Impact of Fungicide Seed Treatments on Rhizoctonia Root Rot, Take-all, Eyespot, and Growth of Winter Wheat

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ABSTRACT

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Fungicides were examined for in vitro activity against *Rhizoctonia solani* AG-8 and *R. oryzae* and for capacity to suppress the incidence and severity of Rhizoctonia root rot of winter wheat in eastern Oregon. Thirteen seed treatments were evaluated at three sites during 1986-87 and five were evaluated at two sites during 1987-88. A factorial experiment with variables of seed treatment and tillage intensity (conventional plowing vs. no tillage) was also performed at two sites. All seed treatments in the seven experiments were ineffective or unreliable for controlling Rhizoctonia root rot. Tolclofos-methyl was highly toxic to both pathogens and strongly reduced the incidence of root rot, but was also phytotoxic. Most of the fungicides reduced the tillering capacity of winter wheat plants, and none of the fungicides consistently improved grain yields. Triadimenol and prochloraz seed treatments strongly reduced the incidence of take-all and eyespot, respectively.

Rhizoctonia root rot is an important disease of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). The disease was first found to affect the growth of these crops in Oregon, Washington, and Idaho during 1984 (21). Rhizoctonia root rot commonly reduces wheat yields by 4% in many nonirrigated fields in eastern Oregon, and the loss in one field was at least 17% (Smiley, *unpublished*). In another field where Rhizoctonia root rot was prevalent, fumigation of soil with methyl bromide during August 1986 increased the production of spring wheat by 32% in 1989 and also allowed crop maturation 21 days earlier than in the surrounding field (Smiley, *unpublished*). The dominant and most virulent species and intraspecific groups (16) of *Rhizoctonia* in affected fields in the Pacific Northwest include *R. solani* Kühn AG-8 (15) (teleomorph *Thanatephorus cucumeris* (Frank) Donk) and *R. oryzae* Ryker & Gooch (4) (teleomorph *Waitea circinata* Warcup & Talbot WAG-0).

Management practices to control Rhizoctonia root rot are currently based on the complete and deep burial of crop debris (straw and roots). Unfortunately, these practices are not acceptable on the highly erodible soils that dominate eastern Oregon's cereal production region, where management systems that retain surface residues to reduce soil loss due to water and wind erosion are emphasized (18). According to the Conservation Compliance Provisions of the Food Security Act of 1985, producers who participate in Federal subsidy programs must utilize acceptable soil and water conservation measures. Unfortunately, these erosion management practices typically lead to increasing amounts of damage from Rhizoctonia root rot (17,21). Documentation of this principal is tempering and, in some regions, reversing the rate at which conservation tillage practices become accepted by producers. New management systems that both conserve soil and water and control Rhizoctonia root rot must be developed.

Cultivars of winter wheat, microbial agents, and fungicides have not been screened for development of management systems for this disease (5). However, in 1986, Cook and colleagues observed that a seed treatment used to grow spring barley in a field infested with *Rhizoctonia* in Washington led to a 37% increase in grain yield (4). The seed treatment was composed of a mixture of carboxin, thiram, iprodione, and chloroneb. Therefore, further evaluations of seed treatments were warranted.

Treatment of wheat seed with fungicides is a standard practice in the Pacific Northwest. Protection of seedlings from infections by damping-off, root rot, and smut fungi with carboxin or its mixture with thiram and/or metalaxyl is the current standard. As much as 25% of the wheat seed planted on 100,000 ha in Umatilla County, OR during 1987 was treated with carboxin and/or thiram (19). Metalaxyl, triadimenol, quintozene, and imazalil are also used on less than 1% of the seed planted. New or additional seed treatments for managing Rhizoctonia root rot must complement and extend the current standard and must not have a deleterious impact on seedling vigor and plant growth. New fungicides with activity against *Rhizoctonia*, including tolclofos-methyl, benodanil, furmecyclox, and iprodione (Table 1), require testing to determine if they are toxic to *R. solani* AG-8 and *R. oryzae* and if seed treatments can be developed to suppress Rhizoctonia root rot.

The objectives of this study were to investigate: 1) the toxicity of selected fungicides to *R. solani* AG-8 and *R. oryzae*, and 2) the effects of fungicide seed treatments on the incidence of Rhizoctonia root rot and on growth, development, and yield of winter wheat.

