Impact of Sulfonylurea Herbicides on Rhizoctonia Root Rot, Growth, and Yield of Winter Wheat

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ABSTRACT

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Chlorsulfuron and metsulfuron-methyl were examined for their potential to predispose winter wheat to Rhizoctonia root rot in eastern Oregon. Soil treated or not treated with chlorsulfuron in the field was collected as intact cores, infested with *Rhizoctonia solani* AG-8, *R. oryzae*, or neither, and evaluated in the greenhouse for effects on disease severity, growth, and development of winter wheat. Seedlings in chlorsulfuron-treated soil had more severe root rot and reduced growth than did those in untreated soil. Eight field experiments were performed at two root rot–affected sites to examine the effect of preplant and postemergence applications of chlorsulfuron on tilled and untilled soil. These studies were performed over two crop seasons, and chlorsulfuron + metsulfuron-methyl was included during 1 yr. Seedlings always had more severe Rhizoctonia root rot and grew less vigorously in plots treated with sulfonylurea herbicides. With time, however, the negative impacts dissipated, and herbicide-treated plots had grain yields that differed from untreated plots in only one of eight experiments. Yield was increased by sulfonylurea herbicides in one experiment, and this was apparently not entirely related to differences in weed populations. Although sulfonylurea herbicides interacted with *Rhizoctonia* spp. to damage roots of winter wheat seedlings, this did not have a direct relationship with the yield of grain under the conditions studied.

Tillage, herbicides, or both are required to control annual broadleaf and grass weeds in the winter wheat (*Triticum aestivum* L.) and summer fallow rotations of the Pacific Northwest. A major advance in weed control was achieved when chlorsulfuron (Glean) became commercially available in 1984. This broad spectrum, preemergence and postemergence sulfonylurea herbicide was accepted rapidly by large numbers of producers because it controls many of the weeds occurring in the region (1,7,23). A related product, composed of chlorsulfuron + metsulfuron-methyl (Finesse), has also been registered for use in small grains. Sulfonylurea herbicides are absorbed by roots and foliage and translocated in the plant to cause death of susceptible species by inhibition of amino acid biosynthesis in both roots and shoots (10). Cereals are considered tolerant because they have the capacity to degrade this group of herbicides into inactive products.

One year after chlorsulfuron was commercialized and immediately achieved extensive use, Rhizoctonia root rot, caused by *Rhizoctonia solani* Kühn AG-8 (teleomorph *Thanatephorus cucumeris* (A. B. Frank) Donk) and *R. oryzae* (Ryker & Gooch) (teleomorph *Waitea circinata* Warcup & Talbot WAG-0) (21) was found to be a widespread and important (but previously undetected) disease of winter wheat in Oregon, Washington, and Idaho (22,30). In Oregon during 1986 and 1987, the authors observed that all fields severely affected by this disease had also been treated earlier with chlorsulfuron and questioned whether this was a coincidence or a causal relationship. At about the same time, a report from Australia (26) indicated that chlorsulfuron caused a dramatic increase in the incidence of Rhizoctonia root rot and up to a 50% reduction in yield of spring wheat and barley. The herbicide had no apparent effect on small grains grown in pathogen-free soil (26).

Although interactions among herbicides, soilborne plant pathogenic fungi, and soil and climatic factors are common (3,4), whether the Australian experience with spring cereals was pertinent to production systems for winter wheat in the Pacific Northwest remained unclear. Of considerable importance is the knowledge that persistence of sulfonylurea herbicides is greatly affected by soil pH, rainfall, and soil temperature (2,5,7,10,18,29); that wheat cultivars differ in tolerance to chlorsulfuron (6,8,14,17,31); and that environmental factors affect the sensitivity of winter wheat to sulfonylurea herbicides (8,12,18). The disease-inducing influence of chlorsulfuron in Australia was on a calcareous loam with pH 8.3, which contrasts with wheat-growing soils in the Pacific Northwest, which rarely have pH values above 7.5 (and usually below 6.0). In the semiarid Pacific Northwest, chlorsulfuron is not registered for use on soils with pH values above 7.9, because of the greatly extended residual activity of this compound in alkaline soils (2). Chlorsulfuron has been shown to be very effective for use on winter wheat in North America (6,9,16,31), but apparently none of the tests were performed on soils known to be infested with species of *Rhizoctonia*. In tests conducted in western Oregon, chlorsulfuron caused only minor injury to and little or no reduction in grain yield of the dominant cultivar (Stephens) of winter wheat produced in eastern Oregon (9).

