Influence of Glyphosate on Rhizoctonia Root Rot, Growth, and Yield of Barley

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ABSTRACT

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Time intervals between applying glyphosate to kill volunteer cereals and weeds and planting spring barley by direct drilling (no-till) into *Rhizoctonia*-infested soil were evaluated in field plots at Pendleton, Oregon, and Lacrosse and Lind, Washington. As the interval was shortened from autumn to spring application or from 3 wk to 3 days before planting in the spring, severity of Rhizoctonia root rot increased and grain yield decreased. When glyphosate applications were delayed until 2 or 3 days before planting (commonly used in production of spring barley in the Pacific Northwest), spring barley yields were reduced as much as 50% compared to when glyphosate was applied in the autumn or early spring. Disease was not as prevalent when glyphosate was applied 1 or 2 days after direct drilling compared with applications made 3 days before planting. Rhizoctonia root rot was least on spring barley when tillage or application of glyphosate was performed in the autumn or in spring 3 wk before planting. Tilling soil 2 days before planting at one site nullified the yield-depressing effect of a preplant glyphosate application. These results suggest that the inoculum potential for *R. solani* AG-8 as a pathogen of spring barley is strongly influenced by the timing of volunteer cereal and weed elimination and that adjustments in such practices can minimize crop damage and maximize yield.

Rhizoctonia root rot caused by *R. solani* (Kühn) AG-8 and *R. oryzae* (Ryker & Gooch) (11) is an important disease of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) in the Pacific Northwest of the United States (12,18,19,22,23). Severely affected crops contain patches of stunted plants that yield less than half as much grain as less-affected plants outside the patches (4,12,20). In Oregon, yields in root rot-affected fields of nonirrigated wheat and barley were reduced by an additional 8 and 17%, respectively, when patches were present (20). Yields in field plots uniformly treated with inoculum of *R. solani* AG-8 have been as low as 6% of yields in adjacent noninfested plots (20).

In the Pacific Northwest, spring barley is used as an annual cash crop or in 2- and 3-yr rotations with winter wheat and peas (*Pisum sativum* L.), lentils (*Lens culinaris* Medik.), or fallow. Spring barley is highly susceptible to Rhizoctonia root rot, and damage can be especially severe when the crop is planted directly into standing stubble containing dead or dying volunteer plants of wheat, barley, or weeds (8,12,13,22). The disease is also damaging in management systems that retain maximum residues on or near the soil surface for soil and water conservation. Each year in the Pacific Northwest, significant acreages of winter wheat are treated with a nonselective herbicide in the spring and then seeded within 1-3 days to spring barley, usually with little or no preplant tillage. This occurs when crop acreage adjustments are required to comply with federal subsidy programs or when winter wheat is damaged beyond recovery from drought, freezing, weeds, insects, or diseases. Also, where spring barley is grown continuously or in rotation after wheat in combination with minimum or mulch (conservation) tillage, volunteer wheat and barley and weeds are killed with nonselective herbicides 1-3 days before barley is planted. The herbicide used most frequently for preplant weed control is glyphosate alone or combined with 2,4-D.

The short time interval between applying glyphosate and planting spring barley is important, as growers allow maximum time for germination of volunteer cereal and weed seed before spraying and also schedule seedbed herbicide application and planting operations between spring rains. Field observations have suggested that glyphosate applied shortly before seeding favors Rhizoctonia root rot. If the spray is applied in the spring 3-6 wk before planting or in the autumn, the damage appears less than if the two procedures are timed more closely. A similar pattern has been demonstrated in Australia with a combination of paraquat + diquat + cyanazine (13; A. D. Rovira, *personal communication*).

The objective of this study was to determine the effects of time intervals between applying glyphosate, tillage, or both, and planting spring barley on the severity of Rhizoctonia root rot, growth, and grain yield of spring barley. Brief accounts of this work were published earlier (16,20).

MATERIALS AND METHODS

Experiments were performed at the Columbia Basin Agricultural Research Center in Pendleton, Oregon, during 1987, 1988, and 1989; in a commercial field near Lacrosse, Washington, during 1987; and at the Washington State University Dryland Research Unit, Lind, during 1987-1988. Soils at Pendleton and Lacrosse are Walla Walla silt loams, and soil at Lind is a Ritzville silt loam. All are coarse-silty mesic Typic Haploxerolls, with about 1.6% organic matter, and have well-drained deep profiles (> 100 cm to hardpan). Many decades of applying ammonium fertilizers have led to surface horizon pH (in 0.01 M $CaCl_2$) values of 5.3-6.0. This area of the Pacific Northwest is characterized by a temperate climate with warm to hot summers, cool to cold winters, and precipitation (250, 360, and 430 mm at Lind, Lacrosse, and Pendleton, respectively) mostly occurring during winter and spring.

All experiments involved Steptoe spring barley (90 kg/ha) planted after winter wheat or barley. Seed was commercially treated with carboxin, thiram, and lindane to suppress smut, seedling diseases, and wireworms, respectively. These compounds do not control Rhizoctonia root rot (18).

