto-enol tautomerism of chlorsulfuron (1, 287) may influence the pH dependence of herbicide liquid-liquid partitioning of this and other sulfonylurea herbicides, influencing extraction recoveries (287).

Bioassays or liquid scintillation spectroscopy of ^{14}C-chlorsulfuron have been used to quantify the herbicide, especially in studies of persistence in soil. A corn (*Zea mays* L.) root length bioassay is used commonly to quantify chlorsulfuron residues in soil (148). Although 0.125 ppb chlorsulfuron could be detected with this bioassay in three Saskatchewan soils, variability has high and depended on corn variety and soil type. Hsiao and Smith (148) also reported a detection limit of 0.1 ppb for three Saskatchewan soils using corn. Others have reported nonlinear dose-response relations for the corn bioassay with either high (95) or low coefficients of determination (r^2 values) (274), or bioassay insensitivity in alkaline soils (89). Sensitive, linear, reproducible bioassays for chlorsulfuron residues in soil were obtained by bioassaying $Ca(OH)_2$ extracts of chlorsulfuron-treated soil (238). Other species used as bioassay plants include: green foxtail [*Setaria viridis* (L.) Beauv. # SETVI], foxtail millet [*Setaria italica* (L.) Beauv. # SETIT)] (89), sorghum [*Sorghum bicolor* (L.) Moench], 'Culbert' flax (*Linum usitatissimum* L.) (273), and lettuce (*Lactuca sativa* L.) (362). Crop species make better choices as bioassay plants than weeds because uniform, nondormant, and genetically defined seed are available.

II. WEED CONTROL

Weeds controlled in cereals. Chlorsulfuron, metsulfuron, or DPX-M6316 control or suppress numerous broadleaf weeds and some grasses in winter, spring, and durum wheat (Tables 3 and 4). "Suppressed" weeds are severely stunted but not killed. Generally, treated weeds die slowly, within 1 to 3 weeks of treatment. Chlorsulfuron and metsulfuron are effective for season-long suppression of Canada thistle [*Cirsium arvense* (L.) Scop. # CIRAR]. However, a single treatment is insufficient to eradicate this weed's perennial root system (398). These herbicides control many of the same broadleaf weeds as do phenoxy herbicides. In addition, these sulfonylurea herbicides control or suppress some grass weeds (Table 5). The registered postemergence application rates for chlorsulfuron, metsulfuron, and DPX-M6316 are lower and narrower than those for other broadleaf herbicides used in cereals and they can be applied over a longer period of crop growth than can other broadleaf herbicides (Table 2). Chlorsulfuron and metsulfuron also have limited preemergence activity and extended soil residual weed control, unlike DPX-M6316 and phenoxy herbicides.

Use of chlorsulfuron or metsulfuron above registered rates can enhance and prolong weed

Table 5. Grass weeds controlled or suppressed by sulfonylurea herbicides.

Weed		Rate		
Common name	Scientific name	(g/ha)	State	References
		Chlorsulfuron		
Alkaligrass	*Puccinellia distans* L.	26 - 158	NV	(69)
Annual bluegrass	*Poa annua* L. # POAAN	18 - 280	IA	(123)
Foxtails	*Setaria* spp.	11 - 22	MN	(21, 23, 29, 38, 42)
		34	MN	(342)
		22	MN	(35)
		4 - 8	MN	(33, 37)
		34 - 67	ND	(212, 213)
		17 - 35	ND	(214, 215)
		9 - 18	ND	(248)
		9 - 35	ND	(359)
		34 - 67	ND	(226)
		9 - 70	ND	(355)
Italian ryegrass	*Lolium multiflorum* Lam # LOLMU	35 - 140	-	(51)
		26	OK	(168)
Perennial ryegrass	*Lolium perenne* L.	141 - 282	-	(191, 192)
Slender foxtail	*Alopecurus myosuroides* Huds. # ALOMY	31 - 62	-	(176)
Sterile brome	*Bromus sterilis* L. # BROST	20	-	(54)
Tall fescue	*Festuca arundinacea* Schreb. # FESAR	282	IO	(170)
		141 - 282	-	(192)
		26 - 158	NV	(69)
Wild garlic	*Allium vineale* L. # ALLVI	36	AR	(165)
		9 - 53	IL	(161)
		10 - 20	IL	(178, 179, 180)
		40	MO	(272)
		20	MO	(270)
		100 - 200	MO	(271)
Yellow foxtail	*Setaria glauca* (L.) Beauv. # SETLU	18	ND	(245)
		Metsulfuron		
Downy brome	*Bromus tectorum* L. # BROTE	18 - 35	KS	(337)
Foxtails	*Setaria* spp.	22	MN	(35)
		9 - 18	ND	(248)
		17 - 35	ND	(215, 216)
Wild garlic	*Allium vineale* L. # ALLVI	10 - 20	IL	(178)
		5 - 20	IL	(180)
		20	MO	(270)
		50 - 200	MO	(271)
		DPX-M6316		
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv. # ECHCG	4 - 16	IL	(162)
Foxtails	*Setaria* spp.	35	ND	(242)
Giant foxtail	*Setaria faberi* Herrm. # SETFA	4 - 16	IL	(162)
Wild garlic	*Allium vineale* . # ALLVI	9 - 70	IL	(122)
Yellow nutsedge	*Cyperus esculentus* L. # CYPES	4 - 16	IL	(162)
	Apera spica-venti	60	-	(9)
		CGA 131036		
Italian ryegrass	*Lolium multiflorum* Lam. # LOLMU	53	OK	(168)

control, but residues may damage rotational crops. Consequently, these herbicides are marketed only in certain regions of the United States and Canada, with registration label restrictions on which crops may be planted after application, replanting interval, and which soils can be treated on the basis of soil pH. "Finesse" is the duPont tradename for a commercial mixture of chlorsulfuron and metsulfuron which is marketed in the Pacific Northwest (Table 2). DPX-L5300 and DPX-M6316 are analogs of chlorsulfuron which control some of the same weeds as chlorsulfuron does in wheat (Tables 3 and 4). Reportedly, the latter two analogs degrade much faster than does chlorsulfuron so that the choice of rotational crop is not restricted (108). The spectrum of weeds controlled or suppressed by DPX-L5300 complements that of DPX-M6316 and includes Canada thistle.

The registration labels state that chlorsulfu-

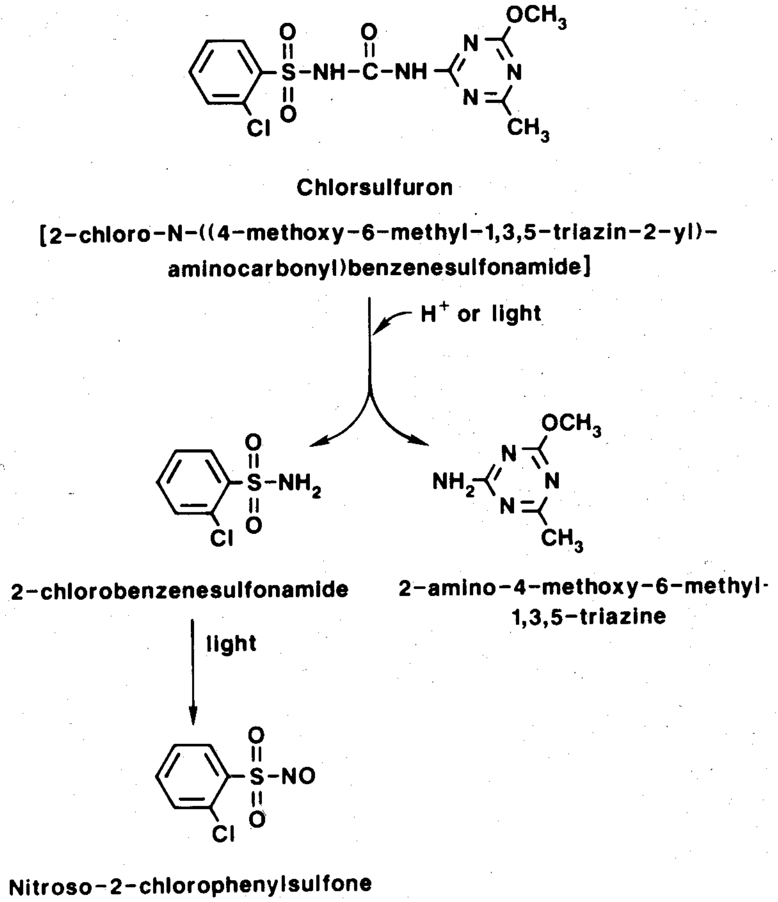

Figure 2. Photochemical and chemical hydrolysis products of chlorsulfuron (144).

ron and metsulfuron differ somewhat in their weed control spectrum (Table 3). Also, weeds listed on the chlorsulfuron label for Canada and the United States are not the same because regional weed problems differ (Table 3). Other weeds not listed on the label may be controlled or suppressed by these herbicides under certain conditions (Table 4 and 5).

Fewer grass species are controlled or suppressed by sulfonylurea herbicides than are broadleaf weeds (Table 5). Often, grass weeds were more sensitive to preemergence chlorsulfuron at 8 to 32 g ai/ha than to postemergence application (57). Foxtails (*Setaria* spp.) in spring wheat and wild garlic (*Allium vineale* L. # ALLVI) and Italian ryegrass (*Lolium multiflorum* Lam. # LOLMU) in winter wheat are suppressed and controlled, respectively, by both chlorsulfuron and metsulfuron (Table 5). Metsulfuron at 5 to 20 g ai/ha and chlorsulfuron at 20 g ai/ha effectively controlled wild garlic in winter wheat and reduced aerial bulblet production when applied in early spring (161), but only metsulfuron was effective in fall in Illinois (180). Lower rates of metsulfuron (5 g ai/ha) than chlorsulfuron (15 g ai/ha) reduced aerial and underground bulb formation. Chlorsulfuron at rates of 30 g ai/ha or higher are now considered excessive, although much higher rates were tested early during herbicide development before the potency of low rates of sulfonylurea herbicides was recognized. Chlorsulfuron at labeled rates controls or suppresses foxtail species and wheat yields may be enhanced compared to weedy controls. Nevertheless, these sulfonylurea herbicides do not control most grasses (Table 6). In the United Kingdom, preemergence-applied mixtures of chlorsulfuron plus metsulfuron at 15 plus 5 g ai/ha controlled slender foxtail (*Alopecurus myosuroides* Hud. # ALOMY) better than either herbicide alone (320). Sulfonylurea herbicides may suppress certain grass weeds by stunting plants and thus reducing weed competitiveness rather than by increasing mortality, as was demonstrated for chlorsulfuron-treated sterile brome (*Bromus*

Table 6. Weeds tolerant to sulfonylurea herbicides.

Weed		References
Common name	Scientific name	
	Chlorsulfuron	
Black nightshade	*Solanum nigrum* L. # SOLNI	(23, 253, 274, 279)
Buffalobur	*Solanum rostratum* Dun. # SOLCU	(67)
Bulbous bluegrass	*Poa bulbosa* L. # POABU	(160, 299)
Cheat	*Bromus secalinus* L. # BROSE	(67, 393)
Common crupina	*Crupina vulgaris* Cass. # CJNVU	(391, 392)
Common speedwell	*Veronica officinalis* L. # VEROF	(117)
Creeping bentgrass	*Agrostis stolonifera* L. # AGSST	(123)
Cutleaf nightshade	*Solanum triflorum* Nutt. # SOLTR	(149, 266)
Diffuse knapweed	*Centaurea diffusa* Lam. # CENDI	(324)
Downy brome	*Bromus tectorum* L. # BROTE	(67, 331, 373)
Eastern black nightshade	*Solanum ptycanthum* Dun. # SOLPT	(301)
Erect knotweed	*Polygonum erectum* L. # POLER	(301)
Field bindweed	*Convolvulus arvensis* L. # CONAR	(67)
Groundcherry	*Physalis* spp.	(67)
Hairy nightshade	*Solanum sarrachoides* Sendtner # SOLSA	(220, 309)
Horsenettle	*Solanum carolinense* L. # SOLCA	(67, 217, 279)
Ivyleaf speedwell	*Veronica hederifolia* L. # VERHE	(110, 300, 301)
Jointed goatgrass	*Aegilops cylindrica* Host # AEGCY	(67)
Knapweed	*Centaurea* spp.	(67)
Kentucky bluegrass	*Poa pratensis* L. # POAPR	(123, 170)
Leafy surge	*Euphorbia esula* L. # EPHES	(111, 210)
Little barley	*Hordeum pusillum* Nutt. # HORPU	(330)
Musk thistle	*Carduus nutans* L. # CRUNU	(263)
Cutleaf nightshade	*Solanum triflorum* Nutt. # SOLTR	(149)
Nightshade	*Solanum* spp.	(67)
Prostrate spurge	*Euphorbia humistrata* Engelm. ex Gray # EPHHT	(168)
Ripgut brome	*Bromus diandrus* Roth # BRODI	(318)
Shattercane	*Sorghum bicolor* (L.) Moench # SORVU	(193)
Sheep sorrel	*Rumex acetosella* L. # RUMAC	(154)
Skeletonweed	*Lygodesmia juncea* (Pursh) D. Don # LYGJU	(67)
Swamp smartweed	*Polygonum coccineum* Muhl. ex Willd. # POLCC	(112)
Tumblegrass	*Schedonnardus paniculatus* (Nutt.) Trel. # SCEPA	(330)
Wild oat	*Avena fatua* L. # AVEFA	(26, 212, 226, 258, 266)
Witchgrass	*Panicum capillare* L. # PANCA	(330, 386)
Woolly croton	*Croton capitatus* Michx. # CVNCP	(168)
	Metsulfuron	
Cleavers	*Galium aparine* L. # GALAP	(344)
Common speedwell	*Veronica officinalis* L. # VEROF	(117)
Fumitory	*Fumaria officinalis* L. # FUMOF	(344)
Ivyleaf speedwell	*Veronica hederifolia* L. # VERHE	(320)
Musk thistle	*Carduus nutans* L. # CRUNU	(263)
Leafy spurge	*Euphorbia esula* L. # EPHES	(111, 190)
Spikeweed	*Hemizonia pungens* (Hook. and Arn.) T. G. # HEZPU	(368)
Field bindweed	*Convolvulus arvensis* L. # CONAR	(113, 305)
Rush skeletonweed	*Chondrilla juncea* L. # CHOJU	(374)
St. Johnswort	*Hypericum* sp.	(375)
Yellow starthistle	*Centaurea solstitialis* L. # CENSO	(370)
	DPX-M6316	
Corn speedwell	*Veronica arvensis* L. # VERAR	(325)
Cutleaf nightshade	*Solanum triflorum* Nutt. # SOLTR	(15)
Foxtail	*Setaria* spp.	(90)
Fumitory	*Fumaria officinalis* L. # FUMOF	(325)
Hairy nightshade	*Solanum sarrachoides* Sendtner # SOLSA	(222)
Henbit	*Lamium amplexicaule* L. # LAMAM	(325)
Honeyvine milkweed	*Ampelamus albidus* (Nutt.) Britt. # AMPAL	(162)
Persian speedwell	*Veronica persica* Poir. # VERPE	(325)

Table 6. Continued.

Weed		
Common name	Scientific name	References
Popcorn flower	*Allocarya figurata* Piper # ALMFI	(200)
Prostrate knotweed	*Polygonum aviculare* L. # POLAV	(325)
Purple deadnettle	*Lamium purpureum* L. # LAMPU	(325)
Violet	*Viola* spp.	(325)
Wild radish	*Raphanus raphanistrum* L. # RAPRA	(325)
	CGA 131,036	
Common lambsquarters	*Chenopodium album* L. # CHEAL	(9)
Ivyleaf speedwell	*Veronica hederifolia* L. # VERHE	(9)
Persian speedwell	*Veronica persica* Poir. # VERPE	(9)
Prostrate knotweed	*Polygonum aviculare* # POLAV	(9)
Prostrate spurge	*Euphorbia humistrata* Engelm. ex Gray # EUHHT	(168)
Woolly croton	*Croton capitatus* Michx. # CVNCP	(168)
	DPX-L5300	
Annual bluegrass	*Poa annua* L. # POAAN	(108)
Bulbous bluegrass	*Poa bulbosa* L. # POABU	(108)
Catchweed bedstraw	*Galium aparine* L. # GALAP	(108)
Cheat	*Bromus secalinus* L. # BROSE	(108)
Corn speedwell	*Veronica arvensis* L. # VERAR	(108)
Downy brome	*Bromus tectorum* L. # BROTE	(108)
Field bindweed	*Convolvulus arvensis* L. # CONAR	(108)
Green foxtail	*Setaria viridis* (L.) Beauv. # SETVI	(108)
Ivyleaf speedwell	*Veronica hederafolia* L. # VERHE	(108)
Mouseearcress	*Arabidopsis thaliana* (L.) Heynh. # ARBTH	(108)
Ripgut brome	*Bromus rigidus* Roth. sensu. Am. auctt. # BRODI	(108)
Rye	*Secale cereale* L.	(108)
Ryegrass species	*Lolium* spp.	(108)
Slenderleaf foxtail	*Alopecurus myosuroides* Huds. # ALOMY	(108)
Wild garlic	*Allium vineale* L. # ALLVI	(108)
Wild oat	*Avena fatua* L. # AVEFA	(108)

sterilis L. # BROST) in winter wheat in England (54).

Some broadleaf weeds, including nightshades (*Solanum* spp.), rush skeletonweed (*Chondrilla juncea* L. # CHOJU), and field bindweed (*Convolvulus arvensis* L. # CONAR) tolerate sulfonylurea herbicides (Table 6). Not all nightshades respond alike to chlorsulfuron (279). In greenhouse trials, hairy nightshade (*Solanum sarrachoides* Sendtner # SOLSA) was more tolerant of chlorsulfuron than black nightshade (*S. nigum* L. # SOLNI) which, in turn, was more tolerant than either American black nightshade (*S. americanum* Mill. # SOLAM) or eastern black nightshade (*S. ptycanthum* Dun. # SOLPT).

Repeated use of sulfonylurea herbicides over several years in continuous wheat and wheat-fallow systems encourages increased numbers and densities of tolerant weeds and resistant weed biotypes. Resistance is the decreased response of a local population of a normally susceptible weed to a herbicide following repeated herbicide treatment, whereas tolerance or nonsusceptibility is a natural characteristic of a weed species that may never have been treated.

Chlorsulfuron- and metsulfuron-resistant weed biotypes have not been documented yet in the scientific literature although the manufacturer acknowledges that resistance has developed in isolated areas. It is probably best to rotate sulfonylurea herbicides with other herbicides to retard or prevent the buildup of resistant or tolerant weed populations and to mitigate the chance of herbicide carry-over damage to rotational crops.

Despite the lack of information on development of sulfonylurea-resistant weeds in the field, limited greenhouse and laboratory information is available on cross resistance of sulfonylurea resistant weed biotypes to other structural classes of herbicides. Cross-resistance of chlorsulfuron-resistant cell suspensions of sacred datura

(*Datura innoxia* Mill. # DATIN) to the imidazolinone class of herbicides was expected because sulfonylurea and imidazolinone herbicides both inhibited acetolactate synthase and are believed to have the same mode of action (304). However, some chlorsulfuron-resistant lines of sacred datura were susceptible to imidazoline herbicides, suggesting that the two groups of herbicides became bound to different sites on the acetolactate synthase molecule (304).

Chlorsulfuron-susceptible and -resistant biotypes of Wimmera ryegrass (*Lolium rigidum* Gaud.), which exhibited different dose-response curves for coleoptile length and shoot dry weight in response to chlorsulfuron, also were cross-resistant and cross-susceptible, respectively, to diclofop at various rates (141). Such cross-resistance between different structural classes of herbicides with different modes of action was unexpected. The extent and agronomic significance of such cross-resistance between sulfonylurea herbicides and grass herbicides remains to be determined since relatively few grass species are controlled or suppressed by sulfonylurea herbicides (Table 5).

Despite the potential for carry-over damage to rotational crops, chlorsulfuron and metsulfuron are useful where extended periods of weed control are needed. Fall application of chlorsulfuron in winter wheat controlled several emerged winter annual weeds and annual weeds germinating in the spring. If chlorsulfuron is applied to spring cereals, residual weed control may extend into the following growing season, especially under dry conditions or on alkaline soils (348). Chlorsulfuron applied in fall at 18 to 70 g ai/ha provided excellent control of Russian thistle (*Salsola iberica* Sennen and Pau # SASKR) until July in spring wheat grown in Utah (386). Similar residual control of Russian thistle was observed in July in eastern Washington 10 months after postharvest application of chlorsulfuron at 18 to 26 g ai/ha (387). Postharvest applications of chlorsulfuron in September provided excellent season-long control of Russian thistle in summer fallow in the following year as measured by reduced density and shoot biomass. Perhaps winter rains moved the herbicide into the top of the soil profile thereby providing control of germinating seedlings. In contrast, new seedlings emerged in mid-July following spring application.

Because of their postemergence and residual phytotoxicity, chlorsulfuron and metsulfuron were considered for chemical fallow or reduced-tillage fallow early in their development both in the United States and abroad (8, 278, 348). However, these herbicides are not now registered for chemical fallow use because such use limited rotational crop options, particularly on alkaline soils. The development of resistant weed biotypes following repeated sulfonylurea herbicide application in winter wheat-fallow rotations was also a concern.

Chlorsulfuron controls several phenoxy-tolerant broadleaf weeds, including pale smartweed (*Polygonum lapathifolium* L. # POLLA) (266), common hempnettle (*Galeopsis tetrahit* L. # GAETE) (154, 266), and corn spurry (*Spergula arvensis* L.) (154). Both chlorsulfuron and bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) control wild buckwheat (*Polygonum convolvulus* L. # POLCO) and some other phenoxy-tolerant weeds in spring wheat in the Northern Great Plains. However, chlorsulfuron at high rates (36 g ai/ha) was required to control wild buckwheat in Canada (154).

Combinations of chlorsulfuron and metsulfuron complement each other because of slight differences in their weed control spectrum (78). Metsulfuron at 4 to 8 g ai/ha was more active than chlorsulfuron on violets (*Viola* spp.), smartweeds (*Polygnum* spp.), and Persian speedwell (*Veronica persica* Poir. # VERPE). However, metsulfuron was less active than chlorsulfuron on catchweed bedstraw (*Galium aparine* L. # GALAP). The manufacturer reports that metsulfuron is slightly less persistent in the field than chlorsulfuron, although published information is limited on this point in the scientific literature.

Chlorsulfuron was tested as a preemergence treatment in its early development. When it was soil applied, rainfall activated chlorsulfuron better than did shallow incorporation (269). Lower rates (15 to 35 g ai/ha) of chlorsulfuron were needed to achieve comparable weed control when it was applied postemergence than preemergence (95 to 100 g ai/ha). When chlorsulfuron at 55 g ai/ha was incorporated twice by harrowing as a postplant-incorporated treatment in spring wheat in North Dakota, it controlled yellow foxtail [*Setaria glauca* (L.) Beauv. # SETLU], wild mustard (*Sinapis arvensis* L. # SINAR), redroot pigweed (*Amaranthus retroflexus* L. # AMARE), and kochia [*Kochia scoparia* (L.) Schrad. # KCHSC] (243, 244, 245).

Incorporation may alter the margin of selectivity of chlorsulfuron to cereal crops. Yields of 'Stout' oats (*Avena sativa* L.) were reduced in Minnesota when either chlorsulfuron or metsulfuron was incorporated preemergence at 22 to 33 g ai/ha despite excellent weed control (24). In contrast, preemergence-applied chlorsulfuron provided acceptable weed control and oat yields. Chlorsulfuron is labeled as a preemergence treatment only for winter oats and as a postemergence treatment on spring oats, whereas metsulfuron is not labeled for oats.

Little is published concerning the effect of carrier volume, type of sprayer, or nozzle type on the herbicidal activity of postemergence-applied chlorsulfuron, metsulfuron, or other sulfonylurea herbicides. Most research concerns the influence of spray additives or time of treatment on herbicide efficacy.