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The objective of this study was to determine the effects of chlorsulfuron and chlorsulfuron + metsulfuron-methyl applied to soil infested with *R. solani* AG-8 on root diseases, growth, development, and grain yield of winter wheat in semiarid eastern Oregon.

MATERIALS AND METHODS

Greenhouse experiment. A study was conducted to examine the impact of chlorsulfuron on the growth, development, and root rot of two winter wheat cultivars grown in soil infested with *R. solani* AG-8 or *R. oryzae*.

Chlorsulfuron was applied (13.2 g/ha on 19 September 1987) with a boom-type sprayer (38 L/ha) to a 10- × 10-m area in a field not previously treated with sulfonylurea herbicides. The herbicide was not incorporated into the soil, but was immediately activated and stabilized by applying 2 cm of water with a sprinkler. An adjacent area of untreated soil, maintained as the control, was also watered before the onset of autumn rains. The field was maintained as an unplanted, weed-free, summer fallow field at the Columbia Basin Agricultural Research Center, 13 km northeast of Pendleton. Wheat plants previously produced on the field were not known to have been affected by Rhizoctonia root rot, although a low level of inoculum of the pathogen(s) is indigenous in the region. The soil was a well-drained Walla Walla silt loam (coarse-silty mesic Typic Haploxeroll) with a surface pH (in 0.01 M $CaCl_2$) of 5.3–5.6. Intact soil cores contained in plastic cylinders (8 cm in diameter and 13 cm high) were randomly collected from the untreated and treated areas on 10 November 1987. These samples were collected with a special soil sampler (28), in which cylinders made from plastic drain tile were inserted into the sampling tube prior to driving the sampler into the soil. A plastic plate was placed under each soil core to retard evaporative water loss from the bottom of the soil column.

Soil cores were incubated at 20–28 C on greenhouse benches. The soil was moistened to approximately −0.1 MPa potential on 2 December, and an experiment with a factorial design was initiated on 15 December. Each of 32 cores was infested with *R. solani* AG-8, *R. oryzae*, or neither pathogen by inserting four pathogen-infested millet seeds (20). Inoculum was placed 5 cm deep at equidistant intervals 1 cm from the perimeter of each core. Sterile millet seeds were inserted into uninoculated soils. On 5 January 1988, the experiment was further divided by planting four seeds per pot of either Stephens or Oveson soft white winter wheat at a depth of 1.5 cm. Wheat seeds were placed between two adjacent sources of inoculum. Four replicate pots of each treatment were prepared for sampling after 300 and 600 postemergence growing-degree days. Watering was performed as needed to maintain the moisture content between −0.1 and −1 MPa potential. No fertilizer was applied.

At the appropriate sampling periods (1 and 24 February), soil was gently washed from the roots, and the plants were refrigerated (at 4 C) until evaluated. Rhizoctonia root rot of seminal roots was assessed using the following severity index: 0 = no lesions, 1 = lesions on <25% of first-order and <50% of second-order lateral branches, 2 = lesions on 25–50% of first-order and >50% of second-order lateral branches, 3 = lesions on >50% of first-order lateral branches, 4 = lesions on one or two main axes, and 5 = lesions on three or more main axes. Other determinations included the Haun growth stage (11,15), number of root axes crossing a horizontal plane 5 cm below the caryopsis, height of longest leaf, and shoot weight. An approximation of root intercepts at a 5-cm depth was made at 600 growing-degree days, using the scale of 1 = <10 root axes, 2 = 10–20, 3 = 21–40, and 4 = >40.