Pendleton experimental site. Experiments at Pendleton were performed on a field infested naturally with *R. solani* (dominated by AG-8, but including several other intraspecific anastomosis groups), *R. oryzae, Pythium* spp., *Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *tritici* J. Walker, *Pseudocercosporella herpotrichoides* (Fron) Deighton, *Fusarium culmorum* (Wm.G. Sm.) Sacc., and *Pratylenchus thornei* Sher & Allen. Moderate amounts of root damage to direct-drilled small grains often occur from a combination of *R. solani, R. oryzae, Pythium* spp., and *G. graminis*, with most damage caused by *R. solani* AG-8 (17).

The field at Pendleton was fallow during the summer of 1985 and was planted to winter barley during the autumn of 1985. The barley was killed

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with glyphosate (Roundup; 1.1 kg/ha in 140 L of water) in April 1986. Weed control included a second application of glyphosate (1.1 kg/ha) in June 1986 and 2,4-D (1.1 kg/ha) in August 1986. Stephens winter wheat was direct-drilled as a cover crop in October 1986.

Large, nonreplicated plots (2.3 × 233 m) were established in the wheat cover crop during early spring 1987. The wheat was sprayed with glyphosate (1.1 kg/ha) at intervals of 38, 31, 24, 12, 10, or 3 days before or 2 days after planting of spring barley. Barley was direct-drilled into the soil with dead or dying wheat plants on 30 March, using a John Deere Model HZ deep-furrow drill with 30-cm row spacings and 5-cm depth. Seedlings emerged on 8 April. Broadleaf weeds were controlled with a uniform post-emergence application of chlorsulfuron (Glean; 0.017 kg/ha) and dicamba (Banvel; 0.070 kg/ha) on 28 April. A broadcast application of ammonium nitrate (112 kg/ha of N) was made 2 days before planting.

The presence of Rhizoctonia root rot on barley plants in the plots was verified by periodic visual assessments and in vitro isolations from damaged roots, but quantitative assessments of this and other root diseases were not made. Percentages of stunted plants in three 50-m sections of each plot were estimated in June by means of the line-intercept technique (1). Twenty intercepts were made in each of the three sections by dropping a 1.5-m section of a small-diameter wood rod across four rows in each of five locations spaced 5 m apart. Data were analyzed as three replicates. Plants less than half the height of the normal plant canopy were considered stunted. In the absence of take-all, nematodes, and other factors that cause severe stunting of cereals, an assessment of the severity and/or frequency of stunting is an accurate and rapid means for quantifying damage from Rhizoctonia root rot. Most roots of stunted plants in this experiment were severed totally by Rhizoctonia root rot. Yield was assessed in July 1987 by harvesting a single 1.7 × 230 m strip from each plot.

The remaining crop was harvested, the stubble was flailed to the soil surface, and a cover crop of winter wheat was direct-drilled on 19 October. The plot received no further management until spring 1988, when the wheat cover crop, along with volunteer barley and weed grasses, each with roots infected by *R. solani* AG-8 and *Pythium* spp., was sprayed with glyphosate (1.1 kg/ha) at 21, 14, 7, 3, or 0.5 days before or 1 day after planting of spring barley. Plots measured 6.5 × 233 m and were replicated three times. Barley was planted on 18 March by means of a Great Plains drill with double-disk openers at 25-cm row spacings. Seedlings emerged on 27 March. Weeds were controlled with a uniform application of chlorsulfuron (0.017 kg/ha) plus a mixture of bromoxynil and MCPA (Bronate; 0.561 kg/ha of each) on 15 April. A broadcast application of ammonium sulfate (67 kg/ha of N) was made 1 day before planting.

Disease and plant growth assessments on this second experiment at Pendleton were made on 8 May, when 40-day-old plants were at Haun plant growth stage 4–5 (6). Seedlings with intact root systems were dug from three randomly selected positions in each plot. Plants were rinsed to remove adhering soil, then were evaluated for incidence and severity of all diseases present. Rhizoctonia root rot ratings (17) on seminal roots were: 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. Periodic confirmatory isolations were made from symptomatic roots. Root segments were washed under running water for 3 hr and then, without surface-disinfection, plated onto 2% water agar treated with 50 μg/ml of rifampicin. Emerging fungal isolates were transferred onto half-strength potato-dextrose agar medium (with 2% water agar).

Plant growth and development were measured on the seedlings evaluated for diseases. Measurements included Haun growth stage (6), plant height, tillers per plant, oven dry weight of shoots, and number of roots intersecting a line 5-cm below the caryopsis. Average height of standing plants in the field was recorded shortly before harvest in August, by measurements at 5-m intervals through each plot. Grain yields were measured in the manner described for the 1987 experiment.

The remaining grain was harvested and the stubble chopped down to the soil surface by skew treading in preparation for a third experiment. Ammonium sulfate (112 kg/ha of N) was broadcast in October. The plot area was not managed further until spring 1989, when an experiment was conducted to examine interactions among tillage, glyphosate application, root rot, and yield. Volunteer barley and seedling weeds were sprayed with glyphosate (1.1 kg/ha) at 3 or 22 days before planting or not at all. Shallow tillage (disking and rod weeding to a depth of 7 cm) was done at 2 or 21 days before planting or not at all. The experimental design was a 3 × 3 factorial plot with five replications, except that a nonsprayed, nontilled treatment was not included. Plots measured 4 × 33 m.