MATERIALS AND METHODS

Fungicide toxicity in vitro. A study was conducted to examine the fungistatic sensitivity of two species of *Rhizoctonia* to the fungicides listed in Table 2. *R. solani* AG-8 and *R. oryzae* were grown on half-strength potato-dextrose agar for 7 days. Agar plugs (3 mm in diameter) were removed and placed on potato-dextrose agar amended with 0, 0.5, 1, 5, 10, or 50 μg a.i./ml. Measurements of fungus growth on 10 replicate plates per isolate were made daily. Fungicide concentrations required to impede fungus growth rate by 50% (EC_{50}) or completely (EC_{100}) were used to place each fungus:fungicide combination into one of four sensitivity classes: very sensitive ($EC_{50} < 0.5$ μg/ml and $EC_{100} < 5$ μg/ml); sensitive ($EC_{50} < 3$ μg/ml and $EC_{100} < 20$ μg/ml); moderately tolerant ($EC_{50} < 3$ μg/ml and $EC_{100} < 50$ μg/ml); and tolerant ($EC_{100} > 50$ μg/ml).

Field experiments. Two soft white winter wheat cultivars were used to assess the impact of fungicide seed treatments on diseases and plant development from 1986 to 1988. The cultivars Stephens and Malcolm are genetically related pure-line selections with high yield potential, moderately susceptible to Rhizoctonia root rot, and widely grown in eastern Oregon.

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Three locations with production constraints from Rhizoctonia root rot were selected for these experiments. The Thompson and Wolfe farm sites are located in Umatilla County and represent Pacific Northwest Agronomic Zone 5 (6). The 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), is well drained, and has a surface horizon pH (in 0.01 M $CaCl_2$) of 6.3. The Wolfe farm site is in a 300 mm precipitation zone 13 km SW 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 pH of 6.8. The Moro site, in Sherman County on the Sherman Experiment Station (0.5 km southeast of Moro), typifies Agronomic Zone 4 with 290 mm precipitation and a deep (>250 cm to basalt), well drained Walla Walla silt loam with a surface pH of 5.1.

Experiments at the Thompson and Moro sites were performed on fields with long histories of 2-yr wheat/fallow rotations, using stubble mulch tillage systems that retain moderate amounts of plant residue on or near the soil surface. The experiment at the Wolfe site was performed on a field that had been utilized for no-till, annual recrop winter barley for four consecutive years. Each of the fields is naturally infested with pathogenic species of *Rhizoctonia*. Roots of affected plants selected from previous crops yielded mostly *R. solani* AG-8 at the Moro and Thompson sites and a mixture of *R. solani* AG-8 and *R. oryzae* at the Wolfe site.

Fungicide screening experiments. Thirteen fungicide seed treatments (Table 3) were evaluated at the three sites during 1986-87, and five were evaluated at two sites during 1987-88. Seed treatments were performed by diluting appropriate amounts of the formulated products with water to prepare suspensions. Ten milliliters of dilute suspension per kilogram of seed was dispensed into continually agitated batches of wheat seed to deliver the desired treatment rates (listed in Table 3). The seed was mixed for 5 min after the fungicide had been added; the seed was then placed in open paper bags for drying and storage. This process was performed by personnel from Gustafson, Inc. (Dallas, TX), who also chemically analyzed selected samples of treated seed to assure that the distribution of fungicide concentrations among individual caryopses was consistent with commercial treatments. All seed was planted within 1 wk after treatment.

1987 Crop. Each experiment during 1986-87 was a randomized complete block design with four replications for each of 14 treatments (13 fungicides or mixtures plus a nontreated control). The four-component mixture of carboxin + thiram + iprodione + chloroneb, shown to be highly effective in the initial study by Cook (4), served as the "standard of excellence" for comparing other treatments. Plots were 2.5 × 15 m and contained 6 rows of plants spaced at 40-cm intervals. The seed was planted at 80 kg/ha in early October of 1986, and was delivered with a John Deere model HZ drill equipped with modified slit openers (22). Liquid urea was dispensed 5 cm below the seed at the rate of 45 kg N/ha at Moro and 55 kg N/ha at the Wolfe and Thompson sites.