Portions of the greenhouse experiment were performed in a preliminary study that included only one cultivar (Stephens) and one sampling at approximately 600 growing-degree days.

Field experiments. Two experimental locations with production constraints from Rhizoctonia root rot were selected for experiments to determine the impact of chlorsulfuron and chlorsulfuron + metsulfuron-methyl on diseases and development of two winter wheat cultivars. Both sites are in Umatilla County, Oregon. Site 1 (Wolfe farm) is in a 300-mm precipitation zone 13 km southwest of Pendleton, with a Condon silt loam (fine silty, mixed, mesic Typic Haploxeroll) that is moderately deep (basalt at about 80 cm) and well drained, with a surface horizon pH (in 0.01 M $CaCl_2$) of 6.8. Site 2 (Thompson farm) is in a 350-mm precipitation zone 24 km north of Pendleton, with a Walla Walla silt loam (coarse silty, mesic Typic Haploxeroll) that is deep (>150 cm to basalt), well drained, and has a surface pH of 6.3.

Experiments at site 1 were performed on a field that had been utilized for no-till annual recrop winter barley for four consecutive years. Experiments at site 2 were performed on a field with a long history of 2-yr wheat and fallow rotation, using stubble mulch tillage systems that retain moderate amounts of plant residue on or near the soil surface. Each of the fields is naturally infested with pathogenic species of *Rhizoctonia*, as described by Ogoshi et al (21). Roots of affected plants selected from previous crops yielded a mixture of *R. solani* AG-8 and *R. oryzae* at site 1 and *R. solani* AG-8 at site 2.

1987–1988. Split-plot experiments at the two field sites during 1987–1988 included main plots of two tillages and subplots of two wheat cultivars and two dates of chlorsulfuron application (plus untreated), with four replications. Main plots were strips (7 × 102 m) that were either not tilled or tilled with a moldboard plow on 18 September 1987. The main plots were then each divided into six subplots (7 × 17 m) that included either Stephens or Oveson wheat planted into untreated soil or into soil treated with chlorsulfuron before planting or after emergence. The preplant application of chlorsulfuron (13.2 g/ha) was made on 18 September. On 28 September, the plowed plots were prepared for planting by using a skew treader and light disking. The 48 plots were planted on 26 October, using a drill equipped with modified slit openers (model HZ, Deere & Co., Moline, IL [32]) and a cone seeder. Seed was delivered into 40-cm row spacings at 80 kg/ha. Liquid urea was dispensed 5 cm below the seed at the rate of 55 kg N/ha at the time of planting. Autumn and early winter rainfall were sparse throughout the region, causing seedling emergence to vary from mid-November to late December, depending upon the initial soil moisture. The postemergence application of chlorsulfuron (13.2 g/ha) was delayed until 15 March.

During mid-spring (16 April) of 1988, at Haun plant growth stages 4 or 5 (e.g., 4 or 5 fully extended leaves on the main stem [11,15]), 25 or more seedlings were removed from each field plot for morphologic and disease assessments, as described for the greenhouse experiment. Seedlings were rinsed to remove adhering soil from root systems. Growth parameters measured on 25 seedlings per plot included plant growth stage, numbers of seminal and coronal roots per plant at 3 and 5 cm below the caryopsis, maximum leaf length, oven-dry shoot weight, number of tillers per plant, and the disease severity index for Rhizoctonia root rot. Routine isolations were made from symptomatic roots. Root segments were washed under running water for 3 hr and then placed, without surface disinfection, onto 2% water agar amended with 50 μg of rifampicin per milliliter. Emerging fungal isolates were transferred onto 0.5-strength potato-dextrose agar for further growth and identification. Grain yields and test weights were measured at maturation (mid-July) by threshing plants in four rows of each plot. Data were analyzed separately for each experimental site.