Inoculum of *R. solani* AG-8 was placed in the soil to increase the uniformity of the pathogen's spatial distribution over the experimental area. Autoclaved millet seeds (9) colonized by the pathogen, then air-dried, were inserted into the soil by three passes of a double-disk seed drill (25-cm spacing). The inoculum was applied 2–7 days before planting (8-cm depth) at a rate of 6 kg/ha (about 12 pathogen foci per meter in rows about 8 cm apart).

Barley was planted on 6 April by use of a Great Plains drill with double-disk openers (25-cm row spacings). Seedlings emerged on 13 April. Broadleaf weeds were controlled with a uniform post-emergence application of bromoxynil + MCPA (0.561 kg/ha of each) on 15 May.

Disease and plant growth assessments were made before head emergence, on 12 June. Plants with intact root systems were collected randomly through each plot, and Rhizoctonia root rot of seminal roots was assessed with the rating index described previously. Ratings on crown roots (17) were based on percentages of main root axes with lesions: 0 = none, 1 = <25%, 2 = 26–50%, 3 = 51–75%, and 4 = >76%. In addition, take-all caused by *G. g. tritici* was quantified as the percentage of root axes showing visual evidence of this disease. Periodic confirmatory isolations were made from symptomatic roots, in the manner described earlier.

In late July, height of standing plants was measured at 5-m intervals through each plot and the average recorded. Grain yields were measured as described earlier.

Lacrosse experimental site. The experiment at Lacrosse was conducted on a field with a fallow/winter wheat/spring barley cropping system and was established in the year of spring barley (1987). The winter wheat stubble was left standing after harvest (August 1986), and by spring the field had a moderately dense and uniform population of downy brome (*Bromus tectorum* L.) and a sparse to light population of volunteer winter wheat. These plants were mostly 7–15 cm tall and growing actively.

Glyphosate (0.4 kg/ha) or glyphosate + 2,4-D (0.4 kg/ha of each) was applied 12, 3, or 0.5 days before planting (9 April). A nontreated control was included. Plots were 6.1 × 10.7 m, with four replicates. On the day of planting, and after early-morning application of the herbicide, the entire plot area was tilled with a field cultivator (15-cm depth), then disked (8-cm depth), fertilized by shanking in aqua ammonia (56 kg/ha of N) and sulfur (11 kg/ha), firmed with a rod weeder, and planted to Steptoe spring barley (4-cm depth) with a double-disk drill (18-cm row spacing). Barley emerged on 19 April. Broadleaf weeds were removed by hand.

Seedlings were collected on 12 May and assessed for shoot weight and presence of Rhizoctonia root rot. The same root disease index (0–5 scale) was used to quantify root rot in selected plots. Grain was harvested on 7 August with a plot combine, yield was measured, and data were subjected to analysis of variance.

Lind experimental site. The study at Lind was conducted on a 0.5-ha site that had been direct-drilled to spring barley for each of the three previous years. Volunteer cereals and weeds typically grew in patches or were most dense in areas corresponding to bands where straw and chaff were deposited in the "combine row." To provide a uniform stand of volunteer plants, Steptoe barley seed (45 kg/ha) was broadcast over the entire plot area on 9 September 1987. After a dense stand was established by sprinkle irrigation with 12–18 cm of water, glyphosate + 2,4-D (0.4 kg/ha of each) was applied at 115 (24 November), 10, 2, or 0.5 days before planting. Steptoe barley was direct-drilled on the day of the last herbicide application on 17 March. Each treatment was replicated four times in a randomized complete block design with plots 30 × 2.6 m. Seed was planted with a drill 2.6 m wide and equipped with eight Acra-Plant openers (Acra-Plant, Kansas City, MO) positioned as four pairs of rows (eight rows) with 17.5 cm between each pair and 42.5 cm between pairs. The drill was also equipped with four shanks (Ripper-Shooter, McGregor Co., Colfax, WA) to inject fertilizer as a band between each pair of rows and 7–8 cm below the seed depth at the time of planting. Thus, each pair of rows shared a common band of N, P, and S (150, 38, and 22 kg/ha, respectively) injected as a liquid mix of urea + ammonium nitrate (Uran; 32-0-0), ammonium phosphate (10-34-0), and ammonium thiosulfate (Thiosol; 12-0-0-26). This rate of fertilization was based on results of a standard soil test and a targeted yield of 4,630 kg/ha (2).

Plant growth parameters and Rhizoctonia root rot severity were determined for each of 25 plants dug at random from each plot on 17 May at Haun growth stage 6–7. Soil was washed from the roots and Rhizoctonia root rot was rated on the 0–5 scale. In addition, tillers per plant were counted and length from the point of seed attachment to the tip of the longest leaf (sixth true leaf) was measured. Grain yield was determined by harvesting the two center pairs (four rows) of each plot with a plot combine.

RESULTS

Pendleton. Application of glyphosate at progressively shorter intervals before direct-drilling spring barley into soil containing dead or dying wheat plants led to an increasing proportion of stunted barley plants ($P = 0.001$) and a progressive decrease in grain yield during 1987 (Fig. 1). Proportions of stunted plants in the plot varied from 10 to 50%, depending on the time of glyphosate application. Some stunting became evident when the herbicide was applied more than 4 wk before planting. A 3- to 4-wk interval between spraying and planting was required in the spring to maximize grain yield. Barley grown on plots sprayed 3 days before planting yielded 37% less than barley grown on plots sprayed 31 days before planting. In contrast, no reduction in yield was evident when the application of glyphosate was delayed until after the barley had been planted. The correlation ($P = 0.007$) for the regression of stunted plants and yield was $r^2 = -0.89$.

