Field Duration of Chlorsulfuron Bioactivity in the Central Great Plains[1]

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ABSTRACT

The duration of chlorsulfuron {2-chloro-*N* [(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl]benzenesulfonamide} bioactivity in Central Great Plains soils was determined by measuring the influence of several environmental factors on chlorsulfuron degradation. Chlorsulfuron was applied at 35 and 70 g ha^{-1} to four soils: Platner sandy loam and Weld (Aridic Paleustolls) loam at Akron, CO; Roxbury (Cumulic Haplustoll) silt loam at Jetmore, KS; and Rosebud (Aridic Argiustolls) sandy loam at Chugwater, WY. Soil pH, organic matter level, number of precipitation events >0.25 cm, and leaching were the major environmental factors influencing chlorsulfuron duration of bioactivity. A chlorsulfuron rate × soil × year interaction occurred, but this interaction was not consistent over all soils. A model developed for predicting chlorsulfuron duration of bioactivity would be more accurate if designed for soils with similar organic matter levels, as organic matter level influenced duration of bioactivity and leaching of chlorsulfuron. Chlorsulfuron leaching was also affected by soil type and year of study. In greenhouse bioassay studies, sunflower (*Helianthus annuus* L.) did not differ from corn (*Zea mays* L.) in sensitivity to chlorsulfuron residues in soil.

Additional Index Words: soil pH, leaching, model, bioassay, pesticides.

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Chlorsulfuron {2-chloro-*N*[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl]benzenesulfonamide} controls broadleaf weeds in winter wheat (*Triticum aestivum* L.) and on fallow land following winter wheat in the Central Great Plains. Chlorsulfuron is highly active in soil at the recommended rates of 13 to 26 g ha^{-1}, and its duration of weed control usually exceeds 1 yr (5, 7). Many crops, however, are very sensitive to chlorsulfuron in soil; corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.), and safflower (*Carthamus tinctorius* L.) have been injured up to 3 yr after application in Colorado and Montana (7).

The wheat-fallow cropping system is the prevalent rotation method in the drier parts of the Central Great Plains (9), but hectarage of a winter wheat–spring crop–fallow rotation is increasing because of improved precipitation storage in the soil during noncrop periods by use of chemical and minimum-till fallow systems. The spring crops successful in this rotation include corn, safflower, and proso millet (*Panicum miliaceum* L.) (1, 4). Since these crops are highly sensitive to chlorsulfuron (7), an understanding of the duration of chlorsulfuron bioactivity in the Central Great Plains would aid in developing guidelines for the use of chlorsulfuron in weed management systems for this two-crop-in-3-yr rotation.

Walker and Brown developed a model for predicting chlorsulfuron persistence in one soil type based on two variables, soil-water content and soil temperature (18). Their results indicated that the model gave a reasonable description of the soil persistence of chlorsulfuron. Laboratory and greenhouse studies have identified two additional environmental factors affecting chlorsulfuron degradation, soil pH and soil texture (2, 3, 10, 17, 18). Another factor that may affect residual amounts of chlorsulfuron is its leaching potential, which has been determined by thin-layer chromatography (12). If chlorsulfuron leaches readily in field situations, this may influence duration of bioactivity. If the influence of these environmental factors on chlorsulfuron degradation in field soils is consistent over several locations, a regional model for predicting chlorsulfuron persistence in the Central Great Plains could be developed. This model would then supply the guidelines for chlorsulfuron use within this winter wheat–spring crop–fallow rotation without spring crop phytotoxicity occurring.

The objectives of this study were to (i) determine if the influence of the environmental factors affecting chlorsulfuron degradation are consistent over four locations in the Central Great Plains, thus being suitable for a regional model predicting chlorsulfuron duration of bioactivity; (ii) determine if leaching of chlorsulfuron occurs in field situations, and if so, whether it varies among soil types; and (iii) determine if corn and sunflower vary in their sensitivity to chlorsulfuron residues in soil.