1989–1990. The main-plot tillage variable for the experiments described above was continued through a fallow season from summer 1988 through summer 1989. On 23 April 1989, the tilled plots were weeded with a spring-tooth harrow, and a nonresidual, broad-spectrum herbicide (glyphosate) was applied to the no-till plots. A second application of glyphosate was made to no-till plots on 4 May. Weeds that became established during the summer were removed by rod-weeding the tilled plots and hand-weeding the no-till plots. The tilled plots were plowed on 31 August 1989 and leveled with a rod weeder on 12 September. Glyphosate was applied to the entire experimental area on 25 September after weeds responded to rain. The uniform application of this nonresidual herbicide is unlikely to have led to interactions with subsequent treatments of residual sulfonylurea herbicides (34).

Only one cultivar (Stephens) was used, because no differences among cultivars occurred in the earlier experiments. Subplots consisted of preplant or postemergence application of chlorsulfuron (17.4 g/ha), chlorsulfuron + metsulfuron-methyl (14.5 + 2.9 g/ha), or no sulfonylurea herbicide. Preplant applications were made on 26 September 1989. Two days later, wheat was planted uniformly over the plots, using the same drill and seeding and fertilizer rates described for the 1987–1988 experiments. Postemergence application of the herbicide was on 27 February 1990. On 6 March, the entire plot area was treated with bromoxynil + MCPA (each at 0.28 kg/ha, as Bronate) and with metribuzin (0.28 kg/ha, as Lexone).

Samples were collected and processed as described for the 1987–1988 experiments. Samples were collected from both sites during autumn (6 and 9 November), winter (9 and 12 February), and late spring (2 and 9 May). Grain yields were measured on 12 and 19 July. Diseases, in addition to Rhizoctonia root rot, included Pythium root rot (caused by *Pythium* spp.), take-all (caused by *Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *tritici* J. Walker), and Bipolaris root rot (caused by *B. sorokiniana* (Sacc.) Shoemaker; teleomorph *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur). Pythium root rot and take-all were quantified as percentages of roots infected, and Bipolaris root rot as percentages of subcrown internodes infected. Periodic isolations of fungi were made as in the earlier experiments.

RESULTS

Chlorsulfuron caused Rhizoctonia root rot to increase in severity on wheat seedlings grown in the greenhouse (Table 1). This response occurred in a soil naturally infested with a low inoculum level of *R. solani* AG-8 as well as in the same soil supplemented with additional inoculum of the pathogen. Seedlings also had fewer root axes in chlorsulfuron-treated than in untreated soil and tended to be shorter and of lower weight when sampled at 300 growing-degree days. Significant inoculum × herbicide interactions indicated that the magnitude for these disease and plant growth responses were each higher in uninoculated than in inoculated soils. As the seedlings aged, however, all earlier differences due to chlorsulfuron were eliminated in both the naturally infested and inoculated soil (Table 1). Root rot and plant growth responses were similar for Stephens and Oveson, and there were no interactions between cultivars and the other variables. The data for the two cultivars were therefore grouped for the analysis presented in Table 1.

Pathogens naturally present in the unpasteurized soil used in the greenhouse caused only minor symptoms of Rhizoctonia root rot (disease severity ratings <1.6; Table 1). Root rot lesions occurred only on first- and second-order lateral roots in the uninoculated soil, and no main root axes were severed. The primary pathogens isolated from plants growing in the naturally infested soil were *R. solani* AG-8 and *Pratylenchus thornei* Sher & Allen. Introduced *R. oryzae* did not cause growth or disease to differ significantly from the uninoculated controls in this experiment. Since chlorsulfuron did not cause additional effects on plant growth or disease in the *R. oryzae* treatment, the data for that inoculum treatment are not presented. Introduction of *R. solani* AG-8 into soil often caused means of root rot indices to exceed 4.0, which indicates severance of main root axes. Indices in inoculated soil at 600 growing-degree days were at or near the maximum for the disease-rating scale used.