In the 1988 experiment at Pendleton, spring barley growth and disease characteristics were again influenced by the time interval between application of glyphosate and planting of spring barley (Table 1). The plant growth stage, plant height, shoot weight, and number of tillers each were progressively more retarded, shorter, or less ($P < 0.05$) as the time interval between application of herbicide and planting was shortened. Also, the height of mature plants was less ($P = 0.026$) in response to short intervals between spraying and planting, and fewer roots ($P = 0.068$) were present 5 cm below the caryopsis on plants in plots treated 7 and 3 days before planting, compared with a longer or shorter interval between herbicide treatment and planting. Rhizoctonia root rot became more severe ($P = 0.010$) as the time interval was shortened from 21 to 3 days. When the herbicide was applied after planting, the number of roots was increased over that for application intervals 7 or fewer days before planting. Grain yields in plots sprayed less than 1 wk before planting averaged 20% less ($P = 0.002$) than in plots sprayed 21 days before planting. Yield was correlated positively ($P < 0.01$) with all plant growth characteristics except root numbers, which were not significantly ($P > 0.10$) related to any other variable (Table 1; Fig. 2). The root rot index was correlated negatively with all growth and yield characteristics ($P < 0.05$) except root numbers ($P = 0.195$). Yield was progressively lower as the time interval decreased (Fig. 2), which differed from the abrupt drop in yield that occurred between 10 and 12 days at the same site during 1987 (Fig. 1).

Pathogenic fungi isolated from roots included *F. culmorum, F. graminearum* Schwabe, *R. solani* AG-8, *G. g. tritici*, and species of *Pythium*. Although we did not quantify these isolations, *F. culmorum* and *F. graminearum* were isolated most

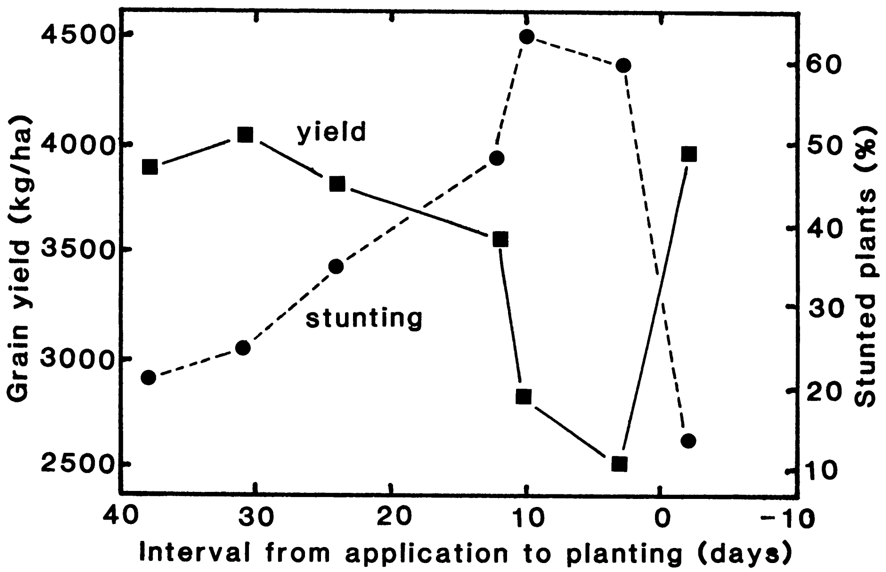

Fig. 1. Plant stunting, caused by Rhizoctonia root rot, and barley yield as influenced by time intervals between application of glyphosate and direct drilling (no-till) of spring barley at Pendleton, Oregon, during 1987.

Table 1. Influence of glyphosate application date on the severity of Rhizoctonia root rot and on plant growth and grain yield for spring barley at Pendleton, Oregon, during 1988

	Days from application to planting							
Characteristic	**21**	**14**	**7**	**3**	**0.5**	**−1**	**Significance of *F* test**	**LSD (0.05)**
Seedlings								
Haun growth stage	4.7	4.4	4.3	4.2	4.0	4.0	0.032	0.4
Plant height (cm)	27	22	20	18	21	19	0.005	4
Tillers per plant	0.8	0.6	0.3	0.1	0.3	0.1	0.001	0.2
Shoot weight (g)	139	93	59	48	68	49	0.001	29
Root intersects (5 cm)	6.8	6.4	3.1	3.2	6.0	6.6	0.068	3.1
Root rot index (0–5)	3.2	4.0	4.4	4.8	4.7	4.2	0.010	0.5
Mature plants								
Plant height (cm)	92	86	81	80	79	78	0.026	8
Grain yield (kg/ha)	3,313	2,865	2,673	2,589	2,532	2,339	0.002	592

frequently. The fusaria were isolated from roots that showed symptoms of root rot as well as from roots with no visible infections and were not considered the principal incitants of the root rots observed. *R. solani* was isolated regularly, although at a lower frequency than the fusaria. Root rots observed in this study were characteristic mostly of those caused by species of *Rhizoctonia*. Roots yielding isolates of *G. g. tritici* had blackened vascular tissue or darkly pigmented ectotrophic "runner" hyphae, characteristic of take-all. *G. graminis* and species of *Pythium* were isolated infrequently and were considered to be components of a complex with *Rhizoctonia*.