Surfactants enhanced the herbicidal activity of sulfonylurea herbicides without changing selectivity (Table 7), but few studies have been published comparing the relative efficacy of various adjuvants. Chow (62) examined the influence of four surfactants on the activity of chlorsulfuron at 2.5 g ai/ha in killing 'Tower' mustard (*Brassica campestis* L.) and 'Jet Neuf' rapeseed (*B. napus* L.). The nonionic surfactants Agral-90, Atplus-411F, Citowett plus, and Renex-36 at 0.5% (v/v) enhanced chlorsulfuron activity at 3 g ai/ha on these species relative to treatment without surfactant. Ammonium sulfate at 0.5% (v/v) had no effect on postemergence activity. Renex-36 at 0.1% (v/v) enhanced foliar penetration of chlorsulfuron by 82% and herbicide translocation to new leaves by 62%. The comparative effects of four additives on the activity of chlorsulfuron at 9 to 35 g ai/ha were examined in field and greenhouse research in North Dakota (358). WK (trimethylnonylpolyethoxyethanol), LOTM (linseed oil plus 5.5 T-MULZ-VO emulsifier), and petroleum oil concentrate enhanced herbicidal activity more than did ethylene glycol. At high chlorsulfuron rates, surfactant did not enhance activity in greenhouse studies. When chlorsulfuron was applied at 2 or 4 g ai/ha, adding WK at 0.5% (v/v) or LOTM at 2.3 L/ha enhanced its herbicidal activity on green foxtail compared

Table 7. The influence of surfactants or other additives on postemergence phytotoxicity of chlorsulfuron.

Weed		Rate	Surfactant			
Common name	Scientific name	(g ai/ha)	Type	Concentration[a]	Effect[b]	Reference
Canada thistle	*Cirsium arvense* (L.) Scop. # CIRAR	41-161	X-77	0.38% (v/v)	0	(97)
		18-35	X-77	0.05-0.5% (v/v)	+	(99)
		18-35	WK	0.5% (v/v)	+	(99)
		67	Oxysorbic	0.2% (v/v)	+	(79)
Common lambsquarters	*Chenopodium album* L. # CHEAL	11	Citowett	0.2% (v/v)	0	(29)
Cowcockle	*Vaccaria pyramidata* Medik. # VAAPY	5	Citowett	0.1 (v/v)	+	(151)
Foxtails	*Setaria* spp.	11-22	Citowett	0.2% (v/v)	+	(21)
			WK	-	+	(381)
		4	WK	0.5% (v/v)	0	(357)
		4	LOTM	2.34 L/ha	0	(357)
		11	Citowett	0.2% (v/v)	+	(38)
		2-4	WK	0.5% (v/v)	+	(38)
		2-4	LOTM	2.36 L/ha	+	(355)
		9-35	Petroleum oil	2.34 L/ha	+	(359)
		9-35	Linseed oil	2.34 L/ha	+	(359)
		9-35	WK	0.25% (v/v)	+	(359)
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	-	WK	0.25% (v/v)	+	(43)
		-	WK	-	+	(381)
Pigweeds	*Amaranthus* spp.	-	WK	0.25% (v/v)	+	(43)
Rapeseed	*Brassica napus* L.	2.5	Agral 90	0.5% (v/v)	+	(62)
		2.5	Atplus 411F	0.5% (v/v)	+	(62)
		2.5	Citowett Plus	0.5% (v/v)	+	(62)
		2.5	Renex-36	0.5% (v/v)	+	(62)
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	18-35	Citowett	0.05-0.5% (v/v)	+	(385)
		4-140	X-77	0.05-0.5% (v/v)	+	(386)
Sunflower	*Helianthus annuus* L. # HELAN	4	WK	0.5% (v/v)	+	(357)
		4	LOTM	2.34 L/ha	0	(357)
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	11	Citowett	0.2% (v/v)	0	(29)
Wild mustard	*Sinapis arvensis* L. # SINAR	11	Citowett	0.2% (v/v)	0	(29)
		4	WK	0.5% (v/v)	0	(357)
		4	LOTM	2.34 L/ha	0	(357)

[a] Expressed on a (v/v) basis.

[b] + = enhances phytotoxicity, 0 = no effect.

to treatment without additives (355). Yet, surfactants did not enhance foxtail control with chlorsulfuron at 9 g ai/ha. Linseed oil and petroleum oil at 2.3 L/ha also enhanced yellow foxtail control with chlorsulfuron at 9 to 35 g/ha (355, 359). Field studies substantiated these greenhouse trials. Added surfactant also enhanced the herbicidal activity of other sulfonylurea herbicides, such as DPX-L5300 at 19 g ai/ha on *Chrysanthemum segetum* L. or fumitory (*Fumaria officinalis* L. # FUMOF) (240).

Adding a surfactant or other additives to chlorsulfuron may improve weed control under environmental stress. Linseed oil and nonionic surfactants (Surfactant WK and Citowett) enhanced chlorsulfuron activity on common lambsquarters (*Chenopodium album* L. # CHEAL) and Russian thistle in low relative humidity environments (269). In the growth chamber, surfactant at 0.5% (v/v) enhanced control of green foxtail and kochia with chlorsulfuron at 4 or 16 g ai/ha more at low humidity (40 to 50%) than at high humidity (95 to 100%) at three air temperatures (10, 20, and 30 C) (251).

Chlorsulfuron and metsulfuron are registered for use in liquid fertilizer. However, there is no published information on the efficacy of this carrier. When liquid fertilizer is used as a carrier, surfactants do not improve efficacy, according to the registration label.

The timing of sulfonylurea treatment is important for successful weed control in both spring- and fall-sown cereals. Weeds are more susceptible to sulfonylurea herbicides at younger growth stages than when they are older. However, weather may restrict the timing of postemergence application. If treatment is delayed too long, spray coverage of weeds may be limited because the crop canopy may intercept the spray. Likewise, if treatment is postponed, weeds may already have inhibited crop growth and reduced potential yield.

Chlorsulfuron's postemergence and residual phytotoxicity may be advantageous for use in no-tillage cereal production systems. In no-till barley in Alaska, control of flixweed [*Decurania sophia* (L.) Webb. ex Prantl # DESSO] and other broadleaf weeds was not influenced by residual straw levels with postemergence chlorsulfuron at 13 g ai/ha (66). In contrast straw reduced the herbicidal activity of postemergence bromoxynil at 0.34 kg ai/ha on the same broadleaf weeds.

Chlorsulfuron treatment may enhance the susceptibility of wheat and barley to some diseases but not to others. In the greenhouse, increasing chlorsulfuron rate between 0.008 and 0.032 μg/g soil increased *Rhizoctonia solani* damage to wheat roots (297). Chlorsulfuron treatment, however, did not enhance damage caused by *Gaeumannomyces graminis* var. *trici*. Neither did chlorsulfuron inhibit this fungi's growth on potato dextrose agar (297).

Canada thistle suppression. Both chlorsulfuron and metsulfuron suppress Canada thistle in cereals. The maximum registered rate is recommended for season-long suppression of Canada thistle in wheat. Two objectives were envisioned in early research on Canada thistle control: immediate control of shoot growth and long-term control of perennial roots in subsequent years. In early research it was not recognized that low rates of chlorsulfuron or metsulfuron would provide season-long control, and that application rates could be reduced significantly by adding surfactant without sacrificing control. Maximum registered use of chlorsulfuron is now 26 g ai/ha. Chlorsulfuron at 18 g ai/ha applied midseason in Wyoming prevented Canada thistle seed production (5). At 36 g ai/ha, chlorsulfuron caused plants to yellow and at 140 to 560 g ai/ha Canada thistle shoots died. Similar results were reported in other states (see below). In Colorado, 71 to 140 g ai/ha chlorsulfuron was needed for effective Canada thistle shoot suppression (394). Chlorsulfuron at low rates of 9 g ai/ha inadequately controlled Canada thistle in barley (*Hordeum vulgare* L.) (309). Chlorsulfuron at 69 to 280 g ai/ha in June controlled 10- to 15-cm-tall Canada thistle in Wyoming (6).

Chlorsulfuron can effectively control Canada thistle shoot growth in wheat at low rates if surfactant is added. In Idaho, Canada thistle was controlled in spring wheat with chlorsulfuron at 18 g ai/ha plus surfactant applied in late May (75). In the greenhouse, added surfactant also enhanced chlorsulfuron damage to Canada thistle shoots (80). Chlorsulfuron prevented regrowth of adventitious shoots from root buds only when applied postemergence with surfactant. However, X-77 surfactant at 0.33% (v/v) failed to enhance parent shoot control with chlorsulfuron at 35 to 140 g ai/ha in a study in Utah (97, 99). These relatively high herbicide rates probably masked the effect of added surfactant in the field.

O'Sullivan (266) controlled Canada thistle shoots with foliar- and soil-applied chlorsulfuron at 50 g ai/ha in the field and greenhouse. He suggested that soil residual carry-over of chlorsulfuron at this rate may be important for

Canada thistle control in the second growing season following foliar treatment. However, Donald (79) observed that chlorsulfuron applied to foliage and soil controlled later regrowth of new shoots from root buds just as well as foliar treatment alone in the greenhouse. Foliar or foliar plus soil treatment controlled regrowth much better than soil treatment alone. Similar results were observed when another perennial, wild garlic, was treated with chlorsulfuron or metsulfuron (181). Soil-applied chlorsulfuron at 17 and 33 g ai/ha both reduced root biomass and increased numbers of visible but unemerged adventitious root buds of Canada thistle in the greenhouse (81). As chlorsulfuron rate was raised, both root biomass and root bud numbers were reduced.

In subsequent field experiments (see below), residual control of Canada thistle with chlorsulfuron was noted but it could not be attributed to shoot or root absorption alone. In Colorado, chlorsulfuron applied at 35, 70, and 140 g ai/ha to Canada thistle in summer provided residual control 17 months later (143). Chlorsulfuron applied in spring wheat suppressed Canada thistle regrowth in the year following treatment in Montana (82, 85). When chlorsulfuron at 17, 35, or 70 g ai/ha was applied to Canada thistle at the 5-leaf stage, stands were reduced 23, 52, and 90%, respectively, 1 year later. However, control in the following year was reduced significantly when chlorsulfuron was applied at the bud stage. In the greenhouse, chlorsulfuron treatment at flowering also was less effective in preventing regrowth from root buds than application at earlier growth stages (79), substantiating these field observations (85).

Fall-applied chlorsulfuron does not control Canada thistle in the following growing season. When chlorsulfuron at 18 g ai/ha plus X-77 surfactant (0.25% v/v) was applied in late September, Canada thistle stands grew normally 1 or 2 years later in Nebraska (350, 398). In Colorado, 35 to 140 g ai/ha chlorsulfuron applied at the rosette stage in mid-May, the prebud stage in early June, the bud or flower stage in late June, and in the fall all provided greater than 90% control in mid-September (142). However, only excessively high rates of chlorsulfuron prevented shoot regrowth in the following growing season. These observations are substantiated by similar studies in Nebraska in which chlorsulfuron at 17 to 269 g ai/ha was applied to Canada thistle at various growth stages from the spring rosette until the fall rosette stage (397, 398). Chlorsulfuron at the highest rate was more effective when applied at the bud and fall rosette stages than the spring rosette stage, as measured by reduced Canada thistle stand, root length, or adventitious shoot density. Roots were not eradicated to a depth of 90 cm in the soil profile with a single application, even at the highest rate. Thus, fall-applied chlorsulfuron at commercial rates (26 g ai/ha) did not control Canada thistle shoot regrowth well enough in the following year to warrant recommendation.

Several other sulfonylurea herbicides also suppress Canada thistle, including metsulfuron and DPX-L5300 (68). Metsulfuron at 35 g ai/ha applied in mid-July provided excellent shoot suppression (74). The 1989 registered rate for use of metsulfuron in wheat was 4.2 g ai/ha. DPX-L5300 at 11 to 67 g ai/ha applied to Canada thistle at the 3- to 4-leaf stage in barley provided acceptable shoot suppression 80 days later (108, 184). In contrast, DPX-M6316 did not control or suppress Canada thistle (233).

The effectiveness of repeated annual applications of chlorsulfuron for eradicating Canada thistle in continuous wheat has received limited attention. Chlorsulfuron at 18, 35, or 70 g ai/ha applied at the bud stage did not provide control in the following year (86). Canada thistle stands gradually decreased when chlorsulfuron was reapplied annually to the same plots over three consecutive years in Montana spring wheat (107).

Chlorsulfuron effectively controlled Canada thistle in pastures. At 280 to 560 g ai/ha it controlled Canada thistle for one growing season in Wyoming (3). Good control was achieved at these rates even when it was applied at full bloom in August under drought conditions. Chlorsulfuron applied at 280 g ai/ha to 2.24 kg ai/ha provided 4 yr of total Canada thistle control, although crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schutt.] was stunted at rates above 280 g ai/ha. In Oregon pastures, chlorsulfuron provided better Canada thistle control than metsulfuron at 280 g ai/ha when applied in July (371). Control with chlorsulfuron lasted at least 1 year until the following July. In North Dakota, 280 g ai/ha provided good control of Canada thistle for 1 year following a June application to 30- to 45-cm tall Canada thistle at the midbud stage (210). However, regrowth began 15 months later (211).

III. CROP TOLERANCE

Cereals. Winter, spring, and durum wheat are very tolerant of chlorsulfuron, metsulfuron, and DPX-M6316 when treated at the 2-leaf stage until tillering even when the herbicides are ap-

Table 8. Wheat tolerance to postemergence sulfonylurea herbicides.

Variety	Herbicide	Rate (g ai/ha)	State	Response[a]	Reference
		Spring wheat			
Alex	Chlorsulfuron	67	ND	T	(223)
Borah	Chlorsulfuron	70	ID	T	(189)
		70	ID	I	(232)
		17-53	ID	T	(185)
	Metsulfuron	9-26	ID	T	(185)
	DPX-M6316	70-140	ID	T	(185)
	DPX-L5300	35-70	ID	T	(185)
Butte	Chlorsulfuron	67	ND	T	(223)
Era	Chlorsulfuron	67	ND	T	(223)
		22-33	MN	T	(24)
		70-280	ND	T	(355)
	Metsulfuron	22-33	MN	T	(34)
Fieldwin	Chlorsulfuron	70	ID	T	(189)
		70	ID	T	(232)
McKay	Chlorsulfuron	70	ID	T	(189)
		70	ID	T	(232)
NK-751	Chlorsulfuron	16-48	WA	T	(329)
	Metsulfuron	8-24	WA	T	(329)
	DPX-M6316	45-140	WA	T	(329)
Olaf	Chlorsulfuron	70-280	ND	T	(355)
Owens	Chlorsulfuron	70	ID	T	(189)
		70	ID	T	(232)
		18-53	ID	T	(185)
		16-48	WA	T	(329)
	Metsulfuron	8-24	WA	T	(329)
		9-26	ID	T	(185)
	DPX-M6316	70-140	ID	T	(185)
		45-140	WA	T	(329)
	DPX-L5300	35-70	ID	T	(185)
Ponderosa	Chlorsulfuron	18-50	ID	T	(185)
	Metsulfuron	9-26	ID	T	(185)
	DPX-M6316	70-140	ID	T	(185)
	DPX-L5300	35-70	ID	T	(185)
Solar	Chlorsulfuron	67	ND	T	(223)
Waldron	Chlorsulfuron	67	ND	T	(223)
Walera	Chlorsulfuron	67	ND	T	(223)
Wampum	Chlorsulfuron	16-48	WA	T	(329)
	Metsulfuron	8-24	WA	T	(329)
	DPX-M6316	45-140	WA	T	(329)
Waverly	Chlorsulfuron	16-48	WA	T	(329)
		18-53	ID	T	(185)
	Metsulfuron	8-24	WA	T	(329)
		9-26	ID	T	(185)
		45-140	WA	T	(329)
	DPX-M6316	70-140	ID	T	(185)
	DPX-L5300	35-70	ID	T	(185)
WB802	Chlorsulfuron	18-53	ID	T	(185)
	Metsulfuron	9-26	ID	T	(185)
	DPX-M6316	70-140	ID	T	(185)
	DPX-L5300	35-70	ID	T	(185)
WB906R	Chlorsulfuron	18-50	ID	T	(185)
	Metsulfuron	9-26	ID	T	(185)
	DPX-M6316	70-140	ID	T	(185)
	DPX-L5300	35-70	ID	T	(185)
		Winter wheat			
Arthur 71	Chlorsulfuron	40-120	MO	T	(277)
Brule		70	NE	T	(379)
Buckskin		70	NE	S	(379)
		50	WY	S	(194)
Centura		70	NE	T	(379)
Centurk		35-70	CO	T	(14)
		40-120	MO	T	(272)

Table 8. Continued.

Variety	Herbicide	Rate (g ai/ha)	State	Response[a]	Reference
Centurk 78		70	NE	T	(379)
Citation		70	NE	T	(379)
Cody		70	NE	T	(379)
Colt		70	NE	T	(379)
Dawn		70	NE	S	(379)
Double crop		40-120	MO	T	(277)
Harrison		40-120	MO	T	(277)
Hart		40-120	MO	T	(277)
Kanby		40-120	MO	T	(277)
Larned		70	NE	T	(379)
Perry		40-120	MO	T	(277)
Rocky		70	NE	S	(379)
Roland		60-120	IL	S	(177)
		10-30	IL	T	(177)
Scout 66		70	NE	T	(379)
Stephens		30-70	OR	T	(50)
		120	OR	I	(50)
Tam 101		40-120	MO	S	(277)
Turkey		70	NE	T	(379)
Vona		35-70	CO	S	(14)
		70	NE	T	(379)
		Durum wheat			
Cando	Chlorsulfuron	67	ND	T	(223)
Edmore	Chlorsulfuron	67	ND	T	(223)
Lloyd	DPX-M6316	20-50	ND	S	(356)
	DPX-L5300	20-50	ND	S	(356)
Vic	Chlorsulfuron	67	ND	T	(223)
		22-34	MN	T	(30)
	Metsulfuron	22-34	ND	S	(30)
Ward	Chlorsulfuron	67	ND	T	(223)

[a] T = tolerant; I = intermediate; S = susceptible.

plied in excess of twice the registered rate (Table 8). None of these herbicides is registered for use after the boot stage. Application of either herbicide before the 2-leaf stage may damage emerging wheat under some circumstances.

In Australia chlorsulfuron applied preemergence at 30 g ai/ha to 20 spring wheat varieties reduced the shoot growth and yield of certain lines, especially semidwarf or dwarf types with Rht/Gai genes for stature or insensitivity to gibberellic acid (108). In the growth chamber, sensitive 'Sonora' spring wheat was damaged by soil-incorporated chlorsulfuron at 40 μg/kg soil more at 13 C than at higher temperatures. Thus, wheat tolerance to soil-applied chlorsulfuron may depend partially on variety and environmental conditions.

Wheat is tolerant of postemergence-applied chlorsulfuron, metsulfuron, DPX-M6316, and DPX-L5300 (Table 8). However, DPX-L5300 at 40 g ai/ha damaged durum wheat and Mexican parentage spring wheat varieties to a limited extent (11 to 13%), but not most spring or winter wheat cultivars (108). Studies on wheat varietal tolerance to postemergence-applied chlorsulfuron at rates exceeding those currently recommended indicate little or no difference in varietal tolerance. Despite this, the relatively few reports of wheat damage usually involve stunting rather than reduced yield (50, 51, 172, 298). Chlorsulfuron at 65 g ai/ha did not injure several major hard red spring wheat varieties in North Dakota when treated at the 2- to 5-leaf stage (223).

Generally, susceptibility of winter wheat to chlorsulfuron or metsulfuron is less when application is delayed from fall until spring (84, 194, 335, 336). In Wyoming, the yield of weed-free 'Buckskin' winter wheat was uninfluenced by chlorsulfuron at 50 g ai/ha when sprayed early in spring (Zadok's Stage 29) (194). Yields were reduced when chlorsulfuron was applied in fall (Zadok's Stage 13) or late spring (Zadok's Stage 44). Perhaps, studies of wheat varietal tolerance may be complicated by interactions with growth stage at spraying.

Other cereals also have adequate but lower tolerance to chlorsulfuron than wheat does. Barley and oats tolerated chlorsulfuron at 125 g ai/ha applied postemergence in the greenhouse and field in Minnesota (129) and several reports indicate that chlorsulfuron was safe on several barley varieties at lower commercial postemergence application rates (31, 64, 65, 98, 185, 186, 187, 341). In general, barley can tolerate chlorsulfuron up to 70 g ai/ha (7, 64, 65, 98, 171, 186, 224). However, chlorsulfuron stunted barley in other research (224, 329). Metsulfuron also damaged barley in Minnesota (31). In greenhouse research, barley was less tolerant of root-applied chlorsulfuron compared with foliar applications (208). However, barley was unaffected when treated with chlorsulfuron, metsulfuron, DPX-M6316 or DPX-L5300 in Idaho (185). Clearly, more research is needed to define the varieties, growth stages, and environmental conditions influencing barley response to these herbicides. Oats may be more sensitive to sulfonylurea herbicides than wheat, especially chlorsulfuron or metsulfuron (24, 241). Neither herbicide should be applied to cereals undersown with small-seeded legumes.

Other crops. The response of crops other than small-grain crops to either spray application (Table 9) or carry-over of soil residues of sulfonylurea herbicides (Table 10) is an important consideration for herbicide use in wheat. Registration labels for chlorsulfuron and metsulfuron suggest that crop rotations be planned carefully before application.

Carry-over damage from chlorsulfuron application can be more of a problem in regions with low annual temperature and alkaline soils. In Alberta, residues of chlorsulfuron applied at 25 g ai/ha killed new alfalfa plantings until 4 years after initial treatment in June on a pH 8 soil (239). It was estimated that greater than 99% of applied chlorsulfuron had been lost at that time.

Of those crops adapted to the Northern Great Plains, some varieties of flax and safflower (*Carthamus tinctorius* L.) tolerate direct applications of chlorsulfuron (61, 225, 243) and metsulfuron (Table 9) (10, 11, 292, 293). Flax tolerated chlorsulfuron residue carry-over better than either corn (*Zea mays* L.) or sorghum in South Dakota (275). Postemergence chlorsulfuron at 26 to 53 g ai/ha did not prevent germination or early establishment growth of several range forage grasses, including crested wheatgrass, Russian wildrye (*Elymus junceaus* Fisch.), and bermudagrass (*Cynodon dactylon* L.) (69). Many crops are potentially susceptible to sulfonylurea herbicide spray drift (Table 9). Other crops, such as grapes (*Vitis* × sp.), had only marginal tolerance to chlorsulfuron and may be damaged by drift (363).

The carry-over of soil residues of chlorsulfuron or metsulfuron applied to cereals is a great concern but can be managed. The results of field trials across the northern United States have been summarized (Table 10). Most of these early studies used high rates of chlorsulfuron in excess of 20 g ai/ha. Despite this, these studies allowed researchers to rank rotational crops in terms of relative susceptibility to carry-over damage from chlorsulfuron or metsulfuron. Wheat, barley, oats, and safflower generally tolerated chlorsulfuron or metsulfuron residues (Table 10). Most other rotational crops grown in the Northern Great Plains and Pacific Northwest can be damaged by these herbicides (Table 10). Application rates and local soil characteristics, especially pH, influence herbicide phytotoxicity and persistence. Varietal differences in response to carry-over residues have not been published but may be significant for some species, such as flax and safflower. Carry-over injury is likely in double-cropping systems in which fall-sown winter wheat is harvested before planting a spring-sown crop, such as soybeans (*Glycine max* L.). Limited published information is available on the influence of minimum tillage, no-tillage, or ecofallow on carry-over damage from sulfonylurea herbicides. The restricted rotational crops and the lengthy interval required before planting other crops following chlorsulfuron or metsulfuron treatment have limited use of these herbicides to areas growing continuous cereals or wheat-fallow. DPX-M6316 and DPX-L5300 are likely to be more widely used on wheat in areas where crop rotations prevent the use of chlorsulfuron or metsulfuron.