Responses of disease and plant growth to application of chlorsulfuron in the field during 1987–1988 were similar to those in the inoculated treatments of the greenhouse experiment. Significant interactions between tillage and herbicide treatments were present for several seedling growth characteristics (plant growth stage, height, weight, and root numbers in February) at site 2, but none occurred at site 1. Interactions were not present for disease severity or grain yield at either location. Preplant and postemergence applications of herbicide always led to an increase in Rhizoctonia root rot ratings on seedlings (Table 2). This often corresponded to a reduction in shoot weight and numbers of roots and tillers, but not plant height or development stage. Rhizoctonia root rot was severe in both the tilled and untilled plots. Grain yields were equivalent in all plots (Table 2). The herbicide caused a trend for increased grain yield in all plots except the tilled plot at site 2.

The experiments were repeated under more normal rainfall conditions during 1989–1990. This followed a season of above-normal rainfall during the fallow year. Seedling emergence in all plots occurred within 10 days after seed was planted in late September. Data for only the preplant application of herbicides in the tilled soil at both sites are presented here (Table 3). Except where noted for

Table 1. Influence of preplant chlorsulfuron (C) treatment of soil on growth, development, and root rot of winter wheat in the greenhouse in pots of field soil naturally infested or inoculated (I) with supplemental *Rhizoctonia solani* AG-8

Wheat samples	Uninoculated soil C-treated	Uninoculated soil Untreated	Inoculated soil C-treated	Inoculated soil Untreated	LSD ($P = 0.05$)	Significance of F value I	Significance of F value C	Significance of F value I × C
At 300 growing-degree days								
Rhizoctonia root rot index[a]	1.6*[b]	0.7	4.5*	3.9	0.3	0.001	0.023	0.019
Roots per plant (5-cm depth)	17.3*	27.1	14.7*	20.9	3.2	0.013	0.018	0.012
Plant growth stage	2.2*	2.9	2.6	2.5	0.3	0.725	0.059	0.023
Plant height (cm)	17.5*	22.3	18.1	20.4	3.8	0.735	0.047	0.065
Plant weight (mg)	33*	46	28	34	8	0.027	0.038	0.021
At 600 growing-degree days								
Rhizoctonia root rot index	0.8	0.7	5.0	4.8	0.6	0.001	0.650	0.940
Root intercept scale[c]	3.1	3.3	1.8	2.3	0.7	0.002	0.316	0.727
Plant growth stage	4.5	4.5	3.9	4.0	0.3	0.001	0.683	0.620
Plant height (cm)	14.9	20.2	9.9	10.7	5.6	0.017	0.283	0.424
Plant weight (mg)	184	192	93	105	27	0.001	0.944	0.673

[a] On a scale of 0–5, severity was indexed as 0 = no lesions, 1 = <25% of first-order and <50% of second-order lateral branches, 2 = lesions on 25–50% of first-order and >50% of second-order lateral branches, 3 = lesions on >50% of first-order lateral branches, 4 = lesions on one or two main axes, and 5 = lesions on three or more main axes.

[b] Asterisk denotes values that differ significantly from the untreated control.

[c] On a scale of 1–4, root intercepts at a 5-cm depth were approximated as 1 = <10 root axes, 2 = 10–20, 3 = 21–40, and 4 = >40.

grain yield, the results of experiments in tilled and untilled treatments and in preemergence and postemergence treatments were similar ($P > 0.10$). As in earlier experiments, the application of sulfonylurea herbicides increased Rhizoctonia root rot and reduced root numbers and plant weight, but these responses were mostly of statistical insignificance (Table 3). During late spring, the only significant plant growth response was a reduction in numbers of tillers in herbicide-treated soils.