MATERIALS AND METHODS

In 1983 and 1984, chlorsulfuron was applied at 35 and 70 g ha^{-1} to four soils in the Central Great Plains: Platner sandy loam (fine, montmorillonitic, mesic Aridic Paleustoll) and Weld loam (fine, montmorillonitic, mesic Aridic Paleustoll) located near Akron, CO; Roxbury silt loam (fine-silty, mixed, mesic Cumulic Haplustoll) located near Jetmore, KS; and Rosebud sandy loam (fine-loamy, mixed, mesic Aridic Argiustolls) located near Chugwater, WY. A different site within the same soil type was used each year. The physical characteristics of each site are presented in Table 1. The herbicide was applied with a sprayer at a delivery rate of 225 L ha^{-1}. The spraying dates at each site are listed in Table 1. Weather data for each site over the duration of the study was obtained from the nearest weather station. A randomized complete block design with four replications was used at all sites. Individual plots were 4 by 8 m long. Soil samples were collected in 5-cm increments with a 6-cm diam soil probe to a depth of 10 cm for the first sampling year and 15 cm in the second sampling year. Treated and nontreated soil samples were collected initially 290 d after application, and every 45 d thereafter until chlorsulfuron bioactivity ceased. Samples were stored at −5 °C until analyzed.

The duration of chlorsulfuron bioactivity was determined with a corn root bioassay. Subsamples of 350 g of the collected soils were placed in 9-cm diam by 9 cm deep plastic pots (without drainage holes). Corn seeds were pregerminated at 24 °C for 48 h for the bioassay. Three seedlings with radicles 1 to 5 mm long were planted 5 to 10 mm deep in each pot. Soil-water level for each soil was established at 80% field capacity (67 mPa) and the pots were covered with aluminum foil to reduce evaporation. After incubation for 96 h at 24 °C, the corn seedlings were

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Table 1. Characteristics of the four soils used for the chlorsulfuron degradation study and the dates of chlorsulfuron application at each site.

Soil and location	Study site	pH†	Organic matter	Sand	Silt	Clay	Cation exchange capacity	Date of application
				kg kg^{-1}			mmol$_c$ kg^{-1}	
Platner sandy loam,	1‡	6.8	0.009	0.79	0.11	0.10	140	11 Aug. 1983
Colorado	2	5.8	0.008	0.59	0.23	0.18	170	30 Aug. 1984
Weld loam,	1	6.8	0.013	0.38	0.39	0.23	240	11 Aug. 1983
Colorado	2	6.4	0.012	0.32	0.46	0.22	220	30 Aug. 1984
Roxbury silt loam,	1	7.8	0.022	0.19	0.56	0.25	300	21 Aug. 1983
Kansas	2	7.4	0.021	0.18	0.49	0.33	340	28 Oct. 1984
Rosebud sandy loam	1	6.5	0.011	0.77	0.10	0.13	140	14 Sept. 1983
Wyoming	2	8.1	0.013	0.73	0.17	0.10	125	6 Sept. 1984

† Soil pH was determined by the saturated paste method (14).
‡ The time period for the first site for each soil was 1983 to 1984, and 1984 to 1985 for the second site.

removed from the soil and the longest primary root of each corn seedling was measured to the nearest millimeter.

Corn was allowed to grow for the full season in 1985 on the Weld loam site at Akron, CO, which had been treated with chlorsulfuron 21 months previously. 'Pioneer 3732' corn was planted without tillage at 38 000 seeds ha^{-1} on 8 May 1985. The area was treated with 1.2 kg ha^{-1} of atrazine [6-chloro-*N*-ethyl-N'(1-methylethyl)-1,3,5-triazine-2,4-diamine] immediately after planting. On 28 June and 11 August, 1 m of row of corn was harvested from each plot to determine wet weight of aboveground biomass. Two rows of corn, 3 m long, were harvested for grain yields and seed test weight on 15 October.