Plant stand counts were made 3–4 wk after planting by counting numbers of seedlings in three 0.5-m lengths of row. During late autumn and winter (November 18, December 8, and January 9 at Wolfe, Thompson, and Moro sites, respectively), at Haun plant growth stages 2–4 (e.g., two to four fully extended leaves on the main stem) (9,10), seedlings were removed from the field plots for morphological and disease assessments. Seedlings were rinsed to remove adhering soil from root systems. Growth parameters measured on 20 seedlings per plot included plant growth stage measured as main stem leaf number (9) and the numbers of seminal and coronal roots per plant. The incidence of Rhizoctonia root rot was measured as the number of main seminal and coronal root axes per plant that were severed by Rhizoctonia. Routine isolations were made from symptomatic

Table 1. Common, trade, and chemical names of fungicides used in experiments

Common name	Trade name	Formulation[a]	Chemical name
Benodanil	Benefit	50W	2-iodo-N-phenylbenzamide
Captan	Captan	50W	N-trichloromethylthio-4-cyclohexene-1,2-dicarboximide
Carboxin	Vitavax 34	34F	5,6-dihydro-2-methyl-N-phenyl-1,4-oxathiin-3-carboxamide
Carboxin + thiram	Vitavax 200	20 + 20F	(as above) + bis(dimethylthiocarbamoyl)disulfide
Chloroneb	FloPro D	65W	1,4-dichloro-2,5-dimethoxybenzene
Furmecyclox	···	500E	2,5-dimethyl-N-cyclohexyl-N-methoxy-3-furancarboxamide
Imazalil	FloPro IMZ	30F	1-(2-(2,4-dichlorophenyl)-2-(2-propenyloxylethyl)-1H-imidazole
Iprodione	Rovral	30F	1-isopropylcarbamoyl-3-(3,5-dichlorophenyl)hydantoin
Metalaxyl	Apron	35W	N-(2,6-dimethylphenyl-N-methoxy-acetyl)alanine methyl ester
Prochloraz	Prochloraz	50W	N-(2-(2,4,6-trichlorophenoxy)ethyl)-N-propyl-1H-imidazole-1-carboxamide
Propiconazole	Tilt	3.6E	1-(2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-ylmethyl)-1H-1,2,4-triazole
Quintozene	Terraclor	24F	pentachloronitrobenzene
Tolclofos-methyl	Rizolex	250F	0,0-dimethyl-0-(2,6-dichloro-4-methylphenyl)phosphorothioate
Triadimenol	Baytan	30F	4-chlorophenoxy-1,1-dimethyl-1,2,4-triazole-1-ethanol

[a] Active ingredient in the commercial wettable powder (W), flowable (F), or emulsifiable (E) formulation, expressed in either percent or g/L.

Table 2. Fungicide concentrations (g a.i./ml) required to inhibit in vitro growth of *Rhizoctonia solani* AG-8 and *R. oryzae* by 50% (EC_{50}) and 100% (EC_{100}) on potato-dextrose agar medium

	R. solani			***R. oryzae***		
Fungicide	EC_{50}	EC_{100}	Sensitivity class[a]	EC_{50}	EC_{100}	Sensitivity class[a]
Benodanil	0.4	2	vs	1.3	20	s
Captan	14.0	>50	t	11	>50	t
Carboxin	0.2	>50	t	0.4	15	s
Carboxin + thiram	0.2	10	s	0.4	6	s
Chloroneb	1.2	8	s	2.5	14	s
Furmecyclox	0.3	40	mt	0.4	20	s
Imazalil	3.0	40	mt	1.5	40	mt
Iprodione	0.5	10	s	2.5	>50	t
Metalaxyl	>50	>50	t	>50	>50	t
Prochloraz	20	>50	t	0.6	>50	t
Propiconazole	0.3	40	mt	0.2	20	s
Quintozene	50.0	>50	t	2.5	>50	t
Tolclofos-methyl	0.2	0.7	vs	0.2	1.5	vs
Triadimenol	1.5	>50	t	0.3	20	s

[a] Sensitivity class: vs = very sensitive, s = sensitive, mt = moderately tolerant, t = tolerant.

roots. Root segments were washed under running water for 3 hr and then, without surface disinfection, placed onto each of three media: 0.5 strength potato-dextrose agar medium with 50 μg tetracycline per milliliter, 2% water agar with 50 μg rifampicin per milliliter, and 0.5 strength potato-dextrose agar medium with 250 μg chloramphenicol, 50 μg streptomycin, and 50 μg neomycin per milliliter.