In the 1989 experiment at Pendleton, Rhizoctonia root rot was most severe ($P = 0.001$) when vegetation control was delayed until 2 or 3 days before planting (Table 2) and least severe either when the soil was tilled or when volunteer and weed plants were sprayed with glyphosate 22 days before planting.

Plant height and grain yield in 1989 were reduced ($P < 0.001$) only when glyphosate was applied 3 days before direct-drilling barley seed. This treatment had the lowest yield (29% less than the best yield), the highest amount of seminal root damage from *Rhizoctonia*, an intermediate amount of damage to crown roots, and the lowest incidence of take-all. Yield and plant height were correlated ($r^2 = -0.72$ and -0.82, respectively; $P < 0.05$) with severity of Rhizoctonia root rot on seminal roots but not with other diseases. The incidence of take-all was related negatively ($r^2 = -0.64$; $P = 0.084$) to severity of Rhizoctonia root rot on seminal roots. Rhizoctonia root rot of crown roots was correlated ($P = 0.086$) with root rot of seminal roots but not with other variables.

Lacrosse. Rhizoctonia root rot on 1-mo-old barley plants was relatively severe in all treatments at Lacrosse, with ratings of 2.7–3.2 (*data not shown*). Applications of glyphosate, alone or with 2,4-D, to volunteer plants within 3 days before planting resulted in 30% lower ($P < 0.05$) yield than applications 12 days before planting (Fig. 3). Yields of control plots not treated with herbicide and tilled the day of planting also were relatively low, similar to yields of plots treated 3 days before or on the day of planting and significantly less ($P < 0.05$) than yields of plots treated 12 days before planting. Results of treatment with glyphosate and with glyphosate + 2,4-D were equivalent. The lack of 2,4-D effects on severity of Rhizoctonia root rot and barley yield was expected because very few broadleaf weeds were present when the herbicides were applied and because 2,4-D does not kill volunteer wheat or downy brome, which are hosts for *Rhizoctonia*.

Lind. Applications of glyphosate in autumn rather than in spring resulted in significant ($P < 0.05$) differences in Rhizoctonia root rot and response of spring barley, i.e., less severe root rot, taller plants, and higher yields. These results were obtained when glyphosate was applied 10 or fewer days before planting in the spring (Table 3). Barley yields for plots treated with glyphosate 10, 2, or 0.5 days before planting were 34–48% less than those with treatments during autumn. All plants formed three or four tillers, regardless of the time of application of glyphosate or severity of Rhizoctonia root rot ($P = 0.414$).

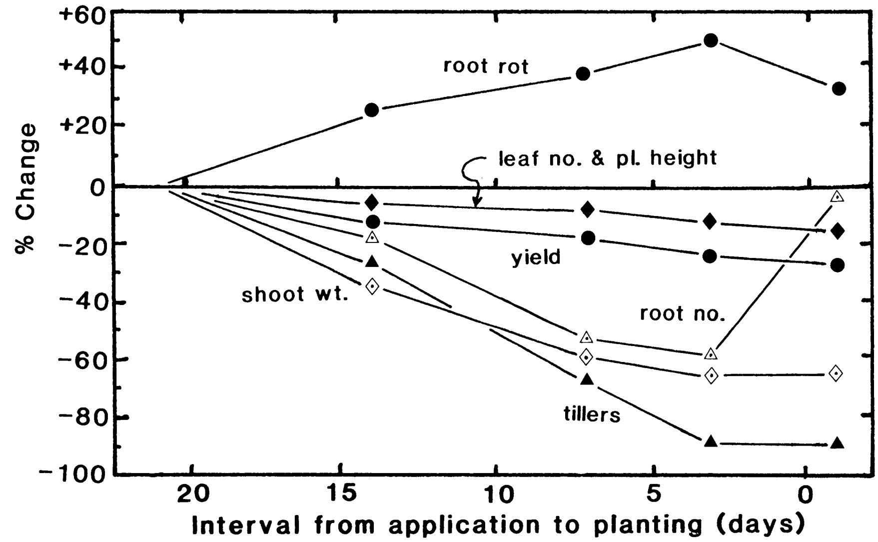

Fig. 2. Relative changes for data reported in Table 1, illustrating the inverse relationship between severity of Rhizoctonia root and plant growth and yield in response to different time intervals between application of glyphosate and planting of spring barley into *Rhizoctonia*-infested soil containing volunteer cereal and weed hosts at Pendleton, Oregon, during 1988.