IV. ENVIRONMENT AND PERFORMANCE

Little is known on how environmental factors influence the phytotoxicity of chlorsulfuron and other sulfonylurea herbicides. Simulated rainfall was used to determine how soon rainfall might occur after application without reducing herbicidal activity. Control of emerged kochia was unaffected by simulated rainfall 1.5 h after chlorsulfuron application, but a 24 h rain-free period was needed to prevent a loss in green foxtail control (251). Less rainfall also was needed to reduce control of green foxtail with 17 g ai/ha chlorsulfuron than kochia with 35 g ai/ha chlorsulfuron. Rainfall less than 24 h after

Table 9. Effect of postemergence treatment with sulfonylurea herbicides on crops other than wheat.

Crop					Rate		Reference
Common name	Scientific name	Variety	State or province	Herbicide	(g ai/ha)	Injury[a]	
Alfalfa	*Medicago sativa* L.	-	MN	Chlorsulfuron	22	S	(340)
			WI	DPX-M6316	18-70	S	(138)
Barley	*Hordeum vulgare* L.	Karla Klages Morex Steptoe	ID/WA	Chlorsulfuron	70	T	(65)
Bean	*Phaseolus vulgaris* L.	-	ND	DPX-M6316	24	S	(76)
Bluegrass	*Poa pratensis* L.	-	IN	Chlorsulfuron	35-140	T	(119)
Bermudagrass	*Cynodon dactylon* L.	-	NV	Chlorsulfuron	26-158	T	(69)
Corn	*Zea mays* L.	-	IN	DPX-M6316	16	T	(162)
Creeping bentgrass	*Agrostis palustris* Huds.	Penncross	-	Chlorsulfuron	141-282	T	(191)
Crested wheatgrass	*Agropyron cristatum* (L.) Gaertn.	-	WY	Chlorsulfuron	280	S	(4)
		Norton	NV	Chlorsulfuron	23-140	T	(69)
Flax	*Linum usitatissimum* L.	-	ND	Chlorsulfuron	22	T	(243)
		Culbert	Man.[b]	Chlorsulfuron	20	T	(61)
		Culbert	Man.	Chlorsulfuron	20	T	(61)
		Dufferin	Man.	Chlorsulfuron	20	S	(61)
		Linott	Man.	Chlorsulfuron	20	T	(61)
		Culbert	ND	Chlorsulfuron	9-18	T	(224)
		Clark	ND	DPX-M6316	9-18	T	(252)
		Flor	ND	DPX-M6316	9-18	S	(252)
Grapes	*Vitis* × spp.	Chancellor	MO	Chlorsulfuron	18	T	(363)
					140	S	(363)
Hard fescue	*Festuca ovina* Koch	Scladis	-	Chlorsulfuron	141-282	T	(191)
Kentucky bluegrass	*Poa pratensis* L.	Parade	-	Chlorsulfuron	141	T	(192)
Orchardgrass	*Dactylis glomerata* L.	-	-	Chlorsulfuron	141	T	(192)
Potato	*Solanum tuberosum* L.	-	ND	DPX-M6316	8-35	S	(254, 255)
Perennial ryegrass	*Lolium perenne* L.	Crown	-	Chlorsulfuron	141-282	S	(191)
Russian wildrye	*Elymus junceus* Fisch.	-	NV	Chlorsulfuron	26-158	T	(69)
Safflower	*Carthamus tinctorius* L.	S-208	CO	Chlorsulfuron	35	T	(10)
		Hartman	CO	Chlorsulfuron	18	S	(13)
		-	ND	Chlorsulfuron	21	T	(291, 292, 293)
		Hartman	CO	Metsulfuron	18	S	(13, 15)
		Hartman	CO	DPX-M6316	5-18	T	(13, 15)
		-	ND	DPX-L5300	24	S	(76)
		-	ND	DPX-L5300	18-35	S	(293)
Smooth bromegrass	*Bromus inermis* Leyss.	-	WY	Chlorsulfuron	140	S	(6)
		-	-	Chlorsulfuron	141-282	T	(191)
Sorghum	*Sorghum bicolor* (L.) Moench	-	CO	Chlorsulfuron	69	S	(18)
Soybean	*Glycine max* L.	-	ND	DPX-M6316	24	S	(76)
		-	IL	DPX-M6316	27	S	(161)
Sugarbeet	*Beta vulgaris* L.	-	ND	DPX-M6316	24	S	(76)
Sunflower	*Helianthus annuus* L.	-	CO	DPX-M6316	5-15	S	(15)
			ND	DPX-M6316	24	S	(76)
Tall fescue	*Festuca arundinaceae* Schreb.	Kentucky 31	-	Chlorsulfuron	141-282	S	(191)
Tame mustard	*Brassica* spp.	-	ND	DPX-M6316	24	S	(76)

[a] T = tolerant, S = susceptible.

[b] Man. = Manitoba, Canada.

DPX-M6316 application at 16 to 32 g ai/ha reduced DPX-M6316 phytotoxicity to kochia in the greenhouse when only the foliage was treated (241).

Soil and environmental conditions favoring active weed growth enhanced the herbicidal activity of sulfonylurea herbicides. For example, increasing soil nitrogen levels from 20 to 140 ppmw increased the phytotoxicity of 2 g ai/ha chlorsulfuron to green foxtail in the greenhouse (251). Likewise, DPX-M6316 was more phytotoxic to kochia when plants were grown in high nitrogen soil than under low nitrogen fertility (241).

Relative humidity had a greater effect on chlorsulfuron phytotoxicity to green foxtail and

Table 10. Crop response to carry-over residues of sulfonylurea herbicides applied in a previous crop.

Crop	State	Herbicide	Rate	Interval	Injury[a]	Reference
			(g ai/ha)	(mo.)		
Alfalfa	CA	Chlorsulfuron	17-35	8	D	(257)
	MT	Chlorsulfuron	4-70	12	D	(55)
			35-140	48	D	(56)
	OR	Chlorsulfuron	35	3	D	(52)
			35	5.8	D	
	OR	Chlorsulfuron	35	26	D	(50)
			35-560	5.8	D	
Barley	MT	Chlorsulfuron	4-70	12	N	(55)
			70	24	D	(85)
	ND	Chlorsulfuron	9-35	12	N	(360)
	WA/OR	Chlorsulfuron	70	6	N	(302)
	CO	Chlorsulfuron	7-18	24	D	(395)
Bean	CO	Chlorsulfuron	9-18	12	D	(284)
			9-18	24	N	(284)
	OR	Chlorsulfuron	35	3	D	(52)
			35	5.8	N	(52)
	CO	Metsulfuron	7-18	24	D	(395)
Carrot	CA	Chlorsulfuron	17-35	8	D	(257)
Corn	CA	Chlorsulfuron	17-35	8	D	(257)
	CO	Chlorsulfuron	9-18	12	D	(284)
			9-18	24	D	(284)
			9-18	36	N	(284)
	MT	Chlorsulfuron	35-140	24	D	(56, 83)
	ND	Chlorsulfuron	9-35	12	D	(360)
	NE	Chlorsulfuron	70-140	13	D	(378)
	OR	Chlorsulfuron	35	3	D	(52)
			35	5.8	N	(52)
	SD	Chlorsulfuron	17-68	12	D	(273, 275)
	VA	Chlorsulfuron	10-40	10	N	(117)
	WA	Chlorsulfuron	35	26	D	(50)
	WA	Chlorsulfuron	35-560	5.8	D	(50)
	CO	Metsulfuron	7-18	24	D	(395)
	ND	Metsulfuron	9-35	12	D	(361)
	VA	Metsulfuron	10-40	10	N	(117)
Cotton	CA	Chlorsulfuron	17-35	8	D	(257)
Cucumber	CA	Chlorsulfuron	17-35	8	D	(257)
Faba bean	MT	Chlorsulfuron	35-140	24	D	(56)
Flax	MT	Chlorsulfuron	35-140	24	D	(56)
	ND	Chlorsulfuron	9-35	12	D	(360, 361)
	SD	Chlorsulfuron	17-68	12	D	(273, 275)
Garbanzo bean	MT	Chlorsulfuron	35-140	24	D	(56)
Italian ryegrass	OR	Chlorsulfuron	35	3	D	(52)
			35	5.8	D	(52)
	OR	Chlorsulfuron	35-560	5.8	D	(50)
			35-560	26	D	(50)
Kidney beans	CA	Chlorsulfuron	17-35	8	D	(257)
Lentils	MT	Chlorsulfuron	4-70	12	D	(55)
			35-140	24	D	(56)
	WA/OR	Chlorsulfuron	70	6	D	(302)
	WA	Chlorsulfuron	18	7	D	(366)
			18	19	N	(366)
Lettuce	CA	Chlorsulfuron	17-35	8	D	(257)
Navy bean	ND	Chlorsulfuron	9-35	12	D	(361)
	ND	Metsulfuron	9-35	12	D	(361)
Oats	ND	Chlorsulfuron	9-35	12	N	(361)
	ND	Metsulfuron	9-35	12	D	(361)
Onion	CA	Chlorsulfuron	17-35	8	D	(257)
Pea	WA	Chlorsulfuron	18	7	D	(366)
			18	19	N	(366)
Pearl millet	KS	Chlorsulfuron	7-26	15	N	(343)
Pinto bean	MT	Chlorsulfuron	35-140	24	D	(56, 85)
Potato	MT	Chlorsulfuron	35-140	36	D	(87)
	PEI[c]	Chlorsulfuron	9-72	12	N	(155)
		Metsulfuron	9-72	12	N	(155)

Table 10. Continued.

Crop	State	Herbicide	Rate	Interval	Injury[a]	Reference
Rapeseed	OR	Chlorsulfuron	35	3	D	(52)
			35	5.3	D	(52)
	OR/WA	Chlorsulfuron	70	12	D	(302)
	OR	Chlorsulfuron	35	26	D	(50)
	Sask.[b]	Chlorsulfuron	5-10	12	D	(152)
Rutabaga	PEI[c]	Chlorsulfuron	9-18	12	N	(155)
		Metsulfuron	9-72	12	N	(155)
Safflower	MT	Chlorsulfuron	4-70	12	N	(55)
	MT	Chlorsulfuron	35-140	24	D	(56)
	MT	Chlorsulfuron	35-70	24	D	(85)
	ND	Chlorsulfuron	9-35	12	N	(360)
	WA/OR	Chlorsulfuron	70	12	N	(302)
Snapbeans	OR	Chlorsulfuron	35	26	D	(50)
	OR	Chlorsulfuron	35-560	5.3	D	(50)
Sorghum	CA	Chlorsulfuron	17-35	8	D	(257)
	KS	Chlorsulfuron	34-67	12	N	(333)
	KS	Chlorsulfuron	2-4	12	N	(338)
	KS	Chlorsulfuron	7-26	15	D	(343)
				27	N	(343)
	SD	Chlorsulfuron	17-68	12	D	(273, 275)
	TX	Chlorsulfuron	17-140	23	D	(380)
			9-18	16	N	
			36-140	38	D	
	KS	Metsulfuron	2-4	12	N	(338)
	TX	Metsulfuron	54	19	D	(380)
Soybean	AR	Chlorsulfuron	36-72	12	D	(164)
	KS	Chlorsulfuron	17-68	14	N	(174)
	MA	Chlorsulfuron	7	12	N	(289)
	MD	Chlorsulfuron	9-18	3-8.5	N	(290)
	ND	Chlorsulfuron	9-35	12	D	(361)
	OH	Chlorsulfuron	70	12	D	(169)
	SD	Chlorsulfuron	17-68	12	D	(273, 275)
	ND	Metsulfuron	9-35	12	D	(361)
	MD	Metsulfuron	9-36	3-8.5	N	(290)
Sugarbeets	CA	Chlorsulfuron	17-35	8	D	(257)
	CO	Chlorsulfuron	9-18	24	D	(284)
			9-18	24	D	(284)
			9-18	36	N	(284)
	MT	Chlorsulfuron	4-70	12	D	(55)
			35-140	24	D	(56)
			35-70	24	D	(83)
	OR	Chlorsulfuron	35	3	D	(52)
			35	5.3	D	(52)
			35	14	D	(53)
			35	26	D	(50)
	CO	Metsulfuron	24	24	D	(395)
Sunflower	CO	Chlorsulfuron	9-18	12	D	(284)
			9-18	24	N	(284)
	MT	Chlorsulfuron	35-140	24	D	(55, 83)
	ND	Chlorsulfuron	9-35	12	D	(360)
	OR	Chlorsulfuron	70	6	D	(302)
	SD	Chlorsulfuron	17-68	12	D	(273, 275)
	CO	Metsulfuron	7-18	24	D	(395)
	ND	Metsulfuron	9-35	12	D	(361)
Tomato	CA	Chlorsulfuron	17-35	8	D	(257)

[a] N = no damage; D = damaged.

[b] Sask. = Saskatchewan, Canada.

[c] PEI = Prince Edward Island, Canada.

kochia than did temperature; phytotoxicity was greater at high humidity (95 to 100% RH) than low humidity (40 to 50%) (251). Surfactant (trimethylnonylpolyethoxyethanol) at 0.5% (v/v) enhanced chlorsulfuron phytotoxicity at both low and high humidity at three temperatures (10, 20, and 30 C). Weed control also was better at high temperatures than at low temperatures for

DPX-L5300 (240) and for DPX-6316 on kochia (241).

Soil moisture conditions favoring more rapid weed growth also enhanced chlorsulfuron phytotoxicity. Control of green foxtail and kochia was greater for plants that were well watered both before and after chlorsulfuron application at 2 or 9 g ai/ha, respectively, than for plants that had been water stressed either before or after treatment (251). Water stress after chlorsulfuron treatment was more detrimental than water stress only before treatment. Adequate moisture for weed growth also enhanced weed control with DPX-L5300 (240) or DPX-M6316 (241) compared to dry conditions. Adding surfactant to DPX-L5300 partially improved control of water-stressed plants. The biochemical and physiological basis for these environmental effects remains to be determined. Environmental effects on weed control and cereal tolerance to sulfonylurea herbicides has been briefly reviewed recently (46).

V. COMBINATIONS WITH OTHER HERBICIDES

Grass herbicides. It would be advantageous to tank-mix chlorsulfuron with postemergence grass herbicides for broad-spectrum weed control in cereals. The influence of sulfonylurea herbicides on the efficacy of several postemergence herbicides is summarized in Table 11. Some sulfonylurea herbicides reduced wild oat (*Avena fatua* L. # AVEFA) control with diclofop {(±)-2-[4-(2,4-dichlorophenoxy)phenoxy] propanoic acid}; chlorsulfuron and metsulfuron are not registered for combination with diclofop in the United States. Chlorsulfuron or other sulfonylurea herbicides did not reduce wild oat control with difenzoquat (1,2-dimethyl-3,5-diphenyl-1*H*-pyrazolium), barban (4-chloro-2-butynyl-3-chlorophenylcarbamate), flamprop [*N*-benzoyl-*N*-(3-chloro-4-fluoro-phenyl)-*DL*-alanine], or AC-222,293 [methyl-2-(4-isopropyl-4-methyl-5-oxo-2-imidozolin-2-yl)M + P-toluate] (Table 11). Sequential application of chlorsulfuron after triallate [*S*-(2,3,3-trichloro-2-propenyl)bis(1-methylethyl)carbamothioate] did not improve wild oat control compared with triallate alone. Likewise, a mixture of propanil (*N*-(3,4-dichlorophenyl)propanamide] and sulfonylurea herbicides failed to control foxtails better than propanil alone, even though both herbicides have activity on foxtails.

Weed growth stage at the time of treatment may modify the extent to which sulfonylurea herbicides antagonize certain grass herbicides. For example, chlorsulfuron at 6 g ai/ha reduced Italian ryegrass (*Lolium multiflorum* Lam. # LOLMU) control with diclofop at 0.45 kg ai/ha in the greenhouse and field in North Carolina (182). Others verified this antagonism for different combinations of rates of chlorsulfuron and diclofop (203). Antagonism was more pronounced at the 3-leaf than the 2-leaf stage (182). Increasing the rate of the grass herbicide, such as diclofop, for some combinations partially or totally overcame antagonism of grass control by sulfonylurea herbicides (63, 203, 267). Chlorsulfuron antagonism of diclofop for control of Italian ryegrass was prevented by applying the herbicides in sequence with chlorsulfuron at 40 g ai/ha applied either 16 or 24 h before or after diclofop at 0.75 kg ai/ha (203). Chlorsulfuron-induced antagonism of diclofop could not be ascribed to changes in the foliar penetration, translocation, or metabolism of diclofop in Italian ryegrass (183).

Diclofop at 0.7 and 1.1 kg ai/ha reduced wild mustard and redroot pigweed control with chlorsulfuron at 10 and 20 g ai/ha in the greenhouse (63). Antagonism of broadleaf weed control by chlorsulfuron when combined with diclofop has not been widely reported and does not appear to be a commercial concern.

There are no published reports of increased injury to cereals when chlorsulfuron was combined with diclofop, difenzoquat, flamprop, barban, or AC-222,293. Generally, the influence of herbicide mixtures on crop yield has not been examined in the absence of weed competition. In Colorado, metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5-(4*H*)-one] at 0.36 kg ai/ha plus chlorsulfuron at 70 g ai/ha damaged 'Vona' winter wheat (14); but the yield loss for the combination was less than the yield loss caused by metribuzin applied alone. However, some winter wheat varieties vary in sensitivity to metribuzin. Metribuzin injury to 'Centurk' was not reduced by chlorsulfuron. Sulfonylurea herbicide damage to crops has been partially antidoted using 1,8-naphthalic anhydride or R-25788 (*N,N*-diallyl-2,2-dichloroacetamide), but cereals generally are tolerant of commercial rates (see above) (46). Conversely, chlorsulfuron at 12 or 23 g ai/ha which was preplant incorporated with triallate at 1.12 kg ai/ha reduced trillate damage to potted 'Len' spring wheat in the greenhouse without compromising wild oat control by triallate (125).

Broadleaf herbicides. Because sulfonylurea

Table 11. Interaction of sulfonylurea herbicides and grass herbicides used in wheat.

Grass herbicide	Rate	Sulfonylurea herbicide	Rate	Common name	Weed Scientific name	Interaction[a]	References
	(kg ai/ha)		(g ai/ha)				
AC-222,293	0.41-0.84	Chlorsulfuron	22	Wild oats	(*Avena fatua* L. # AVEFA)	0	(30)
	0.41		22			0	(32)
	0.56		23			0	(2)
	0.56		17			0	(227)
	0.70		9			0-	(306)
	0.71		18			0	(310,312,313)
	0.41-0.84	Metsulfuron	22			0	(30)
	1.12		18			0	(100, 104)
	0.28-0.56	DPX-M6316	35			0	(90)
	0.28-0.56		18-35			0	(92)
	0.42		18-70			0	(253)
	0.43		18-35			0	(94)
	0.56		34			0	(115,227,235)
	0.71		53			0	(234,312,313)
	0.43-0.56	DPX-L5300	18-35			0	(92)
	0.43		9-18			0	(94)
	0.56		22			0	(115)
	0.56		17			0	(227, 235)
Barban	0.28	Chlorsulfuron	18	Wild oats		0	(310)
	0.42		23			0	(2)
	0.43		35			0	(27)
	0.35	Chlorsulfuron	20			-	(63)
	0.42	Metsulfuron	20			-	(100)
	0.43	DPX-M6316	18-35			0	(92, 94)
	0.42		53			-	(313)
	0.43	DPX-L5300	9-18			0	(94)
			18-35			-	(92)
Diclofop	0.5-0.75	Chlorsulfuron	20,40,60	Oats	(*Avena sativa* L.)	0	(134)
	0.5-1.0		40,60			0	(134)
	0.7		40	Wild oats		0-	(267)
	0.7		20			-	(63)
	1.12		9			0-	(306)
	1.12		18			0	(310)
	1.12		18			0	(312)
	1.12		18			-	(313)
	1.12		22			0	(39)
	1.12		8	Yellow foxtail	(*Setaria glauca* (L.) Beauv. # SETLU)	-	(225)
	0.45		6	Italian ryegrass	(*Lolium multiflorum*) Lam. # LOLMU)	-	(182)
	0.25-0.75		10-40			-	(203)
	1.12	Metsulfuron	7			-	(104, 232)
	1.12		18			-	(102)
	1.12		20			-	(100)
	0.84	DPX-M6316	7-35	Foxtails	(*Setaria* sp.)	-	(91)
	0.84		18-35	Wild oats		-	(92, 94)
	0.84		21-70			0-	(253)
	1.12		18-35			0	(92)
	1.12		18-70			-	(253)
	1.12		34			-	(115)
	1.12		53			-	(312, 313)
	1.12		53			0	(234)
	1.12	DPX-L5300	9-18			-	(94)
			18-35			-	(92)
	1.12		22			-	(115)
	1.12		70			0-	(228)
Difenzoquat	0.42	Chlorsulfuron	12	Wild oats		0	(382)
	0.56		34			+	(27)
	0.7		20			0	(63)

Table 11. Continued.

Grass herbicide	Rate	Sulfonylurea herbicide	Rate	Common name	Weed Scientific name	Interaction[a]	References
	0.84		40			0-	(267)
	1.12		9-35			+	(237)
	1.12		27			0	(228)
	1.12		34			+	(27)
	1.12		9			0-	(306)
	1.12		22			0	(30)
	1.12		18			0	(313)
	1.12	Metsulfuron	7			0	(232)
	1.12		18			0	(104)
	1.12		20			0	(100)
	1.12		22			0	(30)
	0.67-0.90	DPX-M6316	18-35			0	(92)
	0.90		18-35			0	(94)
	0.84		21-70			0-	(253)
	1.12		18-70			0-	(253)
	1.12		34			-	(115)
	1.12		53			0	(313)
	0.67-0.90	DPX-L5300	18-35			0	(92)
	0.90		9-18			0	(94)
Flamprop	0.56	Chlorsulfuron	40	Wild oats		0-	(267)
	0.53		20			0	(63)
Fluchloralin	0.56	Chlorsulfuron	34	Several		+	(22)
Paraquat	0.28	Chlorsulfuron	40	Several		0	(264)
Pendimethalin	1.12	Chlorsulfuron	34	Several		0	(264)
Profluralin	0.56		34	Several		0	(264)
Propanil	1.12	Chlorsulfuron	11	Foxtail sp.		+	(36)
	1.12		11			0	(32)
	1.12	DPX-M6316	7-35			0	(91)
Triallate	1.12	Chlorsulfuron	34	Wild oats		0	(39)
	1.12	Metsulfuron	34			0	(39)
Trifluralin	0.56	Chlorsulfuron	34	Several		0	(22)

[a] 0 = no interaction; − = reduced weed control; + = enhanced weed control.

herbicides control most broadleaf weeds of wheat, combinations of sulfonylureas with other broadleaf herbicides have not been studied extensively. Chlorsulfuron enhanced grass weed control with propanil and AC-222,293 (Table 11). These latter herbicides control some grass weeds but only a few broadleaf weeds.

Combinations of sulfonylurea herbicides have advantages in broadening the spectrum of weed control. For example, preemergence-applied mixtures of chlorsulfuron plus metsulfuron at 15 plus 5 g ai/ha controlled slender foxtail whereas neither herbicide alone provided acceptable control (320). In Europe, DPX-M6316 has been combined with metsulfuron to expand the range of species that are controlled (325). Combinations of DPX-M6316 and DPX-L5300 have been researched in the United States for the same reason.