To determine whether sunflower differed from corn in its sensitivity to chlorsulfuron residue in soil, five sunflower (Northrup-King Hybrid 223) seeds were planted in the Weld loam soil samples immediately after the corn root bioassay was completed. The sunflower seedlings were thinned to two per pot after emergence and watered daily for 21 d. The aboveground biomass (wet weight) was then recorded. The data were expressed as percent growth inhibition, using the nontreated control for comparison.

RESULTS AND DISCUSSION

A significant chlorsulfuron rate × soil type × year interaction affected the duration of chlorsulfuron bioactivity within the four soils. The mean duration of bioactivity over years for 35 g ha^{-1} of chlorsulfuron varied by only 10% among the four soils, but variation among the individual years was 50% (Table 2). The largest variation between years occurred with the Rosebud sandy loam and the Roxbury silt loam. An increase of 139 d for the duration of bioactivity occurred with the Rosebud sandy loam at the second site. The soil pH at this site was 8.1 compared to 6.5 for the first site (Table 1). Chlorsulfuron degradation is reduced in basic soils (3, 8, 10, 13), explaining the increased duration of bioactivity with this soil at the second site. A drought during July and August in 1984 increased the duration of bioactivity 36% with the Roxbury silt loam (Table 2). The soil pH was similar for both sites with this soil (Table 1). A soil type effect on duration of bioactivity occurred at Akron, as chlorsulfuron degraded more rapidly with the Platner sandy loam in both years (Table 2).

A multiple regression analysis of the 35 g ha^{-1} of chlorsulfuron data from all sites indicated that 82% of the variance (r^2) was explained by variation in soil pH, air temperature, number of precipitation events, cation exchange capacity, clay content, and organic matter levels. A step-wise regression analysis indicated that duration of chlorsulfuron bioactivity was influenced most by soil pH in this study, followed by organic matter level and number of precipitation events. The trend over all sites was increased duration of bioactivity at higher soil pH, agreeing with previous research (10, 16, 17). However, exceptions to this trend occurred with the Roxbury silt loam. The duration of chlorsulfuron bioactivity in this soil at site 2, having a pH of 7.4, was not statistically different from its duration of bioactivity at the second site of the Platner sandy loam, which had a pH of 5.8. Chlorsulfuron is absorbed by organic matter (15), which reduces its availability for plant uptake (3). The Roxbury silt loam level of organic matter was 0.021, over twice the organic matter level of the Platner sandy loam, thus reducing chlorsulfuron duration of bioactivity in this soil.

A linear regression analysis of the pH effect on chlorsulfuron duration of bioactivity in all soils resulted in a coefficient of determination (r^2) of 0.51. By analyzing only the soils with similar organic matter levels (Platner sandy loam, Weld loam, and the Rosebud sandy loam), the coefficient of determination increased to 0.78. Thus, a model predicting chlorsulfuron persistence would be more accurate if applied to soil groups with similar

Table 2. Length of time required before inhibition of corn root growth by chlorsulfuron was <20% at the four soils at both sites.

Soil	Study site†	Chlorsulfuron, g ha^{-1} 35	Soil mean	70	Soil mean
		d			
Platner sandy loam	1	338	314	360	335
	2	290		319	
Weld loam	1	368	336	367	362
	2	304		336	
Roxbury silt loam	1	384	334	405	353
	2	283		300	
Rosebud sandy loam	1	276	345	327	457
	2	415		587	
Chlorsulfuron rate mean			332		376

LSD (0.05) for soil levels = 6.0
LSD (0.05) for year levels = 4.2
LSD (0.05) for rate levels = 4.2
LSD (0.05) for soil × year × rate interaction = 12.0

† The first site was treated in 1983 to 1984, and the second site in 1984 to 1985.

Table 3. The total precipitation and the number of events with >0.25 and 0.64 cm of precipitation occurring during the duration of bioactivity of 35 g ha⁻¹ of chlorsulfuron with the four soils.