Application of the sulfonylurea herbicides did not have a significant effect on the incidence or severity of Bipolaris root rot, take-all, and Pythium root rot during 1989–1990. The range in incidence of these diseases was 1–8% of roots with Pythium root rot, 1–6% of roots with take-all, and 27–32% of plants with Bipolaris root rot. Herbicide × tillage interactions were absent for all plant growth and disease characteristics at both loca-

Table 2. Influence of preplant (PP) and postemergence (PE) applications of chlorsulfuron on growth, development, yield, and root rot of winter wheat produced under no-till or conventional tillage at two experimental sites (1987–1988)

	Site 1				Site 2			
	Chlorsulfuron			LSD	Chlorsulfuron			LSD
Tillage[a]	**PP**	**PE**	**Control**	**($P = 0.05$)**	**PP**	**PE**	**Control**	**($P = 0.05$)**
Conventional								
Rhizoctonia root rot index[b]	4.4*[c]	4.2*	3.8	0.3	4.6*	3.9	3.6	0.4
Roots per plant (3-cm depth)	8.6*	10.9	11.5	1.6	7.4*	7.1*	9.3	1.4
Roots per plant (5-cm depth)	6.0*	7.8	9.1	2.0	5.4*	6.1	7.0	1.6
Plant growth stage	4.8	4.7	4.9	NS[d]	4.1	4.3*	3.7	0.5
Plant height (cm)	17.7	19.1	19.6	NS	15.1	15.0	15.9	NS
Plant weight (mg)	96*	99*	125	21	53*	61	70	12
Tillers per plant	0.9	1.0	1.4	NS	0.1*	0.2*	0.6	0.3
Grain yield (kg/ha)	718	785	671	NS	577	557	772	NS
No-till								
Rhizoctonia root rot index	4.4*	4.1*	3.3	0.5	4.3*	3.9	3.6	0.4
Roots per plant (3-cm depth)	11.0	11.1	12.5	NS	10.5*	12.8	13.6	1.7
Roots per plant (5-cm depth)	7.4	7.5	8.7	NS	8.7	9.8	9.4	NS
Plant growth stage	4.5	4.3	4.5	NS	4.0	4.1	4.3	NS
Plant height (cm)	19.8	19.7	20.7	NS	18.3	16.9	18.5	NS
Plant weight (mg)	88*	102	117	19	65*	85	83	13
Tillers per plant	0.6	0.4	0.7	NS	0.2*	0.7	0.7	0.4
Grain yield (kg/ha)	705	678	638	NS	852	953	779	NS

[a] Sampling dates for sites 1 and 2 were 16 and 18 February (for disease and plant growth measurements) and 15 July (for grain yield).

[b] On a scale of 0–5, severity was indexed as 0 = no lesions, 1 = <25% of first-order and <50% of second-order lateral branches, 2 = lesions on 25–50% of first-order and >50% of second-order lateral branches, 3 = lesions on >50% of first-order lateral branches, 4 = lesions on one or two main axes, and 5 = lesions on three or more main axes.

[c] Asterisk denotes values that differ significantly from the untreated control.

[d] Not significant.

Table 3. Influence of preplant treatment of tilled soil with chlorsulfuron (C) or chlorsulfuron + metsulfuron-methyl (M) on growth, development, yield, and root rot of winter wheat at two experimental sites (1989–1990)