In other situations, herbicide mixtures enhanced broadleaf weed control when chlorsulfuron rates were reduced to minimize potential herbicide carry-over. In the Pacific Northwest, chlorsulfuron at 7 to 11 g ai/ha controlled catchweed bedstraw better when combined with bromoxynil at 0.2 kg ai/ha or dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.14 kg ai/ha (146). Likewise, chlorsulfuron provided good control of catchweed bedstraw, fiddleneck (*Amsinckia* spp.), and flixweed in winter wheat only at the highest labeled chlorsulfuron rates in Idaho (308). Control of these weeds was significantly improved when chlorsulfuron at 6 g ai/ha was combined with metribuzin at 0.28 kg ai/ha, bromoxynil at 0.28 kg ai/ha, or dicamba at 0.14 kg ai/ha. Also, adding bromoxynil at 0.21 kg ai/ha or a mixture of bromoxynil plus MCPA [(4-chloro-2-methylphenoxy)acetic acid] each at 0.14 kg ai/ha significantly improved control of common lambsquarters with chlorsulfuron at rates of 2 to 5 g ai/ha in barley (305). Control of mayweed chamomile (*Anthemis cotula* L. # ANTCO) in Washington in the field and greenhouse was enhanced by a combination of bromoxynil at 0.3 kg ai/ha plus chlorsulfuron at 0.8 to 1.5 g ai/ha compared to either compound applied alone (147).

Other combinations have been used to broaden the spectrum of weed control to include chlorsulfuron-tolerant weeds. As new sulfonylurea herbicides, such as DPX-L5300 or DPX-M6316, are commercialized, more research on herbicide mixtures will be needed to identify combinations with broad-spectrum weed control because these new sulfonylurea herbicides control fewer weeds than do either chlorsulfuron or metsulfuron. For example, when DPX-M6316 at 17 g ai/ha was combined with metribuzin at 0.42 kg ai/ha, both wild garlic plant and aerial bulblet control were reduced relative to DPX-M6316 alone (268). In Ohio when 2,4-D at 0.28 kg ai/ha was mixed with either DPX-M6316 or DPX-L5300 at 25 g ai/ha, common chickweed [*Stellaria media* (L.) Vill. # STEME] was controlled better in winter wheat than by 2,4-D [(2,4-dichlorophenoxy)acetic acid] alone (135). When chlorsulfuron at 18 g ai/ha followed triallate at 1.4 kg ai/ha, control of wild buckwheat in winter wheat was improved, whereas control of other weeds was unchanged (306). The potential of this sequence of herbicides to improve weed control should be reexamined at lower chlorsulfuron rates.

Nonselective herbicides. Chlorsulfuron may be applied with nonselective herbicides when planting spring cereals under no-tillage or in chemical farrow. For example, control of volunteer barley, wheat, rapeseed, and oat with paraquat at 0.28 kg ai/ha was not reduced in combination with chlorsulfuron at 40 g ai/ha applied at the 4-leaf stage of the cereals (264).

VI. PERSISTENCE AND FATE IN THE ENVIRONMENT

Adsorption in soil. Studies of sulfonylurea herbicide adsorption to soil have been limited to chlorsulfuron and sulfometuron. By studying adsorption, it should be possible to identify soil characteristics that modify herbicide phytotoxicity and leaching. Chlorsulfuron has a pKa of 3.6, making it a weak acid of moderate strength (321). At soil solution pHs above its pKa chlorsulfuron is unprotonated and negatively charged. The phytotoxicity of chlorsulfuron to sorghum in several soils increased as pH decreased from 7.5 to 5.9 when chlorsulfuron was applied at 0.5 to 1 g ai/ha (118). Fredrickson and Shea (118) suggested that chlorsulfuron's phytotoxicity increased at low pH because the herbicide was either less available at high pH or plant uptake of chlorsulfuron was greater at low pH. Wheat growing in four soils absorbed more ^{14}C-chlorsulfuron at pH 5.9 than at pH 7.5 after 7 days. This laboratory research (118) was substantiated by Mersie and Foy (204). Using a corn root bioassay and six high organic matter soils ranging in pH from 4.2 to 7.8, they demonstrated that as pH increased, phytotoxicity to corn increased above pH 5.6. Phytotoxicity also was inversely correlated with soil organic matter but not with clay content. The organic matter of the six soils ranged from 1.2 to 7.2 %. Amending soil with various forms of organic matter reduced phytotoxicity by increasing chlorsulfuron adsorption (96). Because less than 0.1% (or 50 kg/ha) activated charcoal prevented chlorsulfuron from killing susceptible plants in soil (95, 96), burning cereal straw is likely to inactivate chlorsulfuron that is applied after burning.

As Mersie and Foy (204) and others (256) pointed out, chlorsulfuron adsorption decreased and desorption increased as soil pH increased above 3.6, the pKa of chlorsulfuron. Several authors related herbicide concentration in soil solution to adsorption using ^{14}C-chlorsulfuron and the Freundlich equation (207, 322, 354). In four soils ranging in pH from 6.8 to 8.1, adsorption was relatively low (354); but as herbicide concentration increased, adsorption increased. Adsorption was exothermic; therefore it decreased as temperature increased.

Adsorption of acidic herbicides generally is greater on soil organic matter than on clay (207). Shea (322) suggested that hydrogen bonding and charge transfer formation between the aromatic benzene and triazine rings of the herbicide and the aromatic constituents of activated charcoal were responsible for chlorsulfuron adsorption. Infrared spectroscopy was used to study the mechanism of chlorsulfuron adsorption on purified clays and other soil constituents, such as cellulose and organic matter (321). The chlorsulfuron anion was repelled by the negatively charged mineral clay surfaces of montmorillonite, illite, and kaolinite. Multiple hydrophobic and hydrophilic interactions occurred on exchange resins, cellulose, and organic matter. Using purified constituents of soil, it was verified that chlorsulfuron was not adsorbed by montmorillonite clay (47). Purified humic acid and iron oxides were stronger adsorbents for chlorsulfuron at the low concentrations likely to occur in soil. Borggard and Streibig (47) found that both pH-dependent surface charge and the surface area of adsorbents, as well as chlorsulfuron's pH-dependent acid-base properties, controlled herbicide adsorption.

Environmental conditions may influence herbicide adsorption on soil constituents. Reducing soil moisture content to 25% of field capacity enhanced sorption of [^{14}C] sulfometuron in five soils (365). Borggaard and Streibig (47) calculated that when 10 to 40 g ai/ha chlorsulfuron was applied to water-saturated soil (50% pore space), soil solution concentrations ranged from 0.014 to 0.056 μM assuming a 20-cm-thick plow layer.

Leaching in soil. Sulfonylurea herbicide leaching has been studied using bioassays and radiolabeled herbicide (See section on soil persistence.). Smith and Hsiao (328) found good agreement between these methods of studying chlorsulfuron leaching on two Saskatchewan soils. Chlorsulfuron was readily leached in laboratory studies using packed soil columns and soil thin-layer chromatography (88, 256).

Chlorsulfuron moved 25 cm in soil leaching columns, even though 75% of ^{14}C-chlorsulfuron remained in the top 10 cm of the column. Studies with soil thin-layer chromatography revealed that leaching was greater for soil that was wetted and dried repeatedly than for soil kept continuously wet (88, 95). Mersie and Foy (207) verified that the R_f of chlorsulfuron in soil thin-layer chromatography was correlated with herbicide leaching in hand-packed soil columns.

The extent of chlorsulfuron leaching differs between different soil types (17, 118, 207, 328). In four soils with from 0.16 to 1.42% organic matter and a pH range of 4.6 to 6.9, chlorsulfuron was more mobile in neutral or alkaline soils than in acidic soils (Figure 3) (118, 207). Others verified that chlorsulfuron mobility increased as soil pH rose; chlorsulfuron leached close to the water front at higher pHs (256). As chlorsulfuron rate was increased, herbicide moved deeper in the soil profile (95). The mobility of metsulfuron also depended on soil type; soil organic matter and pH influenced its leaching behavior in a similar manner to chlorsulfuron (137).

Field studies of sulfonylurea herbicide leaching substantiated these controlled laboratory studies. ^{14}C-chlorsulfuron leached 5 to 10 cm in the field in Saskatchewan, depending upon the year of application (328). However, less than 2% of that applied was recovered at the 5 to 10 cm depth compared to 3 to 4% at the 0 to 5 cm depth in two soils (328). As the authors (328) indicated, chlorsulfuron movement was possible below the 10-cm depth, but this was not studied.

Chlorsulfuron leaching and persistence depended on pH in two similar Idaho soils (114). In a pH 5.9 soil, no residues were found at a depth of 7.5 cm after 200 days. However, in a pH 8.7 soil, residues persisted 300 to 400 days at this depth. Other researchers have verified that chlosulfuron at commercial rates can leach 10 to 20 cm in the field (50, 117, 266) although some researchers reported that little moved beyond 10 cm by the end of the growing season after spring application of chlorsulfuron at 10 to 20 g ai/ha (17, 159). Undoubtedly, weather conditions that limit chlorsulfuron degradation allow herbicide leaching to greater depths with subsequent rainfall on permeable soils (17, 159). Leaching of chlorsulfuron may reduce the duration of weed control in the field (17).

Soil persistence. An understanding of the soil persistence of chlorsulfuron and other sulfonylurea herbicides is valuable if potential carry-over problems are to be predicted and avoided. Three methods have been used to study soil persistence: 1) field bioassays in which the herbicide was applied and the treated area later was planted to various crops; 2) greenhouse or growth chamber bioassays in which herbicide residues in field soil, taken at various times after chlorsulfuron treatment, were quantified using the response of bioassay plants, such as corn (16, 328) or lettuce (362); and 3) the disappearance of ^{14}C-chlorsulfuron from soil over time (327, 328).

The carry-over damage of chlorsulfuron to susceptible crops in field bioassays is summarized (Table 10). This early research demonstrates the potential of chlorsulfuron residues to damage rotational crops or double crops. The soil persistence of both chlorsulfuron and metsulfuron has been assayed using field bioassays; chlorsulfuron also has been examined using greenhouse bioassays and radiolabeled herbicide. Results of such studies are likely to pertain to particular sites in the year of study because they are descriptive rather than mechanistic.

Rates and times of chlorsulfuron application, soil type, and weather conditions during the growing season are likely to influence herbicide persistence in the field (159). In eastern Colorado, the persistence of chlorsulfuron phytotoxicity, as measured by bioassay, in four soils depended most on soil pH, organic matter, the number of rainfall events greater than 0.25 cm, and the extent of leaching (17). In these latter field studies, variability in chlorsulfuron phytotoxicity attributable to soil type was 10% whereas that due to year of study was 50%. Unlike later research cited below, Anderson and Humburg (17) felt that organic matter significantly influenced chlorsulfuron persistence and

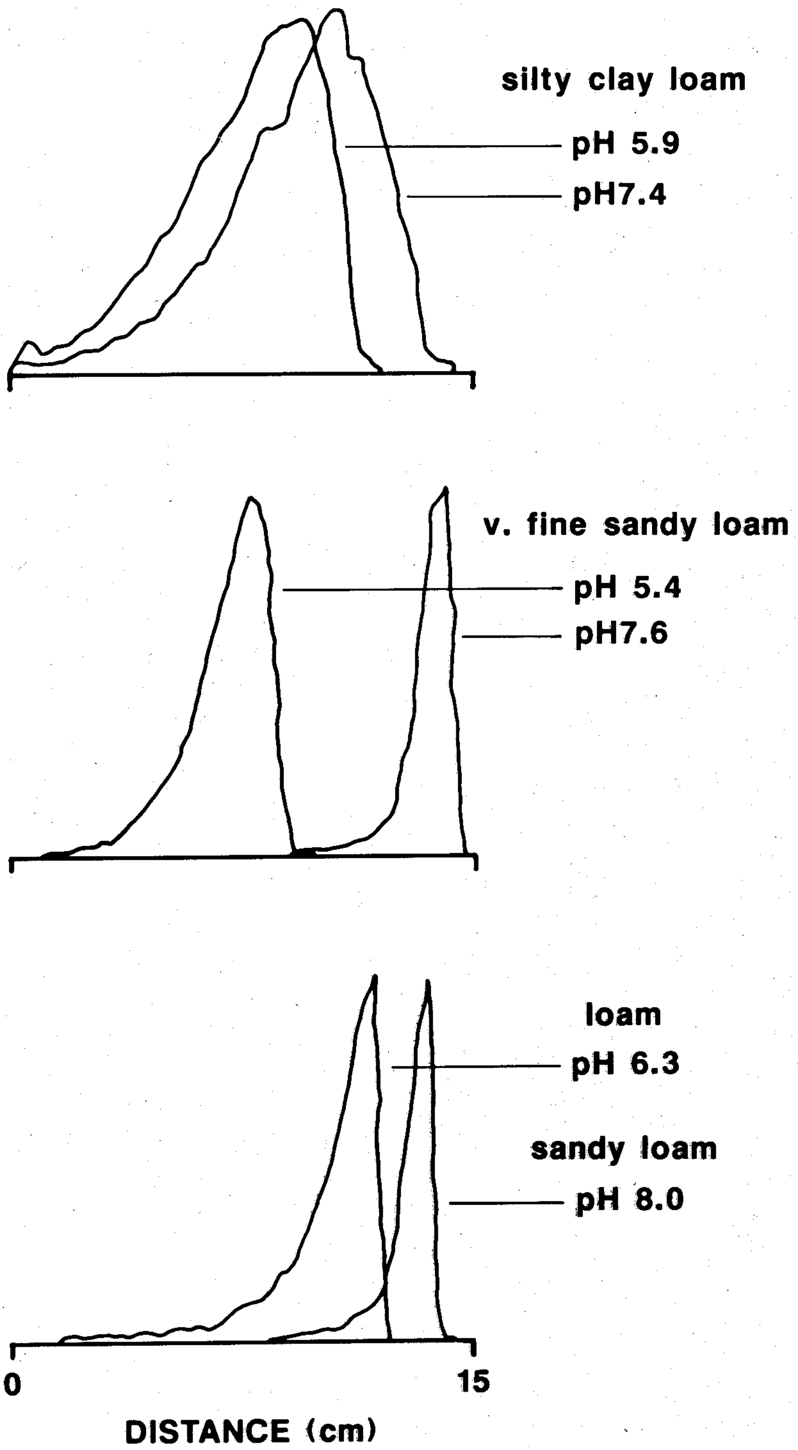

Figure 3. Effect of soil type and pH on movement of ^{14}C-chlorsulfuron on soil thin-layer chromatography (118).

suggested that the accuracy of models for predicting chlorsulfuron persistence could be improved by grouping soils according to soil organic matter.

Detailed kinetic studies of chlorsulfuron loss used bioassays after incubating herbicide-treated soil for various periods of time under controlled conditions. The rate of loss of chlorsulfuron exhibited first-order kinetics in a sandy loam soil that was treated with 30 g ai/ha and incubated at 10 to 30 C and 12% moisture (362). Chlorsulfuron degradation exhibited first-order kinetics with time in a loam and sandy-loam soil over a temperature range of 20 to 40 C at various soil moisture levels (16). When ^{14}C-chlorsulfuron persistence was studied under controlled conditions, it also exhibited first-order kinetics (327). In contrast, Thirunarayanan and coworkers (354) found that chlorsulfuron was rapidly lost over an initial 15-day period before entering a phase of slower first-order kinetics over time (Figure 4). They suggested a two-compartment model to describe these kinetic observations. Field persistence of chlorsulfuron in Alberta also followed a two-compartment dissipation model (239). Such models assumed more rapid herbicide dissipation on plant and soil surfaces prior to slower degradation once herbicides enter the soil and equilibrate with it.

Several factors modify soil persistence of chlorsulfuron, including crop management, soil pH, and environmental factors such as moisture and temperature (17). Chlorsulfuron was least persistent in soil at higher soil temperatures and moisture contents (46). Drought conditions increased chlorsulfuron persistence in four soils in eastern Colorado (17). Incorporating chlorsulfuron (16) or metsulfuron (12) into soil decreased their persistence, presumably because of increased rates of microbial degradation of parent herbicide.

Chlorsulfuron persisted longer in soils with alkaline pH's than acid pH's (114, 118, 354, 380). Chlorsulfuron had a half-life of 10 weeks at pH 7.5 and 1.9 weeks at pH 5.6 (118). There were 20 and 90% losses of chlorsulfuron after 6 weeks in these alkaline and acid soils, respectively. Under field conditions in Idaho chlorsulfuron had a half-life of 4 and 21 weeks at pH 5.9 and 8.7, respectively (114). It took 200 and 500 days for no residues to be detected by corn bioassay in the acid and alkaline soils, respectively. In some parts of North America, soils within only a 640-ha area can vary in pH as much as 1.5 (380). As illustrated by the previous examples, a change in pH from 6.5 to 8 can dramatically lengthen persistence and increase the likelihood of carry-over damage to susceptible crops (380).

Soil pH and hydrolytic degradation rate were inversely related in a laboratory study of four soils (Figure 4) (354). Soil pH was a much more critical factor in explaining chlorsulfuron persistence than was soil organic matter (16). Metsulfuron degradation rates also increased as soil pH dropped from pH 7.5 in a clay soil to pH 5.2 in a clay loam (327). DPX-L5300 also was degraded by hydrolysis in a pH-dependent fashion, much like chlorsulfuron (108).

Temperature and moisture interacted with soil type to modify persistence of chlorsulfuron and its analogs, such as metsulfuron (12) and DPX-L5300 (108). As soil temperature was increased from 10 to 40 C, chlorsulfuron persistence decreased, as measured by bioassay or loss of ^{14}C herbicide (16, 354, 362). These growth chamber studies also established that decreasing soil moisture content reduced the rate of chlorsul-

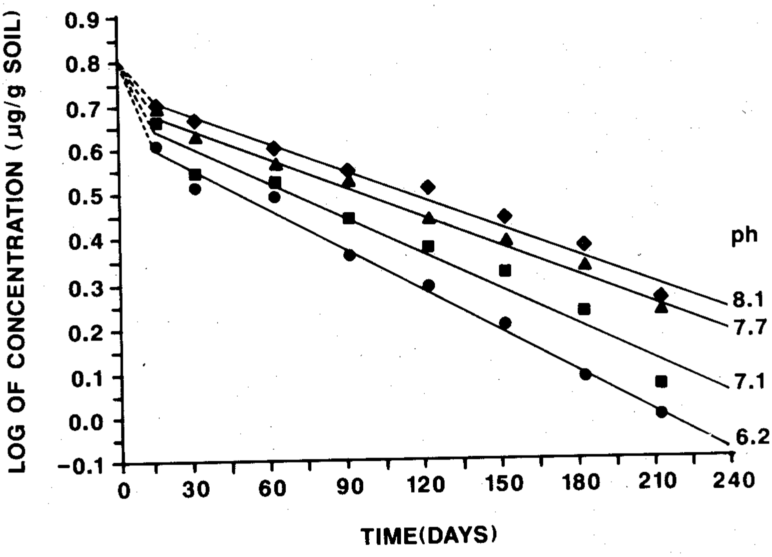

Figure 4. The effect of soil pH on chlorsulfuron degradation (354).

furon degradation; thus chlorsulfuron persisted longest in dry soils (16, 354). However, soil type and accompanying differences in moisture retention may modify the effect of temperature on herbicide persistence. Chlorsulfuron (16) and metsulfuron (12) persistence decreased in a loam soil as soil water content increased, but not in a sandy loam soil (16). Other confounding factors, such as differences in microbial activity, pH, organic matter, or water-holding capacity, may explain the effect of soil type.

Straw residue on the soil surface can intercept a portion of herbicide spray and delay its movement to the soil surface. When metsulfuron was sprayed on surface-lying straw residue, it could be washed off readily by rainfall (12). However, tie-up on straw residues increased the phytotoxicity of metsulfuron.

Chlorsulfuron breaks down to 2-carboxymethylbenzenesulfonamide in soil, according to tentative separations on TLC and comparison with standards (327, 328). Metsulfuron also degraded to similar metabolites in soil under controlled conditions. However, in field plots in Saskatchewan, only 5 and 2% of ^{14}C-parent chlorsulfuron remained after 45 and 95 weeks, respectively (328); fifteen and 20%, respectively, remained as 2-chlorobenzenesulfonamide. Thus, kinetic information would suggest a precursor-product relationship between the two chemicals (328). There are no published reports on whether chlorsulfuron or metsulfuron accumulates in soil after repeated annual applications, although U.S. registration labels caution against repeated annual applications because of potential carry-over damage to rotational crops.

pH-dependent hydrolysis and microbial activity may modify chlorsulfuron degradation to different extents depending upon soil type and local environment (19). Chemical hydrolysis was more important for chlorsulfuron degradation in acidic soil at pH 5.9 than in alkaline soil at pH 8.0 (157). Both chemical and microbial degradation of chlorsulfuron occurred at acidic pH's. Chlorsulfuron did not degrade in an alkaline soil which had been sterilized by steam, ethylene oxide, or gamma irradiation. When microorganisms were added back to soil, degradation resumed, suggesting that chemical degradation was insignificant. Pure cultures of *Streptomyces griseolus, Aspergillus niger,* and *Penicillium* species degraded chlorsulfuron (157, 158), although the herbicide was not completely mineralized.

Knowledge of both herbicide residue persistence and crop susceptibility to sulfonylurea residues are required to understand the agronomic and economic significance of herbicide carry-over. For example, 4 years and dissipation of more than 99% of chlorsulfuron residues were required for alfalfa (*Medicago sativa* L.) plantings to be able to establish on a chlorsulfuron-treated site in Alberta (239).

Chlorsulfuron is not registered in either the United States or Canada for use on soils with pH's above 7.9 because of its soil persistence in alkaline soils. Its use may be restricted to lower pH soils in some states. Metsulfuron should not be used on highly calcareous soils above pH 7.9. The minimal recropping interval after either herbicide depends upon the rotational crop, state, county, soil pH, and cumulative rainfall. The labels should be consulted for current detailed information. Neither chlorsulfuron- nor metsulfuron-treated wheat has grazing restrictions.

Reportedly some sulfonylurea herbicides, such as DPX-L5300 (108), are nonpersistent enough that choice of rotational crop is unrestricted by carry-over.

VII. BASIS FOR SELECTIVITY

Uptake. Foliar absorption of ^{14}C-chlorsulfuron is relatively rapid in a wide range of species. Tolerant species, such as wheat, barley, or wild oats, absorbed 68 to 72% of the applied radiolabel in 24 h (346). Uptake into susceptible crops also was rapid with 56 to 98% taken up in 24 h (346), although susceptible wild garlic plants absorbed ^{14}C-chlorsulfuron and ^{14}C-metsulfuron more slowly than this (181). Differential uptake is not believed to account for selectivity differences between species. Both chlorsulfuron-susceptible velvetleaf (*Abutilon theorphrasti* Medik. # ABUTH) and chlorsulfuron-tolerant eastern black nightshade absorbed approximately equal amounts of ^{14}C-chlorsulfuron over 48 h; 40% of the applied dose was absorbed (131).

The foliar penetration of chlorsulfuron was greater in velvetleaf at pH 2.4 to 3.4 than at pH 4.4 to 5.6 (206, 208). Simulated acid rain of pH 2.5 and 3.4 also synergized the phytotoxicity of chlorsulfuron to velvetleaf compared to pH 5.6 (208). The physiological mechanism for pH dependence of uptake and phytotoxicity has not been determined. However, chlorsulfuron, a weak acid with a pKa of 3.8, is protonated at acid pHs and may have penetrated the leaf cuticle as a neutral molecule under acidic conditions below its pKa, whereas uptake under basic conditions above its pKa probably involved the chlorsulfuron anion (208). Foliar penetration was less under alkaline conditions than under acid pHs because both chlorsulfuron and the leaf cuticle are negatively charged.

Leaves of Canada thistle at the 7- to 8-leaf stage absorbed 39% of applied ^{14}C-chlorsulfuron 48 h after treatment (215). Devine and Vanden Born (71) found that Canada thistle at the 7- to 8-leaf stage absorbed 75% of applied ^{14}C-chlorsulfuron after 72 h with little further uptake after 144 h (Figure 5). Quantitative differences in foliar uptake between these two studies probably can be attributed to the surfactant added in the latter study.