The sampling process was repeated at plant growth stages 7–8 (e.g., seven to eight fully extended leaves on the main stem) (9,10) in April, 1987. Developmental features measured included plant growth stage and height, number of seminal and coronal roots per plant, and percentages of plants containing tiller orders T_0, T_1, T_2, T_3, T_4,, and T_5 (10). Disease parameters included percentages of seminal and coronal root main axes with lesions caused by *Rhizoctonia* or *Gaeumannomyces graminis* (Sacc.) Arx & Olivier var. *tritici* J. Walker (cause of take-all), and culms with lesions caused by *Pseudocercosporella herpotrichoides* (Fron) Deighton (cause of eyespot).

Percentages of stunted plants in each plot were measured after head emergence in late spring (May), using a line-intercept procedure (3) across the four center rows of each plot, and repeated at 1-m intervals over the plot length. Grain yields and test weights were measured at maturation (mid-July) by threshing plants in four rows of each plot.

1988 Crop. The two experiments during 1987-88 were randomized complete block designs with six and ten replications for each of the six treatments (five fungicides or mixtures and a nontreated control) at the Wolfe and Thompson sites, respectively. The experimental design was established to provide maximum opportunity for each fungicide treatment to transect patches caused by Rhizoctonia root rot. Individual treatments were established as 100-m-long rows, with the six treatments being delivered simultaneously through different openers during each pass of the six-row drill. This was accomplished by partitioning the drill's seed box. Treatments were re-randomized within the drill after completion of each replicate, to compensate for minute differences in the performance of individual drill openers. Plots were planted during mid-October of 1987, using the same seeding rate and drill described earlier. Urea and thiosol were applied to deliver 55 kg N and 15 kg S/ha. Samples collected from the experiments in 1987-88 included measurements of seedling growth and development during the winter and measurements of yield components at maturity, as described earlier.

Crop management experiment. An experiment was established to determine the ability of fungicides to suppress Rhizoctonia root rot on winter wheat growing in nontilled as well as conventionally tilled soils. During the autumn of 1986, replicated (×4) plots of both tillage systems were established as 5- × 30-m main plots at the Wolfe and Thompson sites. Stephens winter wheat was either treated with the four-component mixture of carboxin + thiram + iprodione + chloroneb, described in the seed treatment experiment, or left untreated. The fungicide treatments were planted as 2.5- × 30-m subplots paired within each tillage treatment. The sites, previous crops, seed drill, planting and fertilizer rates, and other features were as described for the seed treatment studies for 1986-87.

Samples included measurements of seedling growth and root rot during the autumn and spring and the percentage of stunted plants and yield at maturity. The data were analyzed as a split-plot experimental design.

Table 3. Influence of seed treatments on Rhizoctonia root rot during autumn 1986 and on tillering of winter wheat during spring 1987 (Wolfe site)

Treatment and rate (g a.i./kg seed)	**Rhizoctonia root rot**	**Tillers (percentage of plants with each tiller)**					
		T_0	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**
Nontreated control	2.3	3	100	87	60	33	17
Carboxin (0.54)	0.3	0	100	90	63	33	30*
Carboxin + quintozene (0.54 + 0.54)	2.3	3	90	77	40*	10*	0*
Carboxin + iprodione (0.54 + 0.54)	1.3	3	90	73	30*	10*	0*
Carboxin + benodanil (0.54 + 2.08)	0.3	0	93	80	37*	10*	7*
Carboxin + furmecyclox (0.54 + 0.65)	0.3	0	73*	60*	37*	7*	7*
Carboxin + prochloraz (0.54 + 0.21)	6.0	10	93	83	57	27	7*
Carboxin + tolclofos methyl (0.54 + 0.65)	0	0	80*	53*	27*	10*	7*
Carboxin + thiram (0.54 + 0.54)	1.0	7	83*	70*	53	23	7*
Carboxin + thiram metalaxyl (0.54 + 0.54 + 0.33)	0.3	3	83*	60*	30*	10*	0*
Carboxin + thiram + imazalil (0.54 + 0.54 + 0.05)	0.3	13	93	77	40*	20	7*
Carboxin + thiram + iprodione chloroneb (0.54 + 0.54 + 0.83 + 0.90)	1.3	0	83*	77	43	13*	3*
Captan + triadimenol (0.62 + 0.27)	0	3	90	77	53	20	3*
Captan + propiconazol (0.62 + 0.03)	4.0	3	100	90	70	23	13
Significance of F	NS[a]	NS	0.01	0.01	0.01	0.01	0.01
LSD ($P = 0.05$)	···	···	12	17	19	16	10

[a] NS = not significant ($P > 0.05$). Asterisk denotes values that differ significantly from the nontreated control.