	Site 1				Site 2			
Wheat samples[a]	**C**	**C + M**	**Control**	**LSD ($P = 0.05$)**	**C**	**C + M**	**Control**	**LSD ($P = 0.05$)**
November								
Rhizoctonia root rot index (0-5)[b]	3.9*[c]	3.4	3.1	0.7	3.7	3.2	3.0	NS[d]
Roots per plant (3-cm depth)	7.3	8.0	8.4	NS	13.0	14.3	14.7	NS
(5-cm depth)	1.8*	2.7	3.4	1.4	4.5	4.7	5.5	NS
Plant growth stage	2.5	2.6	2.6	NS	2.5	2.6	2.7	NS
Plant height (cm)	9.1	10.2	10.0	NS	11.0*	11.7	12.3	1.0
February								
Rhizoctonia root rot index								
Seminal roots (0–5)[b]	4.3	4.2	3.9	NS	3.8	3.4	3.5	NS
Coronal roots (0–4)[e]	1.5	1.3	0.9	NS	3.0*	2.7	2.2	0.7
Roots per plant (5-cm depth)	3.3	4.8	5.6	NS	7.4	8.0	8.4	NS
Plant growth stage	...	...	...	...	5.4	5.3	5.2	NS
Plant height (cm)	...	...	...	...	11.9	12.6	12.7	NS
Plant weight (g)	...	...	...	...	2.4	2.7	2.9	NS
May								
Rhizoctonia root rot index (0-4)	3.7	3.3	3.2	NS	3.7	3.7	3.9	NS
Plant weight (g)	...	...	...	...	38.9	40.4	48.5	NS
Tillers per plant	...	...	...	...	4.6*	4.0*	5.4	0.7
Heads per plant	...	...	...	...	2.4	2.7	3.0	NS
July								
Grain yield (kg/ha)	2,309*	2,483*	1,765	342	1,971	2,080	1,852	NS

[a] Sampling dates for site 1 were 6 November, 9 February, 2 May, and 12 July; for site 2, 9 November, 12 February, 9 May, and 19 July.

[b] On a scale of 0–5, severity on seminal roots was indexed as 0 = no lesions, 1 = <25% of first-order and <50% of second-order lateral branches, 2 = lesions on 25–50% of first-order and >50% of second-order lateral branches, 3 = lesions on >50% of first-order lateral branches, 4 = lesions on one or two main axes, and 5 = lesions on three or more main axes.

[c] Asterisk denotes values that differ significantly from the untreated control.

[d] Not significant.

[e] On a scale of 0–4, severity on coronal roots was indexed as 0 = no lesions, 1 = <25% of main root axes with lesions, 2 = 26–50%, 3 = 51–75%, and 4 = >76%.

tions during the three preharvest sampling dates.

Sulfonylurea herbicides tended to increase yields (120–720 kg/ha; range from not significant to significant at $P = 0.02$) in tilled soils (Table 3) and decrease yields (110–150 kg/ha; not significant) in untilled soils during 1989–1990. The yield response to herbicide application was significant in only one of four tests. Yield was increased ($P = 0.02$) by both sulfonylurea herbicides applied to tilled soil at site 1 (Table 3). Yields at both sites tended to be lower in untilled than in tilled soil. Comparative yields in control treatments for tilled and untilled soils were 1,765 vs. 1,687 ($P > 0.10$) at site 1 and 1,852 vs. 1,572 ($P = 0.001$) at site 2. Interactions between herbicide and tillage treatments were significant for grain yield at both sites ($P < 0.02$). Weeds were eliminated by a blanket application of glyphosate during 1989–1990, and therefore did not have an impact on results reported for effects of sulfonylurea herbicides.

DISCUSSION

Results of our experiments with chlorsulfuron applied to wheat and fallow rotations on soils infested with *R. solani* AG-8 in eastern Oregon indicated that the herbicide can be expected to increase the severity of Rhizoctonia root rot. However, contrary to our hypothesis, application of chlorsulfuron never had a deleterious impact on grain yield, and it led to a significant increase in yield in one of eight experiments (2 years, 2 sites, and 2 tillages).

Our data with inoculated and uninoculated soils in the greenhouse and field support earlier observations (9,26) that low rates of chlorsulfuron used commercially are not likely to cause visible damage to wheat seedlings when *R. solani* AG-8 is not present at appreciable inoculum levels. Damage in the field usually becomes visually apparent only when root rot indices approach or exceed values of 4, representing severance of main root axes. When wheat was sampled at 600 growing-degree days in the greenhouse (Table 1), the lack of significance ($P = 0.65$) between root rot indices in chlorsulfuron-treated or untreated soil that had been inoculated with *R. solani* AG-8 presumably occurred because the ratings were at the maximum for the scale used.