Foliar-applied chlorsulfuron at 67 g ai/ha was more phytotoxic to Canada thistle than soil-applied chlorsulfuron (79). Foliar or foliar and soil treatments with chlorsulfuron reduced Canada thistle shoot regrowth from root buds to the same extent at 67 g ai/ha. In contrast, root treatment was thought to contribute significantly to the reduction in shoot regrowth potential of Canada thistle in other greenhouse (133) and field research (266). However, this contribution was noted in the greenhouse only at the highest tested rates, 100 and 200 g ai/ha, which are tenfold greater than commercial rates (133). Results were similar for metsulfuron.

When hydroponically grown Canada thistle at the 7- to 8-leaf stage was root treated with ^{14}C-chlorsulfuron, only 16% of the radiolabel was absorbed after 48 h (276). This was roughly half of that absorbed by the foliage over the same period. Root translocation is likely to be less important than shoot absorption for Canada thistle control (276). Root absorption of ^{14}C-chlorsulfuron by excised pea roots was rapid and linearly related to external herbicide concentration, suggesting that the uptake mechanism was passive nonfacilitated diffusion (73). Uptake was reduced more at high pH (pH 6.4) than at low pH (pH 3.4), suggesting that chlorsulfuron was transported across root plasma membranes as an undissociated molecule and accumulated within cells by an ion tapping mechanism (73). Others (209) verified that ^{14}C-chlorsulfuron uptake by root apices was rapid and pH dependent in another species, velvetleaf. Chlorsulfuron efflux from root segments was biphasic with a short rapid phase followed by a protracted slow rate, suggesting initial dif-

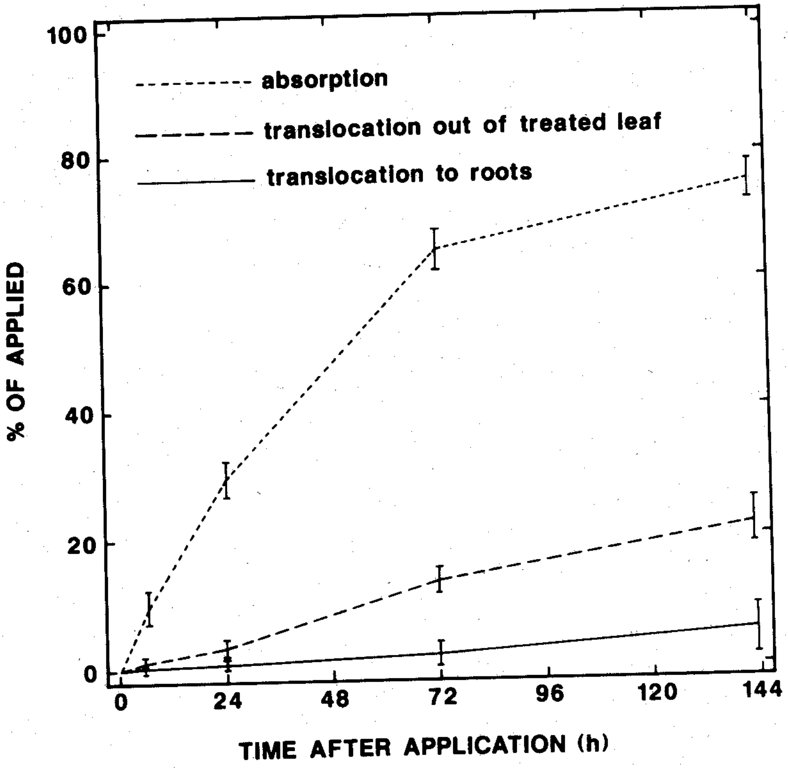

Figure 5. ^{14}C-chlorsulfuron absorption and translocation in Canada thistle following foliar treatment. Translocation was calculated as the total herbicide recovered in all plant parts other than the treated leaf. Vertical bars represent standard errors (71).

fusion from the apoplast followed by movement from the cell interior (209).

Translocation. Chlorsulfuron translocation in plants is limited and follows a source-to-sink pattern. Chlorsulfuron translocated from treated foliage of several susceptible and tolerant species was only 1 to 18% of that applied (181, 346). Only 0.1 to 4% of that applied was translocated from the foliage to the roots. In rapeseed, most chlorsulfuron moved from treated leaves to new leaves. When the third leaf was treated, most radiolabel went to the fourth and fifth leaves. Likewise, radiolabel translocating from ^{14}C-chlorsulfuron- or ^{14}C-metsulfuron-treated wild garlic leaves accumulated most in young shoots (181). Susceptible velvetleaf translocated 20% less chlorsulfuron than tolerant eastern black nightshade over 1 to 2 days (131). The distribution of radiolabel was similar with the shoot apices of velvetleaf and eastern black nightshade receiving 3.6 and 7.9%, respectively, of the applied radiolabel after 48 h. Apparently, differential translocation and accumulation in shoot apices do not explain selectivity.

Movement of ^{14}C-chlorsulfuron in Canada thistle from the shoots to the roots also is limited (Figure 5). When Canada thistle was grown hydroponically and treated at the 7- to 8-leaf stage with foliar-applied ^{14}C-chlorsulfuron, only 10% of applied radiolabel moved to the roots from treated shoots (276). In other studies with 7- to 8-leaf Canada thistle grown in quartz sand, only 5% of applied radiolabel moved to the roots of Canada thistle after 144 h (71). In both studies, most of the translocated radiolabel moved to younger shoots.

Transport form the roots to the foliage following root application also is limited (205, 276). When Canada thistle roots were treated, only 10% of applied herbicide moved in the transpiration stream to the shoots. In wheat and barley grown hydroponically, most ^{14}C-chlorsulfuron applied to the roots remained there (205). Thus translocation of sulfonylurea herbicides is ambimobile, but restricted (46).

Metabolism. Selectivity cannot be attributed to differences in foliar uptake or translocation of chlorsulfuron, but differences in metabolism have been shown to account for selectivity (346). Resistant and susceptible plants differ significantly in their ability to metabolize chlorsulfuron. Wheat, oats, and barley were tolerant of the herbicide and also metabolized it to a nonpolar, biologically inactive 0-glycoside in which the phenyl ring was hydroxylated (Figure 6). In contrast, sensitive broadleaf plants, such as sugarbeet (*Beta vulgaris* L.), soybean, mustard (*Brassica* sp.), and cotton (*Gossypium* sp.), did not metabolize chlorsulfuron. The role of metabolism in chlorsulfuron selectivity was substantiated by Hageman and Behrens (131); susceptible velvetleaf was 20,000 times more sensitive to chlorsulfuron than eastern black nightshade. Velvetleaf also was unable to metabolize chlorsulfuron, whereas resistant eastern black nightshade metabolized chlorsulfuron to a variety of unidentified products. The large difference in metabolism is in sharp contrast to relatively slight differences in retention, absorption, and translocation between resistant and susceptible species. Tolerant flax and black nightshade (153) metabolized chlorsulfuron to a hydroxymethyl derivative (346), unlike other tolerant species (346) (Figure 6). This derivative was less phytotoxic to sensitive sugarbeet or wild mustard than was chlorsulfuron. Thus, conjugation of this hydroxylated metabolite to a glycoside in flax and black nightshade is a detoxification pathway.

Susceptible Canada thistle was unable to metabolize chlorsulfuron following foliar treatment or when chlorsulfuron was added to Canada thistle cell suspensions (242, 349, 351, 352). Although the foliage did not metabolize the herbicide, the roots converted 25% of the applied chlorsulfuron into polar conjugates. Other researchers also have isolated, but not identified, breakdown products of chlorsulfuron in Canada thistle and field pennycress (*Thlaspi arvense* L. # THLAR) (72).

VIII. MODE OF ACTION

Injury symptoms. Chlorsulfuron-treated plants die slowly over 2 to 3 weeks. Injury is characterized initially by inhibition of new growth followed by chlorosis, necrosis, and terminal bud death (280, 281). The leaf veins of treated plants may become discolored. In the field and greenhouse, Tartary buckwheat [*Fagopyrum tataricum* (L.) Gaertn.] failed to form true leaves normally and cotyledon expansion was inhibited following chlorsulfuron treatment (266). Leaves stopped growing and became chlorotic within 2 days following spraying. By 2 weeks, internodes stopped elongating and leaf margins became inverted. Stems became hollow and collapsed, causing plants to fall to the soil surface. Chlorsulfuron at 67 g ai/ha applied to the foliage of Canada thistle caused similar symptoms to those on Tartary buckwheat (79). The shoot apex and young leaves stopped growing

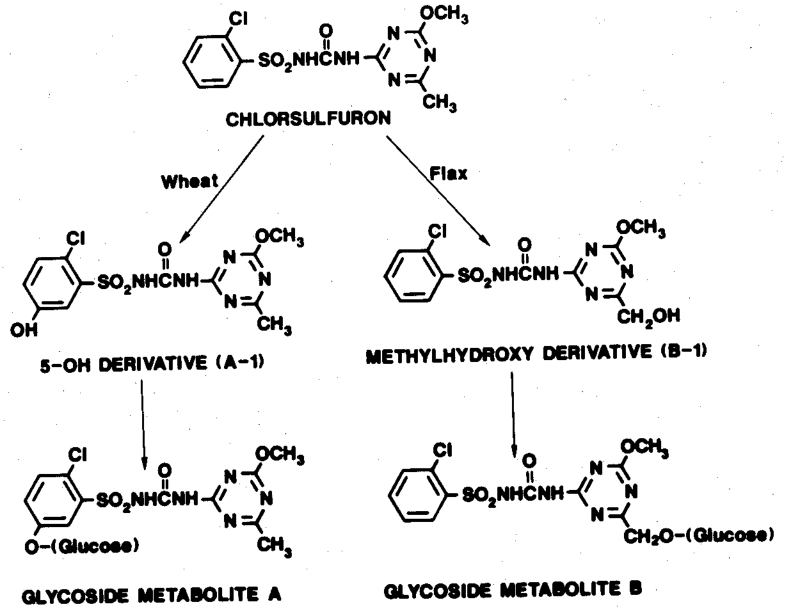

Figure 6. The pathway of chlorsulfuron metabolism in resistant wheat (346) and flax (153).

and became chlorotic within 5 days, resulting in a small chlorotic rosette (Figure 7). In 1 to 2 weeks after treatment, the lower leaves became chlorotic and yellowing progressed up the stem. Petioles became discolored and weakened. Then the petioles of lower leaves collapsed along the side of the stem, but the leaves maintained their turgor for several weeks. Finally, the terminal bud died and necrosis developed up the stem as the shoot died. When chlorsulfuron was applied only to the soil, it stimulated adventitious shoot outgrowth from root buds, although shoots did not reach the soil surface (80). Corn root growth was inhibited within 2 h of direct root treatment with chlorsulfuron (280, 281) and all adventitious roots decayed (265). When velvetleaf was treated with 35 g ai/ha chlorsulfuron, leaves abscised within 72 to 120 h after treatment and plants died within 7 days (130). By 3 days after treatment, growth stopped, foliar chlorosis increased, and leaf expansion ceased. This was followed by epinasty and loss of leaf nyctinasty (diurnal changes in leaf display). Chlorsulfuron-induced leaf abscission is not commonly observed in other sensitive species.

Seed production and germination. With such drastic effects on shoot development, it is not surprising that chlorsulfuron and metsulfuron also inhibit seed production. Chlorsulfuron prevented Canada thistle seed production at rates of 18 g ai/ha (5). Velvetleaf seed production and weight were reduced more by chlorsulfuron applied early during seed production than applied later (45, 167). Overwinter survival of velvetleaf seed was reduced after parent shoots were treated with chlorsulfuron (167). Seed production of dyers woad (*Isatis tinctoria* L. # ISATI) was severely reduced when chlorsulfuron at 53 g ai/ha was applied during late flowering to early fruiting (166). Equivalent rates of metsulfuron had the same effect. When metsulfuron was applied at 23 to 70 g ai/ha to flowering field bindweed, it decreased seed and capsule weight, as well as seed number (195). Germination was severly reduced because seeds were either shrunken or had only an outer seed coat. Chlorsulfuron applied at 18 to 26 g ai/ha after winter wheat harvest to Russian thistle during seed formation in August reduced later germination of large seeds even though total seed production was reduced (387). Young and Whitesides (387) suggested that sufficient herbicide was translocated to developing seed to reduce later germination, a hypothesis that warrants testing.

Germination of tolerant species was unaffected by sulfonylurea herbicides (13, 14, 69, 192, 396). For example, when either 'Vona' or 'Centurk' winter wheat was treated with chlorsulfuron at 35 to 70 g ai/ha in the fall in Colorado, percent germination was unaffected, despite yield reductions in Vona wheat (14). When 'Luke' winter wheat was treated with 9 to 70 g ai/ha chlorsulfuron, germinability also

Figure 7. Chlorsulfuron-treated Canada thistle: (A) greenhouse-grown plants were treated with 67 g ai/ha applied to the roots (left), shoots (middle), or roots plus shoots (right); (B) control shoots; (C) apical chlorosis 7 days after foliar treatment; and (D) apical necrosis 1 month after foliar treatment (Donald, 1989 unpublished).

was unaffected. Likewise when fall-planted rye (*Secale cereale* L.) was treated with 140 g ai/ha chlorsulfuron, there was no effect on subsequent seed germination (396). In Colorado, safflower treated with chlorsulfuron at 18 g ai/ha when 10 to 15 cm tall had no loss in germination despite a yield loss (13). Metsulfuron and DPX-M6316 applied at the same rate also did not adversely affect germination. Germination of susceptible species was not inhibited by sulfonylurea herbicides, but subsequent growth was stopped (46, 69, 303).

Amino acid biosynthesis. Inhibition of amino acid biosynthesis has been demonstrated to be a major mode of action of sulfonylurea herbicides (58, 127, 173, 285, 286). Chlorsulfuron inhibited the activity of acetolactate (acetohydroxy acid) synthase, a major branch point enzyme in the synthesis of the amino acids leucine, isoleucine, and valine in several plants (283) and microorganisms, such as *Escherichia coli, Salmonella typhimurium* (58), and *Saccharomyces cerevisiae* (384). Chlorsulfuron noncompetitively inhibited purified acetolactate synthase isolated from tobacco (*Nicotiana tabacum* L.) cell culture (196).

Chlorsulfuron inhibition of soybean tissue culture growth was reversed by valine and leucine, lending indirect support to the hypothesis that this enzyme was a site of herbicidal action (316). The influence of chlorsulfuron on endogenous changes in amino acid metabolism has been studied in *Lemma minor* L. (286).

Perhaps the most significant evidence for involvement of acetolactate synthase in the mode of action of sulfonylurea herbicides is genetic. Tobacco callus, which was homozygous for the S4 locus, was resistant to chlorsulfuron, whereas heterozygeous lines had intermediate susceptibility (59). The S4 locus is a single dominant nuclear mutation conferring resistance to sulfometuron. Resistance was expressed both by tobacco callus tissue culture and seedlings following regeneration from tissue culture. Selection for resistance to sulfometuron in tobacco tissue culture also conferred even greater resistance to chlorsulfuron. A mutant selected for resistance to chlorsulfuron also had similar resistance to sulfometuron. Chlorsulfuron-resistant lines of rape (345) and sulfometuron-resistant lines of the alga *Chlamydomonas reinhardtii* (136) also had reduced acetolactate synthase sensitivity to the herbicide. Altered herbicide binding to the enzyme helped explain differences in acetolactate synthase sensitivity between susceptible and resistant biotypes (317). Sulfometuron-resistant and -susceptible selections of the microorganisms *Escherichia coli* (384) and *Saccharomyces cerevisiae* (383, 384) exhibited mutational differences in only one amino acid present in the primary amino acid sequence of acetolactate synthase. The resistant lines of *E. coli* had normal levels of acetolactate synthase, but the isolated enzyme was much less sensitive to inhibition by sulfometuron than the enzyme isolated from susceptible lines (384).

Cell division. Chlorsulfuron inhibited cell division in root tips of broad bean (*Vicia faba* L.) (280, 282) and caused chromosomal abnormalities in broad bean and onion (*Allium cepa* L.) (20). The cell cycle of pea root apices was inhibited between the G_2 and M (mitosis) stages; secondary inhibition occurred between the G_1 and S stages (295, 296). DNA synthesis occurs during the S stage. The S and M stages were not affected directly, nor was protein synthesis affected. The S and M stages were indirectly affected because cell cycle specific RNA synthesis was reduced within 24 h. Isoleucine and valine prevented and reversed the reduction in mitotic figures in pea roots observed 4 h after treatment (296), much as they reversed chlorsulfuron inhibition of acetolactate synthase. Ray (282) tested the ability of chlorsulfuron to interfere with DNA synthesis by assaying the direct effect of chlorsulfuron on DNA polymerase and thymidine synthase activity. However, these enzymes were not inhibited by chlorsulfuron even at concentrations of 3×10^{-5}M chlorsulfuron. Reduced mitotic activity likely precedes reduced amounts of DNA and RNA in broad bean and onion root tips treated with chlorsulfuron (20).

Chlorsulfuron inhibited meiosis as well as mitosis. When field-grown rye was treated with 140 g ai/ha chlorsulfuron at flowering, the number of meiotic abnormalities was greater in treated plants than in controls (396). These included unpaired univalents from diakinesis to metaphase 1. Pairing of homologous chromosomes occurs at metaphase 1. Bridges, lagging chromosomes, and chromosome fragments were observed at telophase 1 and 2. A high proportion of pollen was sterile. Normally, chlorsulfuron would be applied much earlier and at lower rates in cereal production.

Physiological processes. Information on which physiological processes are inhibited by chlorsulfuron is limited and scattered. A coherent picture has not yet emerged relating inhibition of amino acid synthesis and cell division to later developing secondary physiological processes. Despite chlorsulfuron-induced chlorosis, the herbicide did not reduce photosynthesis in isolated pea (*Pisum sativum* L.) and spinach (*Spinacia oleracea* L.) chloroplasts at the concentrations that inhibited mitosis (70, 280, 282). When isolated chloroplasts from bean cells were tested, inhibition of photosynthesis occurred only at 0.5 mM chlorsulfuron (70). At lower doses, there was either no effect or a stimulation of oxygen release. ATPase activity of isolated chloroplasts also was unaffected by the herbicide.

Respiration of isolated bean cells was not affected at 10^{-4} M or 5×10^{-4} M chlorsulfuron (70). RNA, protein, and lipid synthesis were inhibited only slightly at the same doses. Ray (280, 282) found that leucine incorporation into protein in corn root tips was unaffected by 1 ppm chlorsulfuron. Using soybean suspension cells, lipid synthesis was more sensitive than RNA synthesis, protein synthesis, or photosynthesis to chlorsulfuron (140).

Chlorsulfuron is not thought to have a direct effect on cell permeability. Little solute leakage was detected by either release of ^{14}C-labeled organic compounds or changes in conductivity of the media when chlorsulfuron was incubated with leaf disks of 'Tower' mustard or 'Jet Neuf' rapeseed (62).

IX. RESEARCH NEEDS

Sulfonylurea herbicides have the potential to replace phenoxy herbicides for broadleaf weed control in wheat in North America. As the number of weed species controlled by chlorsulfuron, metsulfuron, and their analogs is determined, new tolerant species will be identified. Combinations of sulfonylurea and other herbicides should be examined for managing these weeds in wheat. As sulfonylurea herbicide use expands, resistant weeds should be identified as they increase. The effect of sulfonylurea herbicides on weed population biology, seed production, and seed viability also should be determined. The extent to which wheat competition contributes to sulfonylurea herbicide efficacy and enhances yield should be defined better. Comparison yield trials with other postemergence herbicides should be conducted and published in refereed journals.

Little is published about how sprayer type, pressure, or nozzle type influence postemergence weed control with sulfonylurea herbicides. Introduction of new specialized nozzles, such as the controlled droplet applicator, should prompt additional research, especially where farmers wish to apply these herbicides in a minimum volume of water to minimize application cost and improve application timing.

Weed control or suppression is best optimized by identifying which weed growth stages are most susceptible to sulfonylurea herbicides. Comparisons of the herbicidal efficacy of fall- versus spring-applied chlorsulfuron and metsulfuron are needed in winter wheat. More basic information on the relative competitiveness of different weeds with wheat would streamline herbicide data collection on application timing for target weeds.

As new sulfonylurea herbicides are introduced, they should be tested for physical and physiological compatibility with currently registered grass herbicides. Combinations with other broadleaf herbicides should be examined to expand the spectrum of weed control to include sulfonylurea-tolerant or -resistant weed species. While there are label restrictions concerning combinations of chlorsulfuron or metsulfuron with various insecticides, there is nothing in the published literature on the physiological or biochemical basis for such interactions. Where sulfonylurea herbicides antagonize grass herbicides, there is fundamental interest in exploring the mechanism of antagonism. However, there may be more practical importance in identifying pesticide combinations or additives that synergize sulfonylurea activity. Synergists might permit lower rates of sulfonylurea herbicides to be used without reducing efficacy and thus reduce the risk of carry-over damage to rotational crops. The potential of additives, such as surfactants or ammonium sulfate, to overcome reduced herbicidal activity under stressful environmental conditions should be explored.

The potential of sulfonylurea herbicides for long-term control of perennial weeds, such as Canada thistle, should be defined. Repeated annual application of chlorsulfuron and DPX-L5300 reduced the vegetative biomass of Canada thistle roots (Donald, unpublished data). Whether analogs have similar potential or act on other perennial weeds in a similar way should be studied. Integrating sulfonylurea herbicides into systems of managing perennial weeds in a variety of rotational crops deserves attention.

The efficacy of using sulfonylurea herbicides in reduced-, minimum-, or zero-tillage cropping systems should be examined. Economic analysis of sulfonylurea use compared to other currently registered postemergence broadleaf herbicides should be initiated. Likewise, there should be more documentation on residual weed control in successive cereal crops from one year to the next.

Our knowledge of how environmental factors, such as rainfall, temperature, relative humidity, and soil moisture, influence sulfonylurea activity should be expanded to include weed species other than the few that have been discussed. The effects of light intensity, photoperiod, and time of application on sulfonylurea activity deserve more research. The influence of soil type or soil fertility on sulfonylurea action is largely unexplored in the field.

The soil behavior of chlorsulfuron, metsulfuron, and their analogs is inadequately understood and should be investigated further. The potential for carry-over damage by newer analogs needs to be defined on a range of soil types in the field. Computer modeling should be utilized to predict soil persistence of chlorsulfuron, metsulfuron, and new sulfonylurea analogs as has been done by Walker and Brown (362). More rapid tests for determining potential carryover damage to rotational crops are needed.

The extent to which sulfonylurea herbicides modify crop response to environmental stress, diseases, or insects is largely unknown. However, chlorsulfuron at 20 g ai/ha reduced barley leaf scale (*Rhynchosporium secalis*) up to 50% depending upon barley variety (171).