RESULTS

The 14 fungicides evaluated in amended agar medium exerted widely divergent effects on growth of *Rhizoctonia solani* AG-8 and *R. oryzae* (Table 2). Both fungi were very sensitive to tolclofos-methyl, and *R. solani* was also very sensitive to benodanil. Both fungi were sensitive to carboxin + thiram and chloroneb. *R. solani* was also sensitive to iprodione, and *R. oryzae* was sensitive to benodanil, carboxin, furmecyclox, propiconazole, and triadimenol. Both fungi were moderately tolerant of imazalil, and *R. solani* was moderately tolerant of furmecyclox and propiconazole. Both fungi were tolerant of captan, metalaxyl, prochloraz, and quintozene. *R. oryzae* was also tolerant of iprodione, and *R. solani* was tolerant of carboxin and triadimenol.

Pathogenic fungi isolated from affected roots included *Fusarium culmorum* (Smith) Sacc., *F. graminearum* Schwabe, *R. solani* AG-8, *R. oryzae, G. g.* var. *tritici*, and species of *Pythium* (data not presented). *F. culmorum* and *F. graminearum* were most frequently isolated but were not considered the principal incitants of the root rots observed, and were isolated from roots that exhibited symptoms of root rots as well as from roots with no visible infections. *R. solani*, and occasionally *R. oryzae*, were isolated in lower frequencies from roots at all three experimental sites. Most roots observed in this study were damaged in a manner characteristic of Rhizoctonia root rot. *G. g.* var. *tritici* and species of *Pythium* were also isolated from roots at the Thompson and Wolfe sites, with more *G. g.* var. *tritici* than *Pythium* occurring at the Wolfe site, and with the opposite result at the Thompson site. Neither of these pathogens appeared to be involved in root rots occurring at Moro. Roots yielding *Gaeumannomyces* typically contained blackened segments of cortical or vascular tissue, or dark "runner" hyphae. *Pythium* isolations occurred randomly from tissues with various symptoms or without symptoms. *Bipolaris sorokiniana* (Sacc.) Shoem. caused a blackened rot of the subcrown internodes at Moro. This occurred at a low frequency (<2% of plants) and was not measurably influenced by the seed treatments. *Pseudocercosporella herpotrichoides* caused eyespot lesions on the lower culms of tillers at all three experimental sites. The incidence of eyespot was highest at the Wolfe site and lowest at Moro.

Seed treatments applied during 1986-87 were mostly ineffective in improving the stand or reducing the incidence of diseases on winter wheat at each of the three experimental sites. High variability in experimental results is a characteristic for this disease, which typically occurs in clumped distributions in the field. Variability consistently constrained the achievement of statistically significant results among treatments in this study. Data from the Wolfe site (Tables 3 and 4) are representative of those at all three sites. None of the 13 treatments influenced the numbers of leaves or roots or the incidence of Rhizoctonia root rot during the autumn (data not presented). Although there were no statistically significant differences in the severity of Rhizoctonia root rot (Table 3), no root rot lesions occurred on seedlings treated with carboxin + tolclofos methyl or with captan + triadimenol. The two treatments that included iprodione increased the density of seedlings within the row by 35% ($P = 0.02$; data not presented).

As with measurements made during the autumn, the fungicides did not significantly affect most plant growth indices on the samples collected during the spring of 1987 (data not presented). There were, for instance, no differences among treatments for numbers of leaves, seminal roots, and coronal roots and for plant height and percentages of stunted tillers. It was notable, however, that 11 of the 13 seed treatments reduced tillering in these experiments (Table 3). Captan + propiconazole was the only treatment that did not have a negative impact on tillering. Reductions in tillering were generally of two types. One was illustrated by the plants from the carboxin + quintozene treatment, which showed early cessation of tillering with generally T_3, T_4, and T_5 being impacted. The second was illustrated by carboxin + furmecyclox, which showed significant reductions in tiller production throughout the tillering period. In the latter instance, the impact of fungicides on tillering would have first occurred during the autumn, on T_0, T_1, and T_2 tillers, even though this effect was not detected during the measurements made during the autumn.