Enhancement of Rhizoctonia root rot in the greenhouse and field did not respond to application of chlorsulfuron at the high level reported for similar studies in Australia (26). In contrast, our study illustrated that winter wheat recovered from the early enhancement of the disease by this herbicide. It is possible that the relatively weaker predisposing response to chlorsulfuron shown in our studies, as compared to those in Australia, may be related to the expectation that this herbicide will decompose more rapidly in eastern Oregon soil than in the Australian soil (7,10,29). Rovira and McDonald's (26) study was performed on calcareous sandy loam with pH 8.3. Our study was on a silt loam with pH 5.5. The bioactivity of chlorsulfuron in soil is dramatically extended as soil pH and sand content are increased (5,7). Although soil pH and texture may have been dominant differences among these soils, it is also clear that persistence of sulfonylurea herbicides in soil is affected by soil temperature and water and crop residue on the soil surface (5,7). Additionally, our studies were conducted with winter wheat, and those in Australia were conducted with spring wheat. Relative to persistence of chlorsulfuron in soil, winter wheat in the field should be favored over spring wheat, in that the growth periods for winter and spring wheats are approximately 10 and 4 mo, respectively. The half-life for these sulfonylurea herbicides varies greatly but is generally less than 5 mo (5,7,29).

Rhizoctonia root rot in these studies was severe in both the tilled and untilled plots. This was unexpected in view of the preponderance of evidence that the disease is most prevalent when the intensity of tillage is low, as in our no-till treatments (22,30). The volume of wheat straw remaining at or near the surface of tilled soil at the time of planting was low. It is probable that the 1-mo interval from primary tillage to planting, which occurred during both field seasons, enabled the pathogen to become restabilized in the root zone before seedlings became established (19,22,25,30).

Grain yield was never reduced significantly in response to application of chlorsulfuron in eight experiments conducted in the field. There were trends toward reduced yield from sulfonylurea herbicides in three of eight experiments—one in a tilled soil and two in untilled soil. In contrast, these experiments demonstrated an even stronger tendency for sulfonylurea herbicides to increase yields in five of eight experiments.

The positive response to chlorsulfuron appeared to be only partially related to suppression of downy brome (*Bromus tectorum* L.). In our judgment, the density of downy brome (<11 and <2 plants per m^2 during 1987–1988 and 1989–1990, respectively) could not account for the magnitude of positive yield responses (6–18% and 2–29% in 1987–1988 and 1989–1990, respectively) that occurred in five of eight plots. The downy brome population in control plots in our 1987–1988 study was 5–10% of that shown to cause a 40% reduction in yield in this region (27). It appears that control of downy brome represented only part of the yield response from chlorsulfuron in these experiments.

Precipitation during and preceding the experiments in 1987–1988 was exceedingly low. Since chlorsulfuron retards absorption of water by roots (24), the herbicide may have modified the rate of water use early in the experiment to provide the plants an advantage during very dry periods in June and July, when the plant was setting seed and maturing. Deferred extraction of soil water by treated plants could favor the process of grain filling late in the season, when soil water typically becomes a limiting factor. Further investigation is required to examine this relationship and why it occurred in tilled but not untilled soil during 1989–1990.

In addition to reducing water uptake by roots, chlorsulfuron reduces absorption of copper and zinc by roots (24) and also reduces the rates of selected biochemical processes in roots and shoots (7,10). Each of these inhibitory processes could influence the ability of *Rhizoctonia* to colonize roots of treated plants. The reduction in absorption of copper is of particular interest in view of findings that copper-deficient plants are known to become more susceptible to a variety of soilborne and foliar pathogens (13,33). The complex balance between potentially beneficial (e.g., water-use efficiency) and deleterious (e.g., increased susceptibility to root rot) reactions of winter wheat to chlorsulfuron would be expected to differ in response to environmental variables. An understanding of these interacting factors and how they relate to wheat production will require additional study.

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