Table 2. Influence of glyphosate application or tillage and of timing intervals between these practices and planting of spring barley on the incidence or severity of root diseases and on plant growth and grain yield at Pendleton, Oregon, during 1989

Days before planting		Rhizoctonia root rot				Grain yield	
Glyphosate	Tillage	Seminal (0–5)	Crown (0–4)	Take-all (% roots)	Plant height (cm)	kg/ha	% of maximum
22	. . .	3.0	0.7	18	71	4,109	93
22	21	3.1	0.5	11	72	4,319	97
22	2	3.3	0.7	11	73	4,291	97
3	. . .	4.1	0.9	5	62	3,159	71
3	21	3.2	0.7	13	72	4,528	97
3	2	3.5	1.0	10	72	4,319	97
. . .	21	3.2	0.4	8	72	4,305	97
. . .	2	3.6	1.1	14	71	4,430	100
Significance of *F* test		0.001	0.001	0.001	0.001	0.001	
LSD (0.05)		0.5	0.3	6	4	517	

DISCUSSION

Rhizoctonia root rot was more severe and grain yields were lower when intervals were short between treating weeds and volunteer wheat or barley with glyphosate and planting spring barley by direct drilling (no-till) into the residue. Disease was most severe when glyphosate was applied only 2 or 3 days before planting and least severe when glyphosate was applied the previous autumn. Less disease and higher yields in spring barley

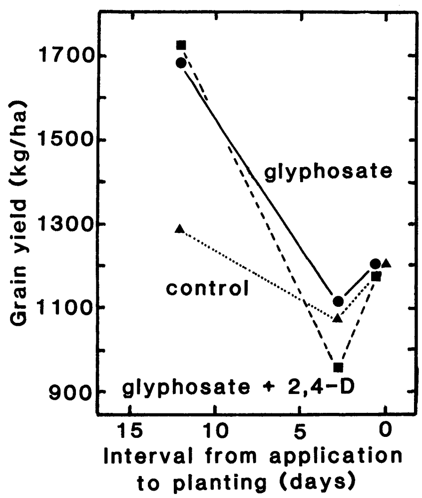

Fig. 3. Grain yield as influenced by time intervals between application of glyphosate or glyphosate + 2,4-D and planting of spring barley into tilled soil at Lacrosse, Washington, during 1987.

were associated with long intervals between spraying and planting at all locations and during each year in this study. This confirms experience in Australia, where Rhizoctonia root rot of direct-drilled wheat was most severe when planting was done immediately after herbicide treatment of grass weeds and least severe when the interval between treatment with herbicide and planting was 3 wk or longer (8,13,14).

Volunteer cereals and weeds, allowed to grow undisturbed up to or near the day of direct-drilling the next crop, can be expected to provide a large root mass as a food base for soilborne pathogens such as *R. solani.* This can explain why the yield of spring barley after winter wheat at Lacrosse was low with all treatments that allowed the weeds and volunteer winter wheat to grow up to the day of planting, including the control plots, which were not sprayed but were tilled on the day of planting. A large root mass available to *R. solani* as a food base can also explain why the autumn application of glyphosate was the only effective treatment at Lind, where the combination of broadcast seeding and autumn irrigation resulted in a solid stand of large plants. Under these circumstances, even the earliest spring application of glyphosate was too late to significantly limit the inoculum of *R. solani* available to attack the next crop of direct-drilled spring barley.

On the other hand, size of the root mass available to *R. solani* as a food base cannot explain why, in the 1989 tillage × herbicide experiment at Pendleton, elimination of host plants by tillage 2 days before planting produced results more or less equivalent (based on root disease severity, plant height, and grain yield) to those produced by treating the plants with glyphosate 22 days before planting. In this experiment, treatment with glyphosate 3 days before direct-drilling barley seed into soil with a low weed density was the only treatment associated with severe Rhizoctonia root rot, the most plant stunting, and the lowest yield. The size of the root mass available as a food base for *R. solani* cannot entirely explain why plants had less disease and yielded more when glyphosate was applied 1 or 2 days after rather than 1 or 2 days before planting at both Pendleton and Lacrosse. When *Rhizoctonia* is not present, *Fusarium* and *Pythium* spp. colonize roots of plants more thoroughly if plants are treated with glyphosate (5,7). *Fusarium* and *Pythium* have been shown to serve a major role in the death of glyphosate-treated plants (5,7). Possibly, *R. solani* also colonizes roots of glyphosate-treated plants more thoroughly, such that it contributes to or accelerates the death of these plants. Conversely, tillage and the resultant temporary burst of microbial activity in soil (15) could accelerate the ecological succession of microorganisms in these root remains, thereby reducing the inoculum potential of the pioneer *R. solani.* Plants killed outright by the tillage without prior predisposition with glyphosate would be equally accessible to colonization by strict as well as facultative saprophytes, some of which may preempt *R. solani* as a colonist of the root tissues and thereby limit inoculum potential of this pathogen.

The deleterious effect of glyphosate on barley yield was not a response to phytotoxic residues on or in soil. Glyphosate is inactivated immediately by adsorption on soil colloids and then degraded by soil microbes (21). In the 1989 experiment at Pendleton, the *Rhizoctonia*-induced damage from glyphosate treatment was not present when weeds were eliminated by tillage 3 wk before planting. At Lacrosse, there was no difference in yield when glyphosate was or was not applied 3 or 0.5 days before planting. These observations support findings of similar studies on winter wheat in fields not known to have damaging levels of Rhizoctonia root rot (10). Application of glyphosate is therefore likely to impact yield only when the soil is infested with a facultative pathogen such as *Rhizoctonia.*

Our results extend the findings of Cook and Haglund (2) for wheat by showing that spring barley can be grown successfully without tillage if root diseases can be controlled. The yield of barley where volunteer plants were sprayed in the autumn at Lind was equal to the yield targeted for this site, based on the agronomic practice of fertilizing for a yield goal from estimates of available water and nitrogen. This result is especially significant, considering that the experiment represented the fourth consecutive planting of spring barley without tillage. Our results also extend the findings of Cook and Haglund (2) for wheat by showing that crop residue is not the primary cause of the disappointingly poor performance of direct-drilled spring barley. All direct-drilled treatments were done without removal or modification of the residues left on the soil surface by the previous cereal crop.