The incidence of take-all and eyespot were significantly increased by two seed treatments at the Wolfe site (Table 4), but this impact was not substantiated by observations at the other sites. Although not statistically significant, the carboxin + prochloraz treatment caused a very strong reduction in the incidence of eyespot at each site, and take-all was strongly suppressed by captan + triadimenol and by carboxin + benodanil.

Regression analyses revealed that the incidence of Rhizoctonia root rot on the seminal roots was inversely correlated with both plant height ($r = -0.28$; $P = 0.03$) and the incidence of eyespot ($r = -0.31$; $P = 0.02$). The development of tillers from the different nodes was also highly interrelated, with most tillers being highly correlated with at least two others. The T_1 tillers were correlated ($r = 0.31$-0.77) with all others at $P < 0.01$, thus exhibiting the highest relationships. Important associations were not found to occur among other variables, including relationships between plant growth or disease variables with the incidence of Rhizoctonia root rot on coronal roots.

Grain yields at the three sites are presented in Table 5. None of the 13 fungicide seed treatments significantly influenced grain yields during 1986-87. Additionally, regression analyses failed to reveal any association between these variables and the plant growth and disease variables. Likewise, the five seed treatments evaluated during 1987-88 failed to influence plant growth or disease (data not presented), or the yield of grain (Table 6).

The four-component fungicide seed treatment evaluated under two tillage systems at two sites during 1986-87 also failed to suppress Rhizoctonia root rot and failed to improve plant growth or the yield of winter wheat. Data from samplings at the Thompson site are presented to illustrate results of this experiment (Table 7). Fungicides did not have a significant effect on any of the disease or plant growth variables examined. In contrast, root infections by *R. solani* were greater, and the percentage of plants with T_4 were less in the no-till than in the conventionally tilled soil. In spite of the elevated disease incidence and amount of stunting in the no-till plots, the yield of grain was higher in the no-till than in the conventionally tilled treatment. Additionally, the grain yield and percentage of T_2 tillers was reduced by the presence of the fungicide in the no-till system. Regression analyses failed to reveal any relationships between the

Table 4. Influence of seed treatments on root and culm diseases of winter wheat (summer, 1987, Wolfe site)

Treatment and rate (g a.i./kg seed)	Rhizoctonia root rot[a] Seminals	Coronals	Take-all (percent roots infected)	Foot rot (% tillers)
Nontreated control	31	39	18	27
Carboxin (0.54)	31	20	27	17
Carboxin + quintozene (0.54 + 0.54)	41	26	35	23
Carboxin + iprodione (0.54 + 0.54)	37	29	15	57*
Carboxin + benodanil (0.54 + 2.08)	30	25	7	27
Carboxin + furmecyclox (0.54 + 0.65)	21	20	10	50
Carboxin + prochloraz (0.54 + 0.21)	38	16	23	3
Carboxin + tolclofos methyl (0.54 + 0.65)	23	18	12	27
Carboxin + thiram (0.54 + 0.54)	30	23	13	30
Carboxin + thiram + metalaxyl (0.54 + 0.54 + 0.33)	49	27	47*	10
Carboxin + thiram + imazalil (0.54 + 0.54 + 0.05)	32	29	13	27
Carboxin + thiram + iprodione + chloroneb (0.54 + 0.54 + 0.83 + 0.90)	38	22	37	27
Captan + triadimenol (0.62 + 0.27)	25	26	5	20
Captan + propiconazol (0.62 + 0.03)	26	26	12	23
Significance of F	NS[b]	NS	0.04	0.02
LSD ($P = 0.05$)	...	...	25	27

[a] Rhizoctonia root rot, expressed as numbers of "spear-tip" termini per plant, on main root axes and on first order branches.

[b] NS = not significant ($P > 0.05$). Asterisk denotes values that differ significantly from the nontreated control.

Table 5. Influence of seed treatments on yield of winter wheat at three experimental sites during 1986-87

Treatment and rate (g a.i./kg seed)	Grain yield (kg/ha) Wolfe	Thompson	Moro
Nontreated control	1,866	3,523	1,186
Carboxin (0.54)	1,711	3,349	1,294
+ quintozene (0.54 + 0.54)	2,075	3,254	1,381
+ iprodione (0.54 + 0.54)	2,082	2,985	1,125
+ benodanil (0.54 + 2.08)	1,914	3,180	1,145
+ furmecyclox (0.54 + 0.65)	2,075	3,302	1,273
+ prochloraz (0.54 + 0.21)	1,482	3,329	1,455
+ tolclofos methyl (0.54 + 0.54)	1,624	3,106	1,112
Carboxin + thiram (0.54 + 0.54)	1,893	3,423	1,273
+ metalaxyl (0.54 + 0.54 + 0.33)	1,994	3,719	1,220
+ imazilil (0.54 + 0.54 + 0.05)	2,075	3,329	1,402
+ iprodione + chloroneb (0.54 + 0.54 + 0.83 + 0.90)	2,075	2,958	1,220
Captan + triadimenol (0.62 + 0.27)	1,994	3,153	1,442
Captan + propiconazol (0.62 + 0.03)	2,082	3,376	1,139
Significance of F	NS[a]	NS	NS