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LITERATURE CITED

1. Ahmad, I. 1987. Capillary column gas chromatographic determination of trace residues of the herbicide chlorsulfuron in agricultural runoff water. J. Assoc. Off. Anal. Chem. 70:745–748.
2. Alley, H. P. 1984. Wild oat control in malting barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 157–158.
3. Alley, H. P. and N. E. Humburg. 1981. Canada thistle control in crested wheatgrass pastures. Res. Prog. Rep. West. Soc. Weed Sci. Page 35.
4. Alley, H. P. and N. E. Humburg. 1982. Longevity of Canada thistle control in a crested wheatgrass pasture. Res. Prog. Rep. West. Soc. Weed Sci. Page 12.
5. Alley, H. P., N. E. Humburg, and R. E. Vore. 1981. Selective control of Canada thistle in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 188–189.
6. Alley, H. P., N. E. Humburg, and R. E. Vore. 1982. Comparison of chlorsulfuron and Dowco 290 for control of Canada thistle in smooth bromegrass pasture. Res. Prog. Rep. West. Soc. Weed Sci. Page 2.
7. Alley, H. P., N. E. Humburg, and R. E. Vore. 1982. Selective control of Canada thistle in spring barley one year after treatment. Res. Prog. Rep. West. Soc. Weed Sci. Page 122.
8. Amor, R. L. and P. E. Ridge. 1987. Chemical fallow systems for wheat production in Victorian Wimmera. Plant Prot. Quart. 2:74–78.
9. Amrein, D. and H. R. Gerber. 1985. CGA 131,036: a new herbicide for broadleaved weed control in cereals. 1985 Br. Crop Prot. Conf. - Weeds. Vol. 1 Pages 55–62.
10. Anderson, R. L. 1985. Chlorsulfuron for weed control in safflower (*Carthamus tinctorius*). Proc. West. Soc. Weed Sci. 38:159–160.
11. Anderson, R. L. 1985. Chlorsulfuron for weed control in safflower (*Carthamus tinctorius*). Weed Sci. 33:840–842.
12. Anderson, R. L. 1985. Environmental effects on metsulfuron and chlorsulfuron bioactivity in soil. J. Environ. Qual. 14:517–521.
13. Anderson, R. L. 1986. Safflower response to postemergence application of three sulfonylurea herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Page 182.
14. Anderson, R. L. 1986. Metribuzin and chlorsulfuron effect on grain of treated winter wheat (*Triticum aestivum*). Weed Sci. 34:734–737.
15. Anderson, R. L. 1987. Broadleaf weed control in safflower (*Carthamus tinctorius*) with sulfonylurea herbicides. Weed Technol. 1:242–246.
16. Anderson, R. L. and M. R. Barrett. 1985. Residual phytotoxicity of chlorsulfuron in two soils. J. Environ. Qual. 14:111–114.
17. Anderson, R. L. and N. E. Humburg. 1987. Field duration of chlorsulfuron bioactivity in the central Great Plains. J. Environ. Qual. 16:263–266.
18. Anderson, R. L., D. E. Smika, and A. B. Page. 1985. Grain sorghum performance on chemical fallow plots. Res. Prog. Rep. West. Soc. Weed Sci. Page 227.
19. Anonymous. 1981. Product Information Bull. DPX 4189 Exp. Herbicide. 8 pp.
20. Badr, A. and A. G. Ibrahim. 1987. Effect of herbicide GLEAN on mitosis, chromosomes, and nucleic acids in *Allium cepa* and *Vicia faba* root meristems. Cytologia 52:293–302.
21. Behrens, R. and M. Elakkad. 1980. Postemergence treatments for weed control in oats and wheat. 1980. Res. Rep. North Cent. Weed Control Conf. 37:97–99.
22. Behrens, R. and M. Elakkad. 1981. Preemergence treatments for weed control in oats and wheat - Rosemount, MN. 1981. Res. Rep. North Cent. Weed Control Conf. 38:82–83.
23. Behrens, R. and M. Elakkad. 1982. Postemergence treatments for weed control in oats and wheat - Rosemount, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:110–111.
24. Behrens, R. and M. Elakkad. 1982. Preemergence treatments for weed control in oats and wheat - Rosemount, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:108–109.
25. Behrens, R. and M. A. Elakkad. 1983. Preplanting and preemergence treatments for weed control in oats and wheat - Rosemount, MN. 1983. Res. Rep. North Cent. Weed Control Conf. 40:97–98.
26. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1980. Preemergence treatments for wild oat control in wheat and barley. 1980. Res. Rep. North Cent. Weed Control Conf. 37:102–103.
27. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1980. Postemergence treatments for wild oat control in wheat and barley. 1980. Res. Rep. North Cent. Weed Control Conf. 37:104–105.
28. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1980. Herbicide evaluation in barley - Crookston, MN. 1980. Res. Rep. North Cent. Weed Control Conf. 37:114–115.
29. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1981. Herbicide evaluation in durum wheat - Crookston, MN. 1981. Res. Rep. North Cent. Weed Control Conf. 38:86.
30. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1982. Herbicide evaluation in durum wheat - Crookston, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:102.
31. Behrens, R., M. A. Elakkad, and J. V. Wiersma.

1982. Herbicide treatments for wild oat control in wheat and barley - Crookston, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:104–105.

32. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1983. Herbicide treatments for wild oat control in wheat and barley - Crookston, MN. 1983. Res. Rep. North Cent. Weed Control Conf. 40:88–89.
33. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1983. Herbicide evaluation in barley - Crookston, MN. 1983. Res. Rep. North Cent. Weed Control Conf. 40:108–109.
34. Behrens, R., M. A. Elakkad, and J. V. Wiersma. 1983. Herbicide evaluation in durum wheat - Crookston, MN. 1983. Res. Rep. North Cent. Weed Control Conf. 40:100–101.
35. Behrens, R., J. H. Ford, and M. A. Elakkad. 1982. Herbicide evaluation in spring wheat - Lamberton, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:100.
36. Behrens, R., W. E. Leuschen, and M. A. Elakkad. 1981. Herbicide evaluation in spring wheat - Waseca, MN. 1981. Res. Rep. North Cent. Weed Control Conf. 38:87.
37. Behrens, R., W. E. Leuschen, and M. A. Elakkad. 1982. Herbicide evaluation in spring wheat - Waseca, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:99.
38. Behrens, R., D. D. Warnes, and M. A. Elakkad. 1981. Herbicide evaluation in spring wheat - Morris, MN. 1981. Res. Rep. North Cent. Weed Control Conf. 38:89.
39. Behrens, R., D. D. Warnes, and M. A. Elakkad. 1982. Wild oat control in spring wheat - Morris, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:98.
40. Behrens, R., J. H. Ford, M. A. Elakkad, and O. E. Strand. 1980. Herbicide evaluation in spring wheat - Lamberton, MN. 1980. Res. Rep. North Cent. Weed Control Conf. 37:110–111.
41. Behrens, R., J. H. Ford, M. A. Elakkad, and O. E. Strand. 1981. Herbicide evaluation in spring wheat - Lamberton, MN. 1981. Res. Rep. North Cent. Weed Control Conf. 38:88.
42. Behrens, R., J. V. Wiersma, M. A. Elakkad, and O. E. Strand. 1980. Herbicide evaluation in spring wheat - Crookston, MN. 1980. Res. Rep. North Cent. Weed Control Conf. 37:112–113.
43. Beling, F. J., L. Wilson, and A. F. Wiese. 1981. Effect of DPX-4189 and DPX-5648 on various sized annual weeds. Proc. South. Weed Sci. Soc. 34:96.
44. Bestman, H. D., M. D. Devine, and W. H. Vanden Born. 1987. Extraction and separation of chlorsulfuron and its metabolites from treated plants. Weed Sci. 35:22–26.
45. Biniak, B. M. and R. J. Aldrich. 1986. Reducing velvetleaf (*Abutilon theophrasti*) and giant foxtail (*Setaria faberi*) seed production with simulated roller herbicide applications. Weed Sci. 34:256–259.
46. Blair, A. M. and T. D. Martin. 1988. A review of the activity, fate, and mode of action of sulfonylurea herbicides. Pestic. Sci. 22:195–219.
47. Borggaard, O. K. and J. C. Steibig. 1988. Chlorsulfuron absorption by humic acid, iron oxides, and montmorillonite. Weed Sci. 36:530–534.
48. Bourdot, G. W. and G. A. Hurrell. 1984. A screening of herbicides for yarrow seedling control. Proc. 37th N. Z. Weed Pest Control Conf. Pages 167–171.
49. Bowren, D. G. and W. M. Blacklow. 1987. Sensitivities of spring wheat cultivars to chlorsulfuron measured as inhibition of leaf elongation rates and there were genotype × environment interactions. Aust. J. Agric. Res. 38:253–262.
50. Brewster, B. D. and A. P. Appleby. 1983. Response of wheat (*Triticum aestivum*) and rotation crops to chlorsulfuron. Weed Sci. 31:861–865.
51. Brewster, B. D., A. P. Appleby, and P. K. Boren. 1980. Italian ryegrass and downy brome control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 302–303.
52. Brewster, B. D., A. P. Appleby, and P. K. Boren. 1980. The effect of DPX 4189 on winter wheat and rotational crops. Res. Prog. Rep. West. Soc. Weed Sci. Pages 324–325.
53. Brewster, B. D., A. P. Appleby, and P. K. Boren. 1981. Bioassay of DPX 4189 soil residues in western Oregon. Res. Prog. Rep. West. Soc. Weed Sci. Pages 298–299.
54. Bulmer, R.H.C., I. Eleftherohorinos, R. W. Snaydon, and D.S.H. Drennan. 1985. The effect of metoxuron and chlorsulfuron on competition between *Bromus sterilis* (Sterile Brome) and winter wheat. Aspects Appl. Biol. 9:75–80.
55. Burkhart, D. C. and P. K. Fay. 1986. Factors affecting the rate of dissipation of chlorsulfuron soil residues in Montana. Abstr. Weed Sci. Soc. Am. Page 98.
56. Burkhart, D. C., W. E. Dyer, and P. K. Fay. 1984. The effect of chlorsulfuron residues on seven crops in Montana. Proc. West. Soc. Weed Sci. 37:188–190.
57. Campion, J. G. and M. Tichon. 1981. DPX 4189 - a new selective herbicide for winter cereals. Proc. 6th Aust. Weeds Conf. Pages 1–6.
58. Chaleff, R. S. and C. J. Mauvais. 1984. Acetolactate synthase is the site of action of two sulfonylurea herbicides in higher plants. Science 224:1443–1445.
59. Chaleff, R. S. and T. B. Ray. 1984. Herbicide resistant mutants from tobacco cell cultures. Science 223:1148–1151.
60. Chase, R. L. 1984. Testiculate buttercup control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 190.
61. Chow, P.N.P. 1982. Flax tolerance and weed control with chlorsulfuron (DPX 4189). 49th Annu. Flax Inst. U.S. Pages 33–36.
62. Chow, P.N.P. 1983. Adjuvant enhancement of herbicidal activity, penetration, and translocation of chlorsulfuron in relation to leaf-cell membrane permeability of rapeseed. Pages 67–77 *in* 11th Workshop on Chemistry and Biochemistry of Herbicides. Res. Stn. Agric. Canada, Brandon, Manitoba.
63. Chow, P.N.P. 1988. Effect of chlorsulfuron on four graminicides for weed control and wheat yield. Weed Res. 28:145–150.
64. Clay, S. A. and D. C. Thill. 1982. Effect of four post-emergence herbicides on four spring barley varieties. Proc. West. Soc. Weed Sci. 35:127.
65. Clay, S. A., D. C. Thill, and V. L. Cochran. 1988. Response of spring barley (*Hordeum vulgare*) to herbicides. Weed Technol. 2:68–71.
66. Conn, J. S. 1987. Effects of tillage and straw management on Alaskan weed vegetation: a study on newly cleared land. Soil Tillage Res. 9:275–285.
67. Cook, G. E., L. F. Taylor, J. R. Wix, and N. D.

McKinley. 1983. Chlorsulfuron EUP review. Proc. West. Soc. Weed Sci. 36:24–26.

68. Davies, C. J. and J. H. Orson. 1987. The control of *Cirsium arvense* (Creeping thistle) by sulfonyl urea herbicides and a comparison of methods of assessing efficacy. 1987 Br. Crop Prot. Conf. - Weeds. Pages 453–460.
69. Davison, J. C., J. M. Krall, and W. S. Johnson. 1987. Response of selected range grass species to chlorsulfuron. Appl. Agric. Res. 2:337–341.
70. DeVilliers, O. T., M. L. Vandenplas, and H. M. Koch. 1980. The effect of DPX 4189 on biochemical processes in isolated leaf cells and chloroplasts. Proc. Br. Crop. Prot. Conf. - Weeds. Pages 237–242.
71. Devine, M. D. and W. H. Vanden Born. 1985. Absorption, translocation, and foliar activity of clopyralid and chlorsulfuron in Canada thistle (*Cirsium arvense*) and perennial sowthistle (*Sonchus arvensis*). Weed Sci. 33:524–530.
72. Devine, M. D., H. D. Bestman, and W. H. Vanden Born. 1986. An alternative procedure for the extraction and separation of chlorsulfuron and its metabolites from treated plants. Abstr. Weed Sci. Soc. Am. Page 85.
73. Devine, M. D., H. D. Bestman, and W. H. Vanden Born. 1987. Uptake and accumulation of the herbicides chlorsulfuron and clopyralid in excised pea root tissue. Plant Physiol. 85:82–86.
74. Dewey, S. A. and P. W. Foote. 1985. Field bindweed, Canada thistle, and common mallow control in non-crop areas. Res. Prog. Rep. West. Soc. Weed Sci. Page 3.
75. Dewey, S. A. and P. W. Foote. 1985. Canada thistle control in spring wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 280.
76. Dexter, A. G. and J. D. Nalewaja. 1985. Herbicides on several crop and weed species. 1985. Fargo, ND. Res. Rep. North Cent. Weed Control Conf. 42:118–119.
77. Dexter, A. G. and L. J. Smith. 1981. Weed beet. Proc. North Cent. Weed Control Conf. 36:109–110.
78. Doig, R. I., C. A. Carraro, and N. D. McKinley. 1983. DPX-T6376 - A new broad spectrum cereal herbicide. Proc. 10th Int. Congr. Plant Prot. 3:324–331.
79. Donald, W. W. 1984. Chlorsulfuron effects on shoot growth and root buds of Canada thistle (*Cirsium arvense*). Weed Sci. 32:42–50.
80. Donald, W. W. 1986. Stimulation of secondary shoot outgrowth from root buds of Canada thistle (*Cirsium arvense* (L.) Scop.) by soil drench applications of chlorsulfuron. Abstr. Weed Sci. Soc. Am. Page 69.
81. Donald, W. W. 1987. Effect of soil-applied chlorsulfuron on Canada thistle (*Cirsium arvense*) root and root bud growth. Weed Technol. 1:154–161.
82. Dyer, W. E. and P. K. Fay. 1983. Canada thistle control the season after chlorsulfuron application. Res. Prog. Rep. West. Soc. Weed Sci. Page 153.
83. Dyer, W. E. and P. K. Fay. 1983. The effect of chlorsulfuron soil residues on seven rotational crops grown in Montana. Res. Prog. Rep. West. Soc. Weed Sci. Pages 156–157.
84. Dyer, W. E. and P. K. Fay. 1983. The effect of time of application and rate of chlorsulfuron on the stand and yield of winter wheat. Res. Prog. Rep. West Soc. Weed Sci. Page 159.
85. Dyer, W. E. And P. K. Fay. 1983. Chlorsulfuron: its use and future in Montana. Proc. West. Soc. Weed Sci. 36:118.
86. Dyer, W. E. and P. K. Fay. 1984. Canada thistle control after 1 or 2 years of chlorsulfuron application. Res. Prog. Rep. West. Soc. Weed Sci. Page 225.
87. Dyer, W. E. and P. K. Fay. 1984. The effect of chlorsulfuron soil residues on 11 crops, 36 months after herbicide application. Res. Prog. Rep. West. Soc. Weed Sci. Page 226.
88. Dyer, W. E., P. K. Fay, and D. K. Burkhart. 1984. Chlorsulfuron movement in soil. Abstr. Weed Sci. Soc. Am. Pages 101–102.
89. Dyer, W. E., P. K. Fay, and R. H. Thompson. 1982. Developing a bioassay for chlorsulfuron residues in Montana soils. Proc. West. Soc. Weed Sci. 35:74.
90. Eberlein, C. V. and T. L. Miller. 1985. Weed control in wheat - Rosemount, MN. 1985. Res. Rep. North Cent. Weed Control Conf. 42:92–93.
91. Eberlein, C. V. and T. L. Miller. 1985. Broadleaf weed control with DPX-M6136 and DPX-L5300 in wheat - Rosemount, MN. 1985. Res. Rep. North Cent. Weed Control Conf. 42:94.
92. Eberlein, C. V. and T. L. Miller. 1985. Influence of DPX-M6316 and DPX-L5300 on wild oats control with four postemergence herbicides - St. Paul, MN. 1985. Res. Rep. North Cent. Weed Control Conf. 42:96–97.
93. Eberlein, C. V. and T. L. Miller. 1989. Corn (*Zea mays*) tolerance and weed control with thiameturon. Weed Tech. 3:255–260.
94. Eberlein, C. V., T. L. Miller, and J. V. Wiersma. 1988. Influence of thiameturon and DPX-L5300 on wild oats (*Avena fatua*) control with barban, diclofop, AC 222,293, and difenzoquat. Weed Sci. 36:792–799.
95. Eleftherohorinos, I. G. 1987. Phytotoxicity and persistence of chlorsulfuron as affected by activated charcoal. Weed Res. 27:443–452.
96. Eleftherohorinos, I. G., D.S.H. Drennan, and K. J. Murphy. 1985. Effects of straw and organic matter additions to soil on chlorsulfuron used preemergence. 1985. Br. Crop Prot. Conf. - Weeds. Pages 639–644.
97. Evans, J. O. and R. W. Gunnell. 1981. Using a surfactant for improved thistle control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 190–191.
98. Evans, J. O. and R. W. Gunnell. 1982. The influence of DPX 4189 residual in spring barley one year after treatment. Res. Prog. Rep. West. Soc. Weed Sci. Page 122.
99. Evans, J. O. and R. W. Gunnell. 1982. Influence of DPX 4189 with and without surfactants for controlling difficult broadleaf weeds. Res. Prog. Rep. West. Soc. Weed Sci. Pages 236–237.
100. Evans, J. O. and R. W. Gunnell. 1983. Postemergence wild oat control in spring planted barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 167–168.
101. Evans, J. O. and R. W. Gunnell. 1983. Chemical fallow in a winter-wheat-fallow cropping system. Res. Prog. Rep. West. Soc. Weed Sci. Pages 160–161.
102. Evans, J. O. and R. W. Gunnell. 1983. Negative interactions of diclofop methyl and DPX-T6376 combinations for wild oat (*Avena fatua*) control. Abstr. Weed Sci. Soc. Am. Page 23.

103. Evans, J. O. and R. W. Gunnell. 1984. Interactions of foliar applied grass specific herbicides with selected herbicides more specific for dicot weeds. Res. Prog. Rep. West. Soc. Weed Sci. Pages 231–232.

104. Evans, J. O. and R. W. Gunnell. 1984. Interactions of DPX-T6376 with postemergence wild oat herbicides under greenhouse conditions. Res. Prog. Rep. West. Soc. Weed Sci. Pages 229–230.

105. Evans, J. O. and R. W. Gunnell. 1985. Postemergence weed control in spring wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 283–284.

106. Evans, J. O. and R. W. Gunnell. 1986. Evaluation of bromoxynil and sulfonylurea herbicides in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 275–276.

107. Fay, P. K. and E. S. Davis. 1986. The effect of repeated application of chlorsulfuron on Canada thistle plant density. Res. Prog. Rep. West. Soc. Weed Sci. Pages 207–208.

108. Ferguson, D. T., S. E. Schehl, L. H. Hageman, G. E. Lepone, and G. A. Carraro. 1985. DPX-L5300 - a new cereal herbicide. 1985 Br. Crop Prot. Conf. - Weeds. Vol. 1. Pages 43–48.

109. Ferrell, M. A. 1986. Herbicide control evaluations on tansy (*Tanacetum vulgare*). Res. Prog. Rep. West. Soc. Weed Sci. Page 52.

110. Ferrell, M.A. and H. P. Alley. 1984. Evaluation of new herbicides for control of leafy spurge (*Euphorbia esula* L.). Res. Prog. Rep. West. Soc. Weed Sci. Page 18.

111. Ferrell, M. A. and H. P. Alley. 1985. Evaluation of new herbicides for control of leafy spurge. Res. Prog. Rep. West. Soc. Weed Sci. Page 29.

112. Finnerty, D. W. and A. V. Glaser. 1980. Control of *Equisetum hyemale* with DPX 4189. Proc. North Cent. Weed Control Conf. 35:103–104.

113. Flom, D. G., D. C. Thill, and R. H. Callihan. 1984. Effect of herbicide treatments on field bindweed control. Res. Prog. Rep. West. Soc. Weed Sci. Pages 3–4.

114. Flom, D. G., D. C. Thill, and R. H. Callihan. 1985. Effect of soil pH on the dissipation of chlorsulfuron. Proc. West. Soc. Weed Sci. 38:113.

115. Flom, D. G., D. C. Thill, and R. H. Callihan. 1986. Wild oat and broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 255–256.

116. Foy, C. L. and W. Mersie. 1984. Chlorsulfuron selectivity and persistence in small grains. Proc. South. Weed Sci. Soc. 37:108.

117. Foy, C. L. and W. Mersie. 1986. Effect of application time on soil residue and efficacy of sulfonylureas. Proc. South. Weed Sci. Soc. 39:446–456.

118. Fredrickson, D. R. and P. J. Shea. 1986. Effect of soil pH on degradation, movement, and plant uptake of chlorsulfuron. Weed Sci. 34:328–332.

119. Freeborg, R. P. and W. H. Daniel. 1981. Turf-broadleaf weed control. Proc. North Cent. Weed Control Conf. 36:36.

120. Gaiser, D. R., D. C. Thill, and R. H. Callihan. 1984. The effect of bromoxynil-chlorsulfuron tank mixtures on broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 197–200.

121. Gaiser, D., D. C. Thill, and R. H. Callihan. 1984. The influence of fall and spring-applied bromoxynil-chlorsulfuron tank mixtures on broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 201–202.

122. Gast, R. E. and F. W. Slife. 1985. Postemergence control of wild garlic aerial bulblets with DPX-M6316 and DPX-R9674 in winter wheat. Res. Prog. Rep. North Cent. Weed Control Conf. 42:109.

123. Gaul, M. C. and N. E. Christians. 1988. Selective control of annual bluegrass in cool-season turfs with fenarimol and chlorsulfuron. Agron. J. 80:120–125.

124. Giardina, M. C., M. DeAgazio, and S. Grego. 1987. Lack of prevention of chlorsulfuron-induced inhibition by amino acids. Weed Res. 27:215–219.

125. Gillespie, G. and J. D. Nalewaja. 1989. Wheat (*Triticum aestivum*) response to triallate plus chlorsulfuron. Weed Tech. 3:20–23.

126. Gregoire, T. D. and S. D. Miller. 1980. Weed control and soil moisture with chemical fallow treatment. Res. Rep. North Cent. Weed Control Conf. 37:76.

127. Gregoire, T. D. and S. D. Miller. 1981. Herbicides for weed control in fallow. Res. Rep. North Cent. Weed Control Conf. 38:73.

128. Groves, K.E.M. and R. K. Foster. 1985. A corn (*Zea mays*) bioassay technique for measuring chlorsulfuron levels in three Saskatchewan soils. Weed Sci. 33:825–828.

129. Hageman, L. H. and R. Behrens. 1981. Response of small-grain cultivars to chlorsulfuron. Weed Sci. 29:414–420.

130. Hageman, L. H. and R. Behrens. 1984. Chlorsulfuron induction of leaf abscission in velvetleaf (*Abutilon theophrasti*). Weed Sci. 32:132–137.

131. Hageman, L. H. and R. Behrens. 1984. Basis for response differences of two broadleaf weeds to chlorsulfuron. Weed Sci. 32:162–167.

132. Hahn, R. R. and P. W. Kanouse. 1983. Corn chamomile control in winter wheat. Proc. Northeast. Weed Sci. Soc. 37:97–98.

133. Hall, J. C., H. D. Bestman, M. D. Devine, and W. H. Vanden Born. 1985. Contribution of soil spray deposit from postemergence herbicide applications to control Canada thistle (*Cirsium arvense*). Weed Sci. 33:836–839.

134. Hall, C., L. V. Edgington, and C. M. Switzer. 1982. Effects of chlorsulfuron or 2,4-D upon diclofop-methyl in oat (*Avena sativa*). Weed Sci. 30:672–676.