Soil	Study sites†	Duration of bioactivity	Rainfall events (cm) >0.25	Rainfall events (cm) >0.64	Total precipitation
		d	no.	no.	cm
Platner sandy loam	1	338	22	13	34
	2	290	21	12	27
Weld loam	1	368	26	16	47
	2	304	24	12	28
Roxbury silt loam	1	384	18	10	51
	2	283	19	12	35
Rosebud sandy loam	1	276	8	2	27
	2	415	24	12	32

† The first site was treated in 1983 to 1984, and the second site in 1984 to 1985.

Table 4. The percent corn root growth inhibition by 70 g kg⁻¹ of chlorsulfuron at various soil depths approximately 290 d after application at the four sites in both years.

Soil	1983–1984 0–5	1983–1984 5–10	1983–1984 Mean	1984–1985 0–5	1984–1985 5–10	1984–1985 10–15	1984–1985 Mean
	% growth inhibition			% growth inhibition			
Platner sandy loam	33	28	31	20	5	2	16
Weld loam	55	62	59	55	29	31	38
Roxbury silt loam	54	24	39	22	4	7	11
Rosebud sandy loam	67	54	61	58	54	54	55
Mean	52	42		39	23	24	

Soil depth, cm.

LSD (0.05) for soil by soil depth interaction = 9; LSD (0.05) for soil levels = 7; LSD (0.05) for soil depth levels = 5 (1983–1984).

LSD (0.05) for soil by soil interaction = 3; LSD (0.05) for soil levels = 3; LSD (0.05) for soil depth levels = 3 (1984–1985).

organic matter levels, since the pH effect on chlorsulfuron degradation was more consistent among these soils in this study.

With precipitation, the number of events with >0.25 cm of precipitation was a more accurate measure of the influence of precipitation on duration of chlorsulfuron bioactivity within a soil type than the total amount received (Table 3). With three of the soils, Platner sandy loam, Weld loam, and Roxbury silt loam, the range of number of precipitation events occurring over the duration of bioactivity for each site was within 10% for each soil, whereas the total precipitation levels over the duration periods for individual soils ranged from 26 to 68%. The large pH difference with the Rosebud sandy loam minimized the influence of precipitation on chlorsulfuron breakdown in this soil. Variability was higher when the number of precipitation events >0.64 cm of water was compared between sites within a soil type.

When the rate of chlorsulfuron was doubled, from 35 to 70 g ha⁻¹, the duration of bioactivity in the top 5 cm of soil increased only 13% over all sites (Table 2). In previous field studies conducted in northeastern Colorado the duration of chlorsulfuron weed control in a chemical fallow program was increased 42% by doubling its rate (5). The explanation for the small increase of chlorsulfuron duration in this study was leaching (Table 4). This leaching of chlorsulfuron reduced its concentration in the upper 5 cm of soil, thus shortening its duration of bioactivity in this soil layer. Chlorsulfuron leaching to a depth of 10 cm has also been found in Canadian prairie soils (16).

Chlorsulfuron leaching was affected by soil type and year of study. From 1983 to 1984, high levels of leaching occurred with all soils except the Roxbury silt loam, shown by comparing the ratio of percent growth inhibition (GI) between the 0- to 5- and 5- to 10-cm depths within each soil (Table 4). The percent GI in the 5- to 10-cm depth for the Roxbury silt loam was less than half of that in the 0- to 5-cm depth, whereas similar levels of percent GI occurred at both depths for the other soils. Herbicide leaching is influenced by its adsorption on the solid phase of soil and level of water flow through the treated soil (11). Because chlorsulfuron is adsorbed by organic matter (15), a situation reducing movement (8), the higher organic matter level and cation exchange capacity in the Roxbury silt loam (Table 1) reduced chlorsulfuron leaching (Table 4). Chlorsulfuron leached less in 1984 to 1985 with the Platner sandy loam, Weld loam, and Roxbury silt loam, as shown by the low levels of percent GI at the 5- to 10-cm depth (Table 4). This is explained by a reduction in total precipitation at the second sites (Table 3), because herbicide movement is closely related to amount of water passing through the soil (11). Chlorsulfuron readily leached in the Rosebud sandy loam at both sites, regardless of rainfall level. Leaching of chlorsulfuron influenced duration of bioactivity and was affected by organic matter level in the soil. A model assessing chlorsulfuron persistence will need to evaluate leaching as affected by soil type to enhance accuracy of prediction.