[a] NS = not significant ($P > 0.05$).

disease measurements and the growth or yield of plants, except for a positive correlation ($P = 0.01$) between coronal root rot and grain yield.

DISCUSSION

The fungicide seed treatments examined here were clearly ineffective or unreliable for managing Rhizoctonia root rot of winter wheat in seven studies conducted in eastern Oregon. This finding contrasts with an initial observation in Washington (4). Several of the fungicides we examined are highly toxic to *R. solani* AG-8 and *R. oryzae* in vitro. Although the reasons for their inability to adequately protect winter wheat seedlings were not examined, it is probable that these compounds were either tested at concentrations below those necessary for disease control or that they had insufficient persistence in soil for protecting wheat seedlings against Rhizoctonia root rot. The prolonged period in which infections by these fungi remain possible suggests that the lack of fungicidal control may have been related to inadequate fungicide persistence for this use. Winter wheat in this region is planted between August and November. Shoot growth is greatly slowed or halted when soils become very cold (usually in December or January) and resumes in February or March as the soils warm. Soils near the surface typically become very dry and warm during late May and June. Temperature and moisture conditions favorable for infection of roots by *R. solani* AG-8 persist for as long as 3 mo during the autumn and for another 3 mo during the spring.

Take-all was strongly (but not significantly) suppressed by the captan + triadimenol treatment in our experiments with winter wheat, thus confirming in the Pacific Northwest the benefit of the triadimenol seed treatment for managing take-all of winter (1) and spring (8,12) wheat. Unlike the previous reports, however, triadimenol did not lead to consistent improvements in grain yields at the three experimental sites in this study. Triadimenol is toxic to *G. g.* var. *tritici*, absorbed by the caryopsis, and translocated basipetally as well as acropetally (20). These attributes are important for preventing or delaying root infections by fungi that colonize tissues basipetal to the spermosphere.

Table 6. Influence of seed treatments on yield of winter wheat at two experimental sites during 1987–88

Treatment and rate (g a.i./kg seed)	Grain yield (kg/ha) Wolfe	Grain yield (kg/ha) Thompson
Nontreated control	2,035	4,088
Carboxin −1x (0.54)	1,985	4,076
−2x (1.08)	2,026	4,084
Carboxin + thiram (0.83 + 0.83)	1,974	4,070
+ metalaxyl (0.83 + 0.83 + 0.22)	2,041	4,073
+ metalaxyl + quintozene (0.83 + 0.83 + 0.22 + 0.62)	2,018	4,076
Significance of F	NS[a]	NS

[a] NS = not significant ($P > 0.05$).

Table 7. Influence of a seed treatment on growth, disease and yield of winter wheat produced in soils prepared by two primary tillage systems during 1986–87

	Tillage system						
	No-till		Plow/disk		Significance of F		
	F[a]	NF	F	NF	Tillage	Fungicide	F × T
Autumn 1986							
Plant growth stage	2.1	2.0	1.7	1.8	NS[b]	NS	NS
Seminal roots/plant	4.4	4.5	4.5	4.7	NS	NS	NS
Rhizoctonia root rot[c]	22.5	28.5	13.1	17.5	0.02	NS	NS
Spring, 1987							
Plant growth stage	5.4	5.4	5.3	5.4	NS	NS	NS
Tillers (% of plants)							
T_0	23	25	27	15	NS	NS	NS
T_1	70	80	78	70	NS	NS	NS
T_2	58	88[d]	55	63	NS	NS	NS
T_3	45	65	40	63	NS	NS	NS
T_4	10	0	23	20	0.05	NS	NS
T_5	0	0	0	10	NS	NS	NS
Seminal roots per plant	5.7	5.5	5.6	6.0	NS	NS	NS
Rhizoctonia root rot (% seminals)	38	45	44	42	NS	NS	NS
Rhizoctonia root rot (% coronals)	76	86	41	40	0.03	NS	NS
Summer, 1987							
Stunted plants (%)	7	6	1	3	0.01	NS	NS
Grain yield (kg/ha)	1,897	2,129	1,667	1,654	0.01	NS	NS

[a] F = fungicide seed treatment containing carboxin + thiram + iprodione + chloroneb; NF = nontreated seed.