R. solani AG-8 is limited in its pathogenic attack of wheat and barley to roots, unlike *G. g. tritici, Cephalosporium gramineum* Nis. & Ika., *F. culmorum*, and *P. herpotrichoides*, which extend, during their pathogenesis, into the tillers of wheat and barley. Root tissues are more ephemeral than tillers as a food base for occupancy by cereal pathogens (24). Dependence of the pathogen on root tissues for its inoculum potential may be the most vulnerable link in the epidemiology of Rhizoctonia root rot. Where winter wheat cereals are direct-

Table 3. Influence of time of application of herbicide (glyphosate + 2,4-D) on Rhizoctonia root rot and growth and yield of spring barley at Lind, Washington, during 1988

Characteristic	Days from application to planting				Significance of *F* test	LSD (0.05)
	115	11	2	0.5		
Root rot index (0–5)	1.5	2.6	2.4	2.5	0.045	0.8
Plant height (cm)	39	30	28	32	0.030	6
Tillers per plant	3.9	3.3	3.6	3.1	0.313	NS[b]
Grain yield						
kg/ha	4,748	2,477	3,115	2,827	0.003	879
Percent of target[a]	102	52	67	61	...	...

[a]Nitrogen fertilization applied for a targeted yield of 4,630 kg/ha.
[b]Not significant.

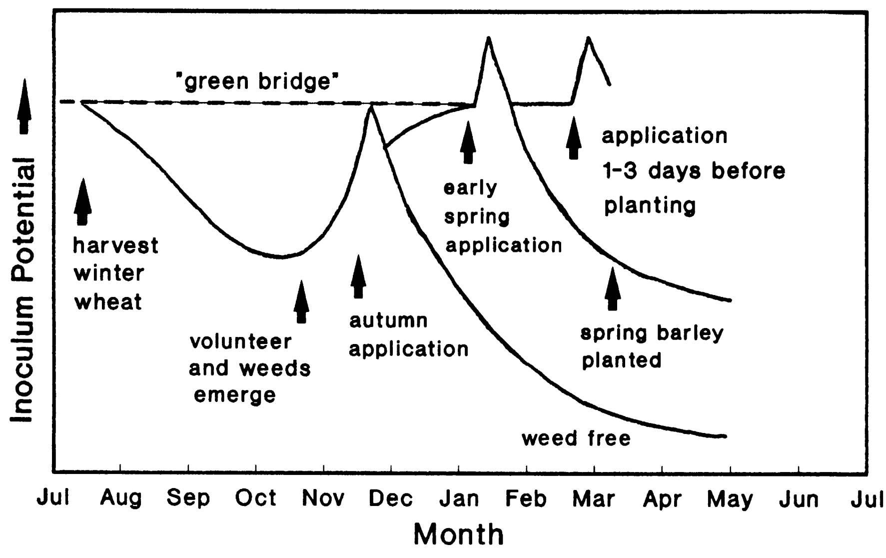

Fig. 4. Effects of the "green bridge" and the timing for application of glyphosate on inoculum potential of *Rhizoctonia solani* pathogenic to small grain crops.

drilled into stubble of a wheat or barley crop harvested only 2 or 3 mo earlier, the inoculum potential of *R. solani* may still be high and hence independent of the available volunteer and weed hosts. With spring cereals, on the other hand, volunteers and weeds may represent the only means for this fungus to maintain its inoculum potential high enough to do significant damage. In fields of spring wheat or spring barley direct-drilled into wheat or barley stubble, it is often easy to discern every combine row from the previous crop. These rows are characterized by stands of spring cereals that are thin, stunted, and late maturing, compared with areas between the combine rows (3). Seeds of wheat, barley, or weeds left with the harvest are concentrated in the combine row and grow most densely in these areas. On the basis of our results, the so-called combine-row effect might now be explained as a "volunteer-row effect."

Our findings suggest that the volunteers and weeds serve as a "green bridge" for maintaining or increasing the inoculum potential of *R. solani* between the harvest of one crop and the planting of the next in systems involving no tillage and no crop rotation (Fig. 4). The results indicate further that the inoculum potential of this pathogen peaks within a few days after treatment of the plants with glyphosate and then declines. We hypothesize that the decline is a response to preemption or displacement by the successions of other microbial colonists of the dead and dying roots of these young plants, a kind of biological control possibly accelerated or facilitated by limited tillage just prior to planting. The actual time of the peak and the effects of competing soil microorganisms with or without the aid of tillage undoubtedly vary with soil temperature, soil moisture, and other conditions suitable or not suitable to *R. solani* and its microbial competitors. The results make clear, however, that even a 2- or 3-wk delay in planting in the spring after application of glyphosate, rather than the common practice in this region of planting immediately after spraying, can make a major difference in the severity of root rot and yield of spring barley grown without benefit of crop rotation or tillage.