Because chlorsulfuron leaches, it moves into more basic subsoils in the Central Great Plains (6), a pH condition that could result in extended chlorsulfuron persistence (10, 17). This distribution of chlorsulfuron in the lower soil profile may reduce season-long growth of susceptible crops planted in succeeding years. At the first Weld loam site where extensive leaching occurred, corn biomass production and grain yield were not affected by chlorsulfuron soil activity during the 1985 growing season (Table 5). Thus, if chlorsulfuron leached below 15 cm, sufficient degradation of the leached chlorsulfuron in the subsoil occurred so that corn production was not affected 2 yr after application.

Table 5. Aboveground biomass and grain yield of corn grown 550 d after chlorsulfuron application on the Weld loam at Akron, CO, in 1985.

Chlorsulfuron rate	Wet weight of aboveground biomass: June 28	Wet weight of aboveground biomass: August 11	Grain harvest: Yield	Grain harvest: Test weight
g ha⁻¹	g m-row⁻¹	g m-row⁻¹	kg ha⁻¹	kg hL⁻¹
35	980	4980	8770	71.5
70	940	4800	8140	72.1
Control	1000	4780	8080	71.1
LSD (0.05)	NS	NS	NS	NS

Table 6. Comparison of growth inhibition by chlorsulfuron of aboveground biomass of sunflower and corn root growth in Weld loam soil.†

	Chlorsulfuron, g ha^{-1}			
	1984		1985	
Crop	35	70	35	70
	% growth inhibition			
Corn	56	55	34	55
Sunflower	54	59	33	57
LSD (0.05)	NS	NS	NS	NS

† Soil samples were collected approximately 330 and 290 d after application in 1984 and 1985, respectively.

Sunflower is another crop grown in the Central Great Plains. If sunflower differed from corn in tolerance to chlorsulfuron in soil, options in crop selection would exist for production systems involving chlorsulfuron usage. However, Table 6 shows that the percent growth inhibition of aboveground biomass of sunflower did not significantly differ from corn root growth reduction when similar levels of chlorsulfuron concentrations in soil were compared (from samples collected 330 and 290 d after application in 1984 and 1985, respectively). Thus, differential crop tolerance to chlorsulfuron did not occur between corn and sunflower.

In summary, the interaction of environmental factors in affecting duration of chlorsulfuron bioactivity was not consistent over all soils. A region-wide model for predicting chlorsulfuron persistence would be more accurate if designed for soils with similar organic matter levels, because organic matter level influenced duration of bioactivity and leaching of chlorsulfuron. Also, due to its leaching, repeated applications of lower rates of chlorsulfuron may be more efficient in maintaining herbicide activity in the surface 5 cm of soil than a single application at a higher rate. Producers should be aware that wide variation in soil pH may exist within a soil type, as occurred with the Rosebud sandy loam. This pH variation may result in areas within a treated field where phytotoxicity occurs to susceptible crops in following cropping seasons.

Chlorsulfuron is also applied to growing winter wheat before the boot growth stage at the rate range of 14 to 26 g ha^{-1} (5). In our study, 35 g ha^{-1} of chlorsulfuron applied after wheat harvest persisted for an average of 332 d over all soils, with the longest duration of bioactivity being 415 d (Table 2). Chlorsulfuron up to 26 g ha^{-1} could be applied in the fall to winter wheat, without phytotoxicity occurring to corn planted in May, 550 d (18 months) after chlorsulfuron application. Thus, chlorsulfuron is suitable for weed management systems for winter wheat in a winter wheat–corn–fallow rotation on these soil types in the Central Great Plains.

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