[b] NS = not significant ($P > 0.05$).

[c] Total root lesions per plant.

[d] Pairs of values among fungicide treatments are underlined when they differ at $P < 0.05$.

The incidence of eyespot was strongly (but not significantly) suppressed by the carboxin + prochloraz treatment. Foliar applications of prochloraz are well known for their efficacy in reducing both the incidence and severity of eyespot (13). However, we are not aware of any previous report that illustrates management of eyespot with any fungicide applied as a seed treatment. This finding warrants further study, especially with respect to the recent discovery of benzimidazole tolerance among populations of *P. herpotrichoides* in the Pacific Northwest (14).

The fungicides we examined were generally of little or no benefit to plant growth and yield in these experiments. Tiller development was suppressed by all but two of the fungicide mixtures. Some of the fungicides suppressed development of all tillers, and others only caused reductions in the higher orders of tillers. The absence of tillers on winter wheat has been characterized as a response to plant stress (10). Our results suggest that the phytotoxic response to seed treatment fungicides is expressed as a stress reaction that inhibits the emergence of one or more tillers, and that this phytotoxic response can be prolonged during the development of the plant. The result of tiller inhibition is a reduction in numbers of heads capable of producing grain. Many of the fungicides in this study were, therefore, directly responsible for a constraint to the tillering component of grain yield. This limitation was also a characteristic response to the carboxin + thiram mixture that is the most commonly used wheat seed treatment in the Pacific Northwest. This is particularly important in that this mixture was among the fungicides that suppressed two of the three tiller orders (T_0, T_1, and T_2) that are the primary contributors to high yields of grain. Suppression of higher order tillers would be expected to have less impact on yield components than suppression of the lower orders. It appears noteworthy that the decline in tillering in these experiments did not lead to a corresponding reduction in grain yield, reflecting the elasticity of head size, seed size, and other yield components in winter wheat.

The negative impact on growth by certain fungicides in the sterol-biosynthesis inhibiting class is well documented (2,7,11). The earlier studies concentrated upon the effect of these fungicides on such plant characteristics as the rate of root growth and the length and weight of leaves. The degree of phytotoxicity is sometimes directly related to the temperature at which the fungicide-treated plants are incubated, as is the case for imazalil (11). We did not detect a negative impact of the fungicides on plant height or numbers of roots or leaves, presumably because we used the very low application rates that characterize seed treatments, and because the seedling stages of growth occurred during cool to cold conditions in the autumn and winter. In our experiment, however, the main impact of the fungicide treatments was a general reduction in the numbers of plant tillers.

During 1986-87, only one mixture provided yields that were numerically higher than those from the nontreated controls at each of the three experimental sites. The consistently superior mixture was composed of carboxin + thiram + metalaxyl. It provided a mean yield improvement of 5% (or 358 kg/ha) for the three sites, which represents an increased grain value of $52/ha. Unfortunately, this mixture failed to provide any improvement in yield for the subsequent wheat crop produced at two of the same sites. Therefore, it too was considered unreliable as a recommended practice in the lower rainfall zones that dominate the principal wheat-production regions in eastern Oregon. The mixture of carboxin + tolclofos-methyl, which has a high inherent toxicity to species of *Rhizoctonia* and was among the treatments with the lowest amount of Rhizoctonia root rot, caused a reduction in mean yield (11%) at the three sites during 1986-87. The deleterious impact of tolclofos-methyl appeared related to a marked reduction in tillering, as exemplified by a 40% reduction in tillering at the Wolfe site. In spite of these deleterious effects, the fact that tolclofos-methyl is highly toxic to both of the principal pathogenic species of *Rhizoctonia* in this region, and is acropetally translocated, suggests that it may be a strong candidate for further evaluation in delivery systems that circumvent the phytotoxic tendencies. The key to controlling Rhizoctonia root rot with chemicals such as tolclofos-methyl may be in the discovery of an economically feasible delivery system that provides spacial separation between the caryopsis and fungicide at the time of planting.

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