135. Harrison, S. K. and J. E. Beuerlein. 1989. Effect of herbicide mixtures and seeding rate on soft red winter wheat (*Triticum aestivum*) yield. Weed Tech. 3:505–508.

136. Hartnett, M. E., J. R. Newcomb, and R. C. Hodson. 1987. Mutations in *Chlamydomonas reinhardtii* conferring resistance to the herbicide sulfometuron methyl. Plant Physiol. 85:898–901.

137. Harvey, J., Jr., J. J. Dulka. and J. J. Anderson. 1985. Properties of sulfometuron methyl affecting its environmental fate: aqueous photolysis, mobility, and adsorption on soils, and bioaccumulation potential. J. Agric. Food Chem. 33:590–596.

138. Harvey, R. G., E. R. Weir, and J. W. Albright. 1985. Alfalfa establishment weed control study. Res. Rep. North Cent. Weed Control Conf. 42:66–69.

139. Hatzios, K. K. 1984. Interactions between selected herbicides and protectants on corn (*Zea mays*). Weed Sci. 32:51–58.

140. Hatzios, K. K. and C. M. Howe. 1982. Influence of the herbicides hexazinone and chlorsulfuron on the metabolism of isolated soybean leaf cells. Pestic. Biochem. Physiol. 17:207–214.

141. Heap, I. and R. Knight. 1986. The occurrence of

herbicide cross-resistance in a population of annual ryegrass, *Lolium rigidum*, resistant to diclofop-methyl. Aust. J. Agric. Res. 37:149–156.

142. Henson, M. A. and R. L. Zimdahl. 1982. The effect of chlorsulfuron on winter wheat yield and Canada thistle (*Cirsium arvense* (L.) Scop.) control. Proc. West. Soc. Weed Sci. 35:118.
143. Henson, M. A. and R. L. Zimdahl. 1983. Residual effect of chlorsulfuron on Canada thistle [*Cirsium arvense* (L.) Scop.] and five crops. Abstr. Weed Sci. Soc. Am. Pages 87–88.
144. Herrmann, M., D. Kotzias, and F. Korte. 1985. Photochemical behavior of chlorsulfuron in water and in adsorbed phase. Chemosphere 14:3–8.
145. Hoag, B. K., J. R. Lukach, J. J. Fisher, and S. D. Miller. 1980. False chamomile control in North Central North Dakota. Proc. North Cent. Weed Control. Conf. 35:86–87.
146. Howard, S. W. and R. E. Whitesides. 1983. Control of catchweed bedstraw with chlorsulfuron. Res. Prog. Rep. West. Soc. Weed Sci. Page 174.
147. Howard, S. W. and R. E. Whitesides. 1985. Interactions of chlorsulfuron with bromoxynil. Res. Prog. Rep. West. Soc. Weed Sci. Pages 356–357.
148. Hsiao, A. I. and A. E. Smith. 1983. A root bioassay procedure for the determination of chlorsulfuron, diclofop acid and sethoxydim residues in soils. Weed Res. 23:231–236.
149. Humburg, N. E. and H. P. Alley. 1982. Rapid response to herbicide applied to stubble immediately after harvest of dryland winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 244–245.
150. Humburg, N. E. and H. P. Alley. 1983. Postemergence herbicide treatments for control of annual weeds in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 181–182.
151. Hunter, J. H. 1982. Chlorsulfuron plus surfactant - weed control, residue and crop tolerance. Proc. North Cent. Weed Control Conf. Page 23.
152. Hunter, J. H. 1982. Effect of an adjuvant on the control of cow cockle with chlorsulfuron. Res. Rep. North Cent. Weed Control Conf. 39:97.
153. Hutchison, R. M., R. Shapiro, and P. B. Sweetser. 1984. Metabolism of chlorsulfuron by tolerant broadleaves. Pestic. Biochem. Physiol. 22:243–247.
154. Ivany, J. A. 1987. Chlorsulfuron use in barley and residual effect on potato and rutabaga grown in rotation. Can. J. Plant Sci. 67:337–341.
155. Ivany, J. A. 1987. Metsulfuron use in barley and residual effect on succeeding crops. Can. J. Plant Sci. 67:1083–1088.
156. Jackson, G. D. and H. P. Alley. 1985. Russian knapweed top growth control resulting from various herbicide treatments. Res. Prog. Rep. West. Soc. Weed Sci. Page 19.
157. Joshi, M. M., H. M. Brown, and J. A. Romesser. 1984. Degradation of chlorsulfuron by soil microbes. Proc. West. Soc. Weed Sci. 37:63.
158. Joshi, M. M., H. M. Brown, and J. A. Romesser. 1985. Degradation of chlorsulfuron by soil microorganisms. Weed Sci. 33:888–893.
159. Junnila, S. 1983. Persistence and movement of chlorsulfuron in soil. Proc. 24th Swed. Weed Conf. Pages 296–301.
160. Kambitsch, D. L., D. C. Thill, W. J. Schumacher, and R. H. Callihan. 1982. Bulbous bluegrass control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 198–199.
161. Kapusta, G. and C. F. Strieker. 1983. Wild garlic control in winter wheat, 1983. Res. Rep. North Cent. Weed Control Conf. 40:119.
162. Kapusta, G. and D. Kunkel. 1985. Corn postemergence weed control with DPX-M6316, 1985. Res. Rep. North Cent. Weed Control. Conf. 42:191.
163. Kelley, M. M., E. W. Zahnow, W. C. Peterson, and S. T. Toy. 1985. Chlorsulfuron determination in soil extracts by enzyme immunoassay. J. Agric. Food Chem. 33:962–965.
164. Khodayari, K. and R. E. Frans. 1983. Curly dock control in a double cropping system (wheat-soybeans). Proc. South. Weed Sci. Soc. 36:134.
165. Khodayari, K., R. E. Frans, and K. H. Akkari. 1985. Evaluation of chlorsulfuron in wheat (*Triticum aestivum*) and in a wheat-soybean (*Glycine max*) double-cropping system. Weed Sci. 33:746–749.
166. King, W. O. and J. O. Evans. 1983. Effects of several foliar applied herbicides on the viability of dyers woad (*Isatis tinctoria* L.) seed. Proc. West. Soc. Weed Sci. 36:98–101.
167. Kintner, D. and R. J. Aldrich. 1984. Effects of postemergence chemicals on velvetleaf (*Abutilon theophrasti* Medic.) seed production and germination. Abstr. Weed Sci. Soc. Am. Pages 61–62.
168. Klingman, T. E. and T. F. Peeper. 1989. Weed control in winter wheat (*Triticum aestivum*) with chlorsulfuron and CGA 131036 and comparison of mode of action. Weed Tech. 3:490–496.
169. Kurtz, A. R. and G. L. Johnson. 1983. Weed control in wheat - doublecrop system with sulfonylurea herbicides. Proc. North Cent. Weed Control Conf. 38:21.
170. Larocque, D. J. and N. E. Christians. 1985. Selective control of tall fescue in Kentucky bluegrass with chlorsulfuron. Agron. J. 77:86–89.
171. Lemerle, D., C. R. Kidd, and B. J. Read. 1986. Tolerances of barley cultivars to post-emergence herbicides. Aust. J. Exp. Agric. 26:383–392.
172. Lemerle, D., A. R. Leys, R. B. Hinkley, and J. A. Fisher. 1985. Tolerance of wheat cultivars to pre-emergence herbicides. Aust. J. Exp. Agric. 25:922–926.
173. LaRossa, R. A. and S. C. Falco. 1984. Amino acid biosynthetic enzymes as targets of herbicide action. Trends Biotechnol. 2:158–161.
174. Leetch, M., O. G. Russ, and M. M. Claassen. 1984. Effect of chlorsulfuron on weed control in winter wheat and subsequent recropping with grain sorghum or soybeans. Proc. North Cent. Weed Control Conf. 39:121.
175. Levitt, G. 1983. Sulfonylureas: new high potency herbicides. Pages 243–250 *in* J. Miyamoto and P. C. Kearney, eds. Pesticide Chemistry: Human Welfare and the Environment. Vol. 1. Synthesis and Structure-Activity Relationships. Pergamon Press, New York.
176. Levitt, G., H. L. Ploeg, R. C. Weigel, Jr., and D. J. Fitzgerald. 1981. 2-chloro-*N*-(4-methoxy-6-methyl-1,3,5-triazin-2-yl) aminocarbonyl)benzensulfonamide, a new herbicide. J. Agric. Food Chem. 29:416–418.
177. Leys, A. R. and F. W. Slife. 1982. The effect of sulfonylurea herbicides on wild garlic, winter wheat, and double-cropped soybeans. Proc. North Cent. Weed Control Conf. 37:16.
178. Leys, A. R. and F. W. Slife. 1984. The use of chlorsulfuron and DPX 6376 for control of wild garlic (*Allium vineale* L.). Abstr. Weed Sci. Soc. Am. Page 16.
179. Leys, A. and F. W. Slife. 1986. The response of

wild garlic (*Allium vineale*) to the timing of spray applications of chlorsulfuron. Weed Sci.34:718–723.

180. Leys, A. R. and F. W. Slife. 1987. Comparison of chlorsulfuron and metsulfuron for control of *Allium vineale* L. Weed Res. 27:35–41.
181. Leys, A. R. and F. W. Slife. 1988. Absorption and translocation of carbon-14 chlorsulfuron and carbon-14 metsulfuron in wild garlic (*Allium vineale*). Weed Sci. 36:1–4.
182. Liebl, R. A. and A. D. Worsham. 1984. Annual ryegrass (*Lolium multiflorum*) control with diclofop plus chlorsulfuron combinations in wheat. Proc. South. Weed Sci. Soc. 37:110.
183. Liebl, R. A. and A. D. Worsham. 1987. Effect of chlorsulfuron on the movement and fate of diclofop in Italian ryegrass (*Lolium multiflorum*) and wheat (*Triticum aestivum*). Weed Sci. 35:623–628.
184. Lish, J. M. and D. C. Thill. 1986. Canada thistle control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Page 189.
185. Lish, J. M. and D. C. Thill. 1986. Tolerance of spring wheat and spring barley varieties to sulfonyl urea herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Pages 202–203.
186. Lish, J. M., D. C. Thill, and R. H. Callihan. 1982. Canada thistle control in barley. Res. Prog. Rep. West. Soc. Weed Sci. Page 123.
187. Lish, J. M., D. C. Thill, and R. H. Callihan. 1982. Harvest aid control of Canada thistle in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Page 124.
188. Lish, J. M., D. C. Thill, and R. H. Callihan. 1983. Chemical fallow weed control in southeast Idaho. Res. Prog. Rep. West. Soc. Weed Sci. Pages 206–208.
189. Lish, J. M., W. J. Schumacher, D. C. Thill, and R. E. Ohms. 1982. The influence of four herbicides on four spring wheat varieties under weed free conditions in Idaho. Proc. West. Soc. Weed Sci. 35:127–128.
190. Lym, R. G. and C. G. Messersmith. 1983. Herbicide screening trials for leafy spurge control. Res. Rep. North Cent. Weed Control Conf. 40:40–41.
191. Maloy, B. M. and N. E. Christians. 1986. Chlorsulfuron activity on seven cool-season grasses. HortScience 21:1012–1014.
192. Maloy, B. M. and N. E. Christians. 1986. Tolerance of tall fescue and Kentucky bluegrass to chlorsulfuron under field conditions. Weed Sci. 34:431–434.
193. Martin, A. R. And G. A. Regimbal. 1982. Shattercane control in grain sorghum. Res. Rep. North Cent. Weed Control Conf. 39:143.
194. Martin, D. A., S. D. Miller, and H. P. Alley. 1989. Winter wheat (*Triticum aesitvum*) response to herbicides applied at three growth stages. Weed Technol. 3:90–94.
195. Mashhadi, H. R. and J. O. Evans. 1986. Effect of bloom application of metsulfuron on seed size, viability and seedling vigor of field bindweed (*Convolvulus arvensis* L.). Proc. West. Soc. Weed Sci. 39:36–39.
196. Matsunaka, S., M. Nakata, K. Hioki, Y. Noguchi, and O. Yoshitake. 1985. Comparison of the mode of action of chlorsulfuron between higher plants and animals. 1985 Br. Crop Prot. Conf. - Weeds. Vol. 1. Pages 139–145.
197. Mekwatanakarn, P. and K. Sivasithamparam. 1987. Effect of certain herbicides on growth and pathogenicity of take-all fungus on wheat (*Triticum aestivum*). Biol. Fert. Soils 5:31–35.
198. Mengel, M. L. and D. C. Thill. 1985. Annual broadleaf weed control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 161–162.
199. Mengel, M. L., D. C. Thill, and R. H. Callihan. 1986. Broadleaf weed control in winter wheat at Potlach, Idaho. Res. Prog. Rep. West. Soc. Weed Sci. Pages 259–260.
200. Mengel, M. L., D. C. Thill, and R. H. Callihan. 1986. Broadleaf weed control with fluorochloridone in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 261–262.
201. Mengel, M. L., D. C. Thill, and R. H. Callihan. 1986. Broadleaf weed control in no-till winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 263–264.
202. Mengel, M. L., D. C. Thill, and R. H. Callihan. 1986. Dicamba chlorsulfuron antagonism study. Res. Prog. Rep. West. Soc. Weed Sci. Pages 277–278.
203. Mersie, W. and C. L. Foy. 1985. Interaction of chlorsulfuron and diclofop on Italian ryegrass. Proc. South. Weed Sci. Soc. 38:426–431.
204. Mersie, W. and C. L. Foy. 1985. Phototoxicity and adsorption of chlorsulfuron as affected by soil properties. Weed Sci. 33:564–569.
205. Mersie, W. and C. L. Foy. 1986. Absorption and translocation of root applied chlorsulfuron in wheat and barley. Proc. South. Weed Sci. Soc. 39:435–440.
206. Mersie, W. and C. L. Foy. 1986. Interaction of simulated rain solutions and chlorsulfuron on velvetleaf (*Abutilon theophrasti* Medic.). Abstr. Weed Sci. Soc. Am. Page 69.
207. Mersie, W. and C. L. Foy. 1986. Adsorption, desorption, and mobility of chlorsulfuron in soils. J. Agric. Food Chem. 34:89–92.
208. Mersie, W. and C. L. Foy. 1986. Effects of acidity of simulated rain and its influence on the phytotoxicity of chlorsulfuron on velvetleaf and barley. Environ. Exp. Bot. 26:341–347.
209. Mersie, W. and C. L. Foy. 1987. Influence of pH on the absorption of chlorsulfuron by leaves and excised roots of velvetleaf (*Abutilon theophrasi*). Weed Sci. 35:11–14.
210. Messersmith, C. G. and R. G. Lym. 1980. Herbicide and plant growth regulator screening trials on leafy spurge. Res. Rep. North Cent. Weed Control Conf. 37:60–61.
211. Messersmith, C. G. and R. G. Lym. 1980. Herbicide evaluation for Canada thistle and prickly lettuce control. Res. Rep. North Cent. Weed Control Conf. 37:63.
212. Miller, S. D. 1980. Herbicides applied postemergence for chemical fallow. Res. Rep. North Cent. Weed Control Conf. 37:75.
213. Miller, S. D. 1981. Herbicides applied in the fall or early spring for chemical fallow. Res. Rep. North Cent. Weed Control Conf. 38:74–75.
214. Miller, S. D. 1982. Split herbicide treatments for weed control in fallow, 1982. Res. Rep. North Cent. Weed Control Conf. 39:91.
215. Miller, S. D. 1982. Postemergence herbicides in fallow, 1982. Res. Rep. North Cent. Weed Control Conf. 39:93.
216. Miller, S. D. 1983. Herbicides applied in the fall for chemical fallow, 1982–1983. Res. Rep. North Cent. Weed Control Conf. 40:68.

217. Miller, S. D. 1986. Evaluation of herbicides for broadleaf weed control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 196–197.

218. Miller, S. D. 1986. Broadleaf weed control in spring wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 213.

219. Miller, S. D. 1986. Broadleaf weed control in winter wheat with sulfonylurea herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Page 271.

220. Miller, S. D. and H. P. Alley. 1985. Evaluation of herbicides for broadleaf weed control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 164–165.

221. Miller, S. D. and H. P. Alley. 1985. Evaluation of herbicides for broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 297–298.

222. Miller, S. D. and H. P. Alley. 1985. Evaluation of herbicides for broadleaf weed control in spring wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 299–300.

223. Miller, S. D. and J. D. Nalewaja. 1981. Hard red spring and durum wheat response to herbicides. Res. Rep. North Cent. Weed Control Conf. 38:102–103.

224. Miller, S. D. and J. D. Nalewaja. 1981. Barley response to herbicides. Res. Rep. North Cent. Weed Control Conf. 38:102–104.

225. Miller, S. D. and J. D. Nalewaja. 1982. Grass weed control in flax with postemergence herbicides. Res. Rep. North Cent. Weed Control Conf. 39:143.

226. Miller, S. D. and J. D. Nalewaja. 1983. Chlorsulfuron for weed control in fallow. Abstr. Weed Sci. Soc. Am. Page 18.

227. Miller, S. D. and M. S. Page. 1986. Wild oat control in spring wheat with AC-222,293 alone and in combination with broadleaf herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Page 222.

228. Mitich, L. W. and N. L. Smith. 1986. Comparison of AC 222,293 with other wild oat herbicides for wild oat and broadleaf weed control in wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 220–221.

229. Morishita, D. W., G. A. Lee, and W. S. Belles. 1980. Field evaluation of DPX-4189 in winter wheat in two tillage systems. Proc. West. Soc. Weed Sci. 33:72–76.

230. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1983. Postemergence herbicide applications for weed control in minimum tillage winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 238–239.

231. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1983. Tolerance of spring wheat varieties to five herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Pages 242–243.

232. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1983. Wild oat control in irrigated spring barley and wheat in southern Idaho. Res. Prog. Rep. West. Soc. Weed. Sci. Pages 244–247.

233. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1985. Canada thistle control in spring wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 7–8.

234. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1985. Wild oat control in irrigated spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 168–169.

235. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1986. Wild oat control in small-grain cereals with AC 222,293. Res. Prog. Rep. West. Soc. Weed Sci. Pages 225–226.

236. Morishita, D. W., D. C. Thill, and R. H. Callihan. 1986. Broadleaf weed and downy brome control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 236–237.

237. Morishita, D. W., D. C. Thill, R. H. Callihan, and W. J. Schumacher, 1982. Control of wild oat and broadleaf weeds in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 126–127.

238. Morishita, D. W., D. C. Thill, D. G. Flom, T. C. Campbell, and G. A. Lee. 1985. Method for bioassaying chlorsulfuron in soil and water. Weed Sci. 33:420–425.

239. Moyer, J. R., P. Bergen, and G. C. Kozub. 1989. Chlorsulfuron persistence and response of legumes in an alkaline soil. J. Environ. Sci. Health B24:37–56.

240. Muntan, L. and A. Bencivelli. 1987. Weed control in winter cereals with DPX-L5300 in Mediterranean countries. 1987 Br. Crop Prot. Conf. - Weeds. Pages 445–451.

241. Nalewaja, J. D. and K. A. Adamczewski. 1988. Thiameturon phytotoxicity to kochia (*Kochia scoparia*). Weed Sci. 36:296–300.

242. Nalewaja, J. D. and G. R. Gillespie. 1984. Postemergence broadleaf weed control in wheat. Res. Rep. North Cent. Weed Control. Conf. 37:144.

243. Nalewaja, J. D. and S. D. Miller. 1980. Weed control in flax. Res. Rep. North Cent. Weed Control Conf. 37:142–143.

244. Nalewaja, J. D. and S. D. Miller. 1981. Preemergence incorporated herbicides for foxtail control in wheat. Res. Rep. North Cent. Weed Control Conf. 38:96.

245. Nalewaja, J. D. and S. D. Miller. 1981. Postemergence foxtail control in wheat. Res. Rep. North Cent. Weed Control Conf. 38:97.

246. Nalewaja, J. D. and S. D. Miller. 1981. Broadleaf weed control in wheat. Res. Rep. North Cent. Weed Control Conf. 38:98.

247. Nalewaja, J. D. and S. D. Miller. 1981. Weed control in flax. Res. Rep. North Cent. Weed Control Conf. 38:125.

248. Nalewaja, J. D. and S. D. Miller. 1982. Postemergence foxtail control in wheat. Res. Rep. North Cent. Weed Control Conf. 39:133.

249. Nalewaja, J. D. and D. E. Peterson. 1985. Postemergence herbicides in wheat. Res. Rep. North Cent. Weed Control Conf. 42:104.

250. Nalewaja, J. D. and D. E. Peterson. 1985. Postemergence weed control in sunflower. Res. Rep. North Cent. Weed Control Conf. 42:121.

251. Nalewaja, J. D. and Z. Woznia. 1985. Environment and chlorsulfuron phytotoxicity. Weed Sci. 33:395–399.

252. Nalewaja, J. D., D. E. Peterson, and C. R. Thompson. 1985. Postemergence control in flax. Res. Rep. North Cent. Weed Control Conf. 42:124.

253. Nalewaja, J. D., G. R. Gillespie, C. R. Thompson, and N. R. Riveland. 1985. Wild oats herbicides plus sulfonyl ureas in wheat. Res. Rep. North Cent. Weed Control Conf. 42:98.

254. Nelson, D. C., S. L. Brolsma, R. L. Conlon, and M. C. Thoreson. 1985. Phytotoxicity of bentazon, metribuzin, and DPX-M6316 to eight potato cultivars. Res. Rep. North Cent. Weed Control Conf. 42:44.

255. Nelson, D. C., S. L. Brolsma, R. L. Conlon, and M. C. Thoreson. 1985. Postemergence herbicides for potato weed control, 1985. Res. Rep. North Cent. Weed·Control Conf. 42:46.