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LITERATURE CITED

1. Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. J. For. 39:388-394.
2. Cook, R. J., and Haglund, W. A. 1991. Wheat yield depression associated with conservation tillage caused by root pathogens in the soil, not phytotoxins from the straw. Soil Biol. Biochem. 23:1125-1132.
3. Cook, R. J., and Veseth, R. J. 1991. Wheat Health Management. American Phytopathological Society, St. Paul, MN.
4. Cotterill, P. J. 1990. Assessment of yield loss caused by Rhizoctonia root rot in a barley crop sown following cultivation at Nhill Northwest Victoria, Australia. Australas. Plant Pathol. 19:77-78.
5. Johal, G. S., and Rahe, J. E. 1984. Effect of soilborne plant-pathogenic fungi on the herbicidal action of glyphosate on bean seedlings. Phytopathology 74:950-955.
6. Klepper, B., Rickman, R. W., and Peterson, C. M. 1982. Quantitative characterization of vegetative development in small cereal grains. Agron. J. 74:789-792.
7. Levesque, C. A., and Rahe, J. E. 1987. Effects of glyphosate on *Fusarium* spp.: Its influence on root colonization of weeds, propagule density in the soil, and crop emergence. Can. J. Microbiol. 33:354-360.
8. MacNish, G. C. 1985. Methods of reducing Rhizoctonia patch of cereals in Western Australia. Plant Pathol. 34:175-181.
9. McDonald, H. J., and Rovira, A. D. 1985. Development of inoculation technique for *Rhizoctonia solani* and its application to screening cereal cultivars for resistance. Pages 174-176 in: Ecology and Management of Soilborne Plant Pathogens. C. A. Parker, A. D. Rovira, K. J. Moore, P. T. W. Wong, and J. F. Kollmorgen, eds. American Phytopathological Society, St. Paul, MN.
10. Ogg, A. G., Jr., and Young, F. L. 1991. Effects of preplant treatment interval and tillages on herbicide toxicity to winter wheat (*Triticum aestivum*). Weed Technol. 5:291-296.
11. Ogoshi, A., Cook, R. J., and Bassett, E. N. 1990. *Rhizoctonia* species and anastomosis groups causing root rot of wheat and barley in the Pacific Northwest. Phytopathology 80:784-788.
12. Pumphrey, F. V., Wilkins, D. E., Hane, D. C., and Smiley, R. W. 1987. Influence of tillage and nitrogen fertilizer on Rhizoctonia root rot (bare patch) of winter wheat. Plant Dis. 71:125-127.
13. Roget, D. K., Venn, N. R., and Rovira, A. D. 1987. Reduction of Rhizoctonia root rot of direct-drilled wheat by short-term chemical fallow. Aust. J. Exp. Agric. 27:425-430.
14. Rovira, A. D. 1986. Influence of crop rotation and tillage on Rhizoctonia bare patch of wheat. Phytopathology 76:669-673.
15. Rovira, A. D., and Graecen, E. L. 1957. The effect of aggregate disruption on the activity of microorganisms in the soil. Aust. J. Agric. Res. 8:659-673.
16. Smiley, R. W., Uddin, W., and Rhinhart, K. E. L. 1989. Rhizoctonia root rot of barley affected by timing of glyphosate application. (Abstr.) Phytopathology 79:1217.
17. Smiley, R. W., Uddin, W., Ott, S., and Rhinhart, K. E. L. 1990. Influence of flutolanil and tolclofos-methyl on root and culm diseases of winter wheat. Plant Dis. 74:788-791.
18. Smiley, R. W., Wilkins, D. E., and Case, S. E. 1991. Barley yields as related to use of seed treatments in eastern Oregon. J. Prod. Agric. 4:400-407.
19. Smiley, R. W., Wilkins, D. E., and Klepper, E. L. 1990. Impact of fungicide seed treatments on Rhizoctonia root rot, take-all, eyespot, and growth of winter wheat. Plant Dis. 74:782-787.
20. Smiley, R., Wilkins, D., Uddin, W., Ott, S., Rhinhart, K., and Case, S. 1989. Rhizoctonia root rot of wheat and barley. Oreg. Agric. Exp. Stn. Spec. Rep. 840:68-79.
21. Torstensson, N. T. L., and Aamisepp, A. 1977. Detoxification of glyphosate in soil. Weed Res. 17:209-212.
22. Weller, D. M., Cook, R. J., MacNish, G., Bassett, E. N., Powelson, R. L., and Peterson, R. R. 1986. Rhizoctonia root rot of small grains favored by reduced tillage in the Pacific Northwest. Plant Dis. 70:70-73.
23. Wiese, M. V. 1987. Compendium of Wheat Diseases. 2nd. ed. American Phytopathological Society, St. Paul, MN.
24. Wilkinson, H. T., Cook, R. J., and Alldredge, J. R. 1985. Relation of inoculum size and concentration to infection of wheat roots by *Gaeumannomyces graminis* var. *tritici*. Phytopathology 75:98-103.