256. Nicholls, P. and A. A. Evans. 1985. Adsorption and movement in soils of chlorsulfuron and other weak acids. 1985 Br. Crop Prot. Conf. - Weeds. Pages 333–339.
257. Norris, R. F., R. A. Lardelli, and D. Ayres. 1981. Efficacy and carryover of herbicides for winter annual weed control in wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 287.
258. Norris, R. F., T. E. Kearney, L. D. Clement, and R. A. Lardelli. 1981. Postemergence herbicides for control of broadleaf weeds in wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 286.
259. Norwood, C. A. 1982. Fallow weed control with fall and spring applied herbicides. Res. Rep. North Cent. Weed Control. Conf. 39:81–82.
260. Norwood, C. A. 1982. Fallow weed control with spring applied herbicides. Res. Rep. North Cent. Weed Control Conf. 39:80–81.
261. Norwood, C. A. 1982. Extended weed control using chlorsulfuron. Res. Rep. North Cent. Weed Control Conf. 39:79.
262. Norwood, C. A. 1982. Use of chlorsulfuron in the wheat fallow and wheat sorghum fallow systems. Proc. North Cent. Weed Control Conf. 37:22–23.
263. O'Bryan, K. A. and T. F. Peeper. 1986. Development and competition of musk thistle (*Carduus nutans* L.) with winter wheat. Abstr. Weed Sci. Soc. Am. Pages 57–58.
264. O'Donovan, J. T. and P. A. O'Sullivan. 1986. Annual weed control with paraquat in combination with other herbicides. Can. J. Plant Sci. 66:153–160.
265. O'Leary, N. F. and G. N. Prendeville. 1985. Uptake and phytotoxicity of chlorsulfuron in *Zea mays* L. in the presence of 1,8-naphthalic anhydride. Weed Res. 25:331–339.
266. O'Sullivan, P. A. 1982. Response of various broadleaved weeds, and tolerance of cereals, to soil and foliar applications of DPX-4189. Can. J. Plant Sci. 62:715–724.
267. O'Sullivan, P. A. and K. J. Kirkland. 1984. Chlorsulfuron reduced control of wild oat (*Avena fatua*) with diclofop, difenzoquat, and flamprop. Weed Sci. 32:285–289.
268. Oakes, J. L., G. N. Rhodes, Jr., and R. M. Hayes. 1987. Effects of DPX-M6316 on wheat and wild garlic. Proc. South. Weed Sci. Soc. 40:78.
269. Palm, H. L., J. D. Riggleman, and D. A. Allison. 1980. Worldwide review of the new cereal herbicide - DPX 4189. Proc. Br. Crop Prot. Conf. - Weeds. Pages 1–5.
270. Peters, E. J. and R. A. McKelvey. 1982. Postemergence herbicides for control of wild garlic in winter wheat. Res. Rep. North Cent. Weed Control Conf. 39:96.
271. Peters. E. J. and R. A. McKelvey. 1984. Chlorsulfuron and related compounds for control of wild garlic in winter wheat. Abstr. Weed Sci. Soc. Am. Page 1.
272. Peters, E. J., R. McKelvey, and J. C. Smith. 1981. Postemergence herbicides on wild garlic in winter wheat. Res. Rep. North Cent. Weed Control Conf. 38:80.
273. Peterson, M. A. and W. E. Arnold. 1983. Effect of soil type on chlorsulfuron carryover in eastern South Dakota. Proc. North Cent. Weed Control Conf. 38:35.
274. Peterson, M. A. and W. E. Arnold. 1984. Bioassays for chlorsulfuron soil residues. Proc. North Cent. Weed Control Conf. 39:7.
275. Peterson, M. A. and W. E. Arnold. 1986. Response of rotational crops to soil residues of chlorsulfuron. Weed Sci. 34:131–136.
276. Peterson, P. J. and B. A. Swisher. 1985. Absorption, translocation, and metabolism of ^{14}C-chlorsulfuron in Canada thistle (*Cirsium arvense*). Weed Sci. 33:7–11.
277. Poku, J. A., H. D. Kerr, and E. J. Peters. 1981. Response of small grain cultivars to postemergence herbicides. Proc. North Cent. Weed Control Conf. 36:105–109.
278. Pollock, D. C. and R. C. Davis. 1984. Conservation tillage farming in northern New South Wales and Queensland with chlorsulfuron. Proc. 7th Aust. Weeds Conf. 2:1–7.
279. Quackenbush, L. S. and R. N. Anderson. 1985. Susceptibility of five species of the *Solanum nigrum* complex to herbicides. Weed Sci. 33:386–390.
280. Ray, T. B. 1980. Studies on the mode of action of DPX 4189. Proc. Br. Crop Prot. Conf. - Weeds. Pages 7–14.
281. Ray, T. B. 1982. The mode of action of chlorsulfuron: a new herbicide for cereals. Pestic. Biochem. Physiol. 17:10–17.
282. Ray, T. B. 1982. The mode of action of chlorsulfuron: the lack of direct inhibition of plant DNA synthesis. Pestic. Biochem. Physiol. 18:262–266.
283. Ray, T. B. 1984. Site of action of chlorsulfuron. Inhibition of valine and isoleucine biosynthesis in plants. Plant Physiol. 75:827–831.
284. Reyes, C. C. and R. L. Zimdahl. 1986. Re-cropping after chlorsulfuron use. Proc. West. Soc. Weed Sci. 39:146–147.
285. Reynolds, T. L. 1986. Effects of chlorsulfuron, valine and isoleucine, on division and tracheary element differentiation in cell suspension cultures of *Solanum carolinense* L. J. Plant Physiol. 125:179–184.
286. Rhodes, D., A. L. Hogan, L. Deal, G. C. Jamieson, and P. Haworth. 1987. Amino acid metabolism in *Lemma minor* L. II. Responses to chlorsulfuron. Plant Physiol. 84:775–780.
287. Ribo, J. M. 1988. The octanol/water partition coefficient of the herbicide chlorsulfuron as a function of pH. Chemosphere 17:709–715.
288. Ridgway, J. A., R. H. Callihan, C. H. Huston, and D. C. Thill. 1985. Effect of selective herbicides on grass and common tansy in a lowland pasture. Res. Prog. Rep. West. Soc. Weed Sci. Pages 57–58.
289. Ritter, R. L. and T. C. Harris. 1983. Residual effects of chlorsulfuron on double cropped soybeans. Abstr. Weed Sci. Soc. Am. Page 20.
290. Ritter, R. L., T. C. Harris, and L. M. Kaufman. 1988. Chlorsulfuron and metsulfuron residues on double-cropped soybeans (*Glycine max*). Weed Tech. 2:49–52.
291. Riveland, N. and G. T. Bradbury. 1985. Timing of postemergence chlorsulfuron treatments on safflower. Res. Rep. North Cent. Weed Control Conf. 42:125.
292. Riveland, N. and G. T. Bradbury. 1985. Weed control in safflower. Res. Rep. North Cent. Weed Control Conf. 42:126.
293. Riveland, N. and G. T. Bradbury. 1985. Postemergence weed control in safflower. Res. Rep. North Cent. Weed Control Conf. 42:127.
294. Robbins, J. and T. L. Rost. 1987. Chlorsulfuron inhibition of cell cycle progression and the recovery

of G1 arrested cells by Ile and Val. J. Plant Growth Regul. 6:67–74.

295. Rost, T. L. 1984. Comparative cell cycle and metabolic effects of chemical treatment on root tip meristems. III. Chlorsulfuron. J. Plant Growth Regul. 3:51–63.

296. Rost, T. L. and T. Reynolds. 1985. Reversal of chlorsulfuron induced inhibition of mitotic entry by isoleucine and valine. Plant Physiol. 77:481–482.

297. Rovira, A. D. and H. J. McDonald. 1986. Effects of the herbicide chlorsulfuron on *Rhizoctonia* bare patch and take-all of barley and wheat. Plant Dis. 70:879–882.

298. Rydrych, D. J. 1980. Selective weed control in winter wheat with DPX 4189. Res. Prog. Rep. West. Soc. Weed Sci. Page 299.

299. Rydrych, D. J. 1986. Bulbous bluegrass control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 245.

300. Sampson, T. C., G. A. Lee, and D. C. Thill. 1981. Effects of DPX-4189 compared to terbutryn on yield and weed vigor in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 293–294.

301. Sampson, T. C., D. C. Thill, and R. H. Callihan. 1982. Effect of chlorsulfuron on winter wheat yield and biomass production of rotational crops. Proc. West. Soc. Weed Sci. 35:125–126.

302. Sampson, T. C., D. C. Thill, and R. H. Callihan. 1982. Effect of chlorsulfuron soil persistence on biomass production of five crops. Res. Prog. Rep. West. Soc. Weed Sci. Pages 229–230.

303. Sauers, R. F. and G. Levitt. 1984. Sulfonylureas: new high potency herbicides. Pages 21–28 *in* P. S. Magee et al., eds. Pesticide Synthesis Through Rational Approaches. Am. Chem. Soc., Washington, DC.

304. Saxena, P. K. and J. King. 1988. Herbicide resistance in *Datura innoxia* cross-resistance of sulfonylurea-resistant cell lines to imidazolinones. Plant Physiol. 86:863–867.

305. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1983. Broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 255–256.

306. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1983. Control of wild oat and broadleaf weeds in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 257–259.

307. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1983. Postemergence broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 260–261.

308. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1983. Broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 255–256.

309. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1984. Broadleaf weed control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 166–169.

310. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1984. Wild oat and broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 178–180.

311. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1984. Broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 193–196.

312. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1985. Wild oat and broadleaf weed control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 170–172.

313. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1985. Wild oat and broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 316–317.

314. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1985. Broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 318–319.

315. Schaat, B. G., D. C. Thill, and R. H. Callihan. 1985. Broadleaf weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 320–321.

316. Scheel, D. and J. E. Casida. 1985. Sulfonylurea herbicides: growth inhibition in soybean cell suspension cultures and in bacteria correlated with block in biosynthesis of valine, leucine, or isoleucine. Pestic. Biochem. Physiol. 23:398–412.

317. Schloss, J. V., L. M. Ciskanik, and D. E. Van Dyk. 1988. Origin of the herbicide binding site of acetolactate synthase. Nature 331:360–362.

318. Schumacher, W. J., D. C. Thill, and R. H. Callihan. 1982. Influence of preemergence surface and postemergence herbicide applications for ripgut brome control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 217–218.

319. Schumacher, W. J., D. C. Thill, D. W. Morishita, and R. H. Callihan. 1982. The effect of spring-applied herbicides for broad-spectrum weed control in winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Pages 219–220.

320. Selley, A. P., P. J. Haney, and J. R. Austin. 1985. The use of metsulfuron-methyl alone and in mixture with chlorsulfuron for weed control in cereals in the United Kingdom. 1985 Br. Crop Prot. Conf. - Weeds. Pages 931–938.

321. Shea, P. J. 1982. Soil adsorption characteristics of chlorsulfuron. Proc. North Cent. Weed Control Conf. 37:54.

322. Shea, P. J. 1986. Chlorsulfuron dissociation and adsorption on selected adsorbents and soils. Weed Sci. 34:474–478.

323. Schumacher, W. J., G. A. Lee, and D. C. Thill. 1981. Broadleaf weed control in winter wheat using post applied herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Pages 295–296.

324. Sheley, R. L. and B. F. Roche. 1982. Effect of herbicides on diffuse knapweed density. Res. Prog. Rep. West. Soc. Weed Sci. Pages 22–23.

325. Sionis, S. D., H. G. Drobny, P. Lefevre, and M. E. Upstone. 1985. DPX-M6316 - a new sulfonylurea cereal herbicide. 1985. Br. Crop Prot. Conf. - Weeds. Vol. 1. Pages 49–54.

326. Slates, R. V. 1983. Determination of chlorsulfuron residues in grain, straw, and green plants of cereals by high-performance liquid chromatography. J. Agric. Food Chem. 31:113–117.

327. Smith, A. E. 1986. Persistence of the herbicides [^{14}C] chlorsulfuron and [^{14}C] metsulfuron methyl in prairie soils under laboratory conditions. Bull. Environ. Contam. Toxicol. 37:698–704.

328. Smith, A. E. and A. I. Hsiao. 1985. Transformation and persistence of chlorsulfuron in prairie field soils. Weed Sci. 33:555–557.

329. Spratling, D. L. and R. E. Whitesides. 1986. Differential tolerance of spring wheat and spring barley cultivars to three sulfonylurea herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Pages 204–206.

330. Stahlman, P. W. 1980. Herbicides for weed control in fallow. Res. Rep. North Cent. Weed Control Conf. 37:72–73.

331. Stahlman, P. W. 1980. Downy brome control in

winter wheat. Res. Rep. North Cent. Weed Cont. Conf. 37:84–85.

332. Stahlman, P. W. 1982. Weed control in fallow and herbicide effect on wheat. Res. Rep. North Cent. Weed Control Conf. 39:83–85.

333. Stahlman, P. W. 1982. Herbicides for weed control in fallow and their effect on sorghum. Res. Rep. North Cent. Weed Control Conf. 39:86–87.

334. Stahlman, P. W. 1982. Herbicides applied in early spring for weed control in fallow. Res. Rep. North Cent. Weed Control Conf. 39:88.

335. Stahlman, P. W. 1983. Effect of DPX-T6376 on winter wheat. Res. Rep. North Cent. Weed Control Conf. 40:114–115.

336. Stahlman, P. W. 1983. Wheat tolerance at two growth stages to DPX-T6376 as affected by surfactant concentration. Res. Rep. North Cent. Weed Control Conf. 40:116.

337. Stahlman, P. W. 1983. Downy brome control in winter wheat with postemergence-applied herbicides. Res. Rep. North Cent. Weed Control Conf. 40:118.

338. Stahlman, P. W. 1986. Chlorsulfuron and metsulfuron carryover in grain and forage sorghum. Proc. West. Soc. Weed Sci. 39:146.

339. Stewart, V. R. and T. K. Keener. 1983. Evaluation of broadleaf herbicides alone and in combination for weed control in Nugaines winter wheat. Res. Prog. Rep. West. Soc. Weed Sci. Page 267.

340. Strand, O. E. and D. Rabas. 1981. Weed control in oats underseeded to alfalfa at Grand Rapids, MN. 1981. Res. Rep. North Cent. Weed Control Conf. 38:81.

341. Strand, O. E. and D. Rabas. 1982. Weed control in oats underseeded to alfalfa at Grand Rapids, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:113.

342. Strand, O. E. and R. Samuelson. 1982. Weed control in spring wheat, Grant County, MN. 1982. Res. Rep. North Cent. Weed Control Conf. 39:112.

343. Sutherland, P. L. and J. H. Long, Jr. 1987. Comparative tolerance of no-till sorghum and proso millet to soil-applied chlorsulfuron as related to cropping interval. Appl. Agric. Res. 2:330–336.

344. Swann, N. B. 1984. Two new herbicides for use in spring barley in northern Britain. Proc. Crop Prot. North. Br. Pages 4–9.

345. Swanson, E. B., M. P. Coumans, G. L. Brown, J. D. Patel, and W. D. Beversdorf. 1988. The characterization of herbicide tolerant plants in *Brassica napus* L. after in vitro selection of microspores and protoplasts. Plant Cell Rep. 7:83–87.

346. Sweetster, P. B., G. S. Schow, and J. M. Hutchison. 1982. Metabolism of chlorsulfuron by plants: biological basis for selectivity of a new herbicide for cereals. Pestic. Biochem. Physiol. 17:18–23.

347. Swensen, J. B., D. C. Thill, and R. C. Callihan. 1986. Broadleaf weed control in spring barley at Potlach, Idaho. Res. Prog. Rep. West. Soc. Weed Sci. Pages 191–193.

348. Swinnerton, P. W. and R. C. Davis. 1984. Conservation tillage farming in the Wimmera with chlorsulfuron. Proc. 7th Aust. Weed Conf. 1:29–35.

349. Swisher, B. 1983. Uptake and metabolism of chlorsulfuron by Canada thistle cell cultures. Proc. North Cent. Weed Control Conf. 38:39–40.

350. Swisher, B. A. 1985. Canada thistle and field bindweed control with herbicides following annual, semiannual, or fewer applications. Res. Rep. North Cent. Weed Control Conf. 42:89–90.

351. Swisher, B. A. and M. R. Weimer. 1986. Comparative detoxification of chlorsulfuron in leaf disks and cell cultures of two perennial weeds. Abstr. Weed Sci. Soc. Am. Pages 85–86.

352. Swisher, B. A. and M. R. Weimer. 1986. Comparative detoxification of chlorsulfuron in leaf disks and cell cultures of two perennial weeds. Weed Sci. 34:507–512.

353. Thill, D. C., W. J. Schumacher, R. H. Callihan, and B. G. Schatt. 1982. Broadleaf weed control in spring barley. Res. Prog. Rep. West. Soc. Weed Sci. Pages 132–133.

354. Thirunarayanan, K., R. L. Zimdahl, and D. E. Smika. 1985. Chlorsulfuron adsorption and degradation in soil. Weed Sci. 33:558–564.

355. Thompson, C. R. 1983. Chlorsulfuron for weed control in wheat. M. S. Thesis, N.D. State Univ. 46 pp.

356. Thompson, C. R. and B. K. Hoag. 1985. Response of 'Lloyd' durum to sulfonylurea herbicides. Res. Rep. North Cent. Weed Control Conf. 42:95.

357. Thompson, C. R. and J. D. Nalewaja. 1980. Response of various species to DPX-4189 plus additives. Res. Rep. North Cent. Weed Control Conf. 37:168.

358. Thompson, C. R. and J. D. Nalewaja. 1981. Chlorsulfuron plus additives for weed control in wheat. Res. Rep. North Cent. Weed Control Conf. 38:94.

359. Thompson, C. R. and J. D. Nalewaja. 1982. Chlorsulfuron with additives for weed control in wheat. Res. Rep. North Cent. Weed Control Conf. 39:130.

360. Ulrich, T. S. 1984. Soil persistence of chlorsulfuron and metsulfuron in North Dakota. M. S. Thesis, N.D. State Univ. 87 pp.

361. Ulrich, T. S. and S. D. Miller. 1983. Soil persistence of chlorsulfuron and metsulfuron in North Dakota. Proc. North Cent. Weed Control Conf. 38:44.

362. Walker, A. and P. A. Brown. 1983. Measurement and prediction of chlorsulfuron persistence in soil. Bull. Environ. Contam. Toxicol. 30:365–372.

363. Warmund, M. R. and W. K. Patterson. 1986. Vegetative and fruiting responses of grapes to chlorsulfuron and oryzalin. HortScience 21:250–251.

364. Warner, R. W., C. W. Kral, M. A. Henson, and J. L. Saladini. 1986. Metsulfuron methyl - a new alternative for broadleaf weed control in cereals and reduced tillage fallow. Proc. West. Soc. Weed Sci. 39:129–133.

365. Wehtje, G., R. Dickens, J. W. Wilcut, and B. F. Hajek. 1987. Sorption and mobility of sulfometuron and imazapyr in five Alabama soils. Weed Sci. 35:858–864.

366. Whitesides, R. E. and D. G. Swan. 1986. Soil persistence of chlorsulfuron, dicamba, and picloram as measured in a bioassay study with peas and lentils. Res. Prog. Rep. West. Soc. Weed Sci. Page 166.

367. Whitesides, R. E. and D. G. Swan. 1986. Control of blue mustard in winter wheat from applications of bromoxynil and sulfonylurea herbicides. Res. Prog. Rep. West. Soc. Weed Sci. Page 274.

368. Whitson, T. D. and R. Costa. 1985. Spikeweed control in pastureland. Res. Prog. Rep. West. Soc. Weed Sci. Pages 50–51.

369. Whitson, T. D. and R. Costa. 1986. Spikeweed control in pastureland. Res. Prog. Rep. West. Soc. Weed Sci. Pages 39–40.

370. Whitson, T. D. and R. Costa. 1986. Evaluation of various herbicides for control of yellowstar thistle (*Centaurea solstitialis* L.). Res. Prog. Rep. West. Soc. Weed Sci. Page 51.

371. Whitson, T. D. and M. A. Ferrell. 1986. Evaluations of herbicides for Canada thistle control. Res. Prog. Rep. West. Soc. Weed Sci. Page 55.

372. Whitson, T. D. and B. Tuck. 1986. Evaluation of herbicides for field bindweed (*Convolvulus arvensis* L.) control and crop tolerance. Res. Prog. Rep. West. Soc. Weed Sci. Page 190.

373. Whitson, T. D., M. A. Ferrell, and H. P. Alley. 1986. Evaluations of fall applications of herbicides for control of downy brome. Res. Prog. Rep. West. Soc. Weed Sci. Page 22.

374. Whitson, T. D., K. French, D. Humphrey, and P. S. Friedrichsen. 1986. Herbicide applications at three growth stages for control of rush skeletonweed (*Chondrilla juncea* L.). Res. Prog. Rep. West. Soc. Weed Sci. Pages 36–37.

375. Whitson, T. D., D. Humphrey, P. S. Friedrichsen, and K. French. 1986. Evaluation of herbicides for control of St. Johnswort (*Hypericum perforatum* L.) in pastureland. Res. Prog. Rep. West. Soc. Weed Sci. Page 48.

376. Whitson, T. D., B. Hawkes, J. Brown, D. Humphrey, and D. Langland. 1985. Effect of herbicide treatments on tansy ragwort control. Res. Prog. Rep. West. Soc. Weed Sci. Pages 52–53.

377. Whitson, T. D., B. Hawkes, J. Brown, D. Humphrey, and D. Langland. 1986. Effect of herbicide treatments on tansy ragwort control. Res. Prog. Rep. West. Soc. Weed Sci. Pages 53–54.

378. Wicks, G. A., C. R. Fenster, and S. A. Valenti. 1983. Herbicides for controlling weeds in winter wheat and stubble. Abstr. Weed Sci. Soc. Am. Page 18.

379. Wicks, G. A., P. T. Nordquist, and J. W. Schmidt. 1987. Response of winter wheat (*Triticum aestivum*) to herbicides. Weed Sci. 35:259–262.

380. Wiese, A. F., M. L. Wood, and E. W. Chenault. 1988. Persistence of sulfonylureas in Pullman clay loam. Weed Technol. 2:251–256.

381. Woznia, Z. J. and J. D. Nalewaja. 1981. Environment and chlorsulfuron phytotoxicity. Proc. North Cent. Weed Control Conf. 36:55.

382. Wright, S. D., L. W. Mitich, and R. S. Neilson. 1985. Wild oat and coast fiddleneck control in dryland barley using tank mix combination. Res. Prog. Rep. West. Soc. Weed Sci. Pages 177–178.

383. Xiao, W., P. K. Saxena, J. King, and G. H. Rank. 1987. A transient duplication of the acetolactate sysnthase gene in a cell culture of *Datura innoxia*. Theor. Appl. Genet. 74:417–422.

384. Yadav, N., R. E. McDevitt, S. Benard, and S. C. Falco. 1986. Single amino acid substitutions in the enzyme acetolactate synthase confer resistance to the herbicide sulfometuron methyl. Proc. Nat. Acad. Sci. U.S.A. 83:4418–4422.

385. Young, F. L. and D. R. Gealy. 1984. Evaluation of chlorsulfuron for Russian thistle (*Salsola kali* L. var. *rusthenica*) control. Abstr. Weed Sci. Soc. Am. Page 5.

386. Young, F. L. and D. R. Gealy. 1986. Control of Russian thistle (*Salsola iberica*) with chlorsulfuron in a wheat (*Triticum aestivum*) summer-fallow rotation. Weed Sci. 34:318–324.

387. Young, F. L. and R. E. Whitesides. 1987. Efficacy of postharvest herbicides on Russian thistle (*Salsola iberica*) control and seed germination. Weed Sci. 35:554–559.

388. Zahnow, E. W. 1984. On the analysis of the herbicide chlorsulfuron in soil by liquid chromatography. J. Agric. Food Chem. 32:953.

389. Zahnow, E. W. 1985. Analysis of the herbicide sulfometuron methyl in soil and water by liquid chromatography. J. Agric. Food Chem. 33:479–483.

390. Zahnow, E. W. 1985. Analysis of the herbicide sulfometuron methyl in fish and green plants by liquid chromatography. J. Agric. Food Chem. 33:1206–1208.

391. Zamora, D. L., D. C. Thill, and R. H. Callihan. 1986. Efficacy of sequential applications of selected herbicides on control. Res. Prog. Rep. West. Soc. Weed Sci. Pages 17–18.

392. Zamora, D. L., D. C. Thill, and R. H. Callihan. 1986. Efficacy of spring-applied herbicides on control, density, and biomass of common crupina. Res. Prog. Rep. West. Soc. Weed Sci. Pages 19–20.

393. Zamora, D. L., D. C. Thill, and R. H. Callihan. 1986. Broadleaf weed control in spring barley at Bonners Ferry, Idaho. Res. Prog. Rep. West. Soc. Weed Sci. Pages 194–195.

394. Zimdahl, R. L. 1981. Canada thistle control with Dowco-290 and DPX-4189. Res. Prog. Rep. West. Soc. Weed Sci. Pages 6–7.

395. Zimdahl, R. L. and W. A. Fithian. 1984. Chlorsulfuron soil persistence. Res. Prog. Rep. West. Soc. Weed Sci. Pages 278–281.

396. Zollinger, R. K. and J. O. Evans. 1985. Effects of chlorsulfuron on meiosis and seed viability in rye (*Secale cereale* L.). Proc. West. Soc. Weed Sci. 38:114–118.

397. Zuris, N. K. and R. G. Wilson. 1984. Effect of plant growth stage and rate of chlorsulfuron on Canada thistle control. Proc. North Cent. Weed Control Conf. 39:79.

398. Zuris, N. K., R. G. Wilson, and L. A. Nelson. 1987. Effects of plant growth stage on chlorsulfuron suppression of Canada thistle (*Cirsium arvense*) shoots and roots. Weed Technol. 1:10–13.