Application of Propiconazole in Management of Stem Rust in Perennial Ryegrass Grown for Seed

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ABSTRACT

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Stem rust caused by *Puccinia graminis* subsp. *graminicola* was controlled by propiconazole in perennial ryegrass (*Lolium perenne*) grown for seed. Between 1986 and 1992, the fungicide was applied up to six times per year to plants in different stages of growth. A two-application treatment (126 a.i./ha) was effective for increasing seed yield and controlling stem rust, with the first application when spikes began to emerge from the boot and the second when spikes were fully emerged. Stem rust was first observed as early as 29 April and as late as 16 July. Seed yields were smaller when stem rust epidemics began in early spring. A threefold to 10-fold increase in seed yield was observed among cultivars treated with propiconazole compared with nontreated controls. Regardless of treatment, cultivars Birdie II and Linn produced greater seed yields than Palmer, Delray, Yorktown II, and Ovation. Significant differences occurred in thousand seed weight and biomass dry weight (seeds and straw) between fungicide treatments and among cultivars.

Stem rust caused by *Puccinia graminis* Pers.:Pers. subsp. *graminicola* Z. Urban is widespread (2) on perennial ryegrass (*Lolium perenne* L.) used for forage (11) and turfgrass (12,13) and is a serious disease in the Willamette Valley of Oregon, where perennial ryegrass is grown for seed (6). In 1991, seed of perennial ryegrass was produced on 43,845 ha with an estimated farm value of $61.4 million (8). Fungicides are commonly used by grass seed producers to control stem rust, and applications are usually repeated at 10- to 14-day intervals from May to July (5). Although reductions in seed yield attributed to stem rust have been reported as high as 93% (6), no data are available from field studies to estimate yield loss among cultivars of perennial ryegrass with and without fungicide treatments.

The objectives of this study were to: 1) determine the effect of one or more applications of a fungicide on stem rust and seed yield, 2) establish the number of fungicide applications needed to produce the largest seed yield, 3) compare year-to-year variation in the occurrence and development of stem rust, and 4) compare seed yield components and biomass production among cultivars with and without stem rust control. A portion of this work was published earlier (15).

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MATERIALS AND METHODS

General information. *Field plots.* Four field experiments were done, either in a field of Woodburn fine-silt loam (pH 5.8) at the Hyslop Field Laboratory or in a field of Chehalis-Willamette sandy loam with gravel (pH 6.7–6.9) at the Botany Farm. Both fields are near Oregon State University, Corvallis. Soil was tested before seeding and annually thereafter for nutrient availability. Lime and fertilizer were applied according to soil test recommendations (1) to maintain vigorous growth and obtain maximum seed yield, i.e., usually about 60 kg/ha of N, 0–60 kg/ha of K, and 30–60 kg/ha of P in the fall, plus 120 kg/ha of N in the spring. Weed and insect problems were controlled with conventional practices. Depending on the experiment, perennial ryegrass was either drill-seeded in rows on 30.5-cm centers or grown in the greenhouse and transplanted as individual plants into the field. When drill-seeded, grass was mowed in strips 1.2 m wide to separate plots and replications and to reduce interplot interference.

Fungicide application. In all experiments, fungicides were mixed with water and applied at 280 L/ha (30 gal/acre) at 172.4 kPa (25 psi) with a spray boom fitted with flat-fan nozzles (type 8004). Control plots were sprayed with water. Sprays were applied at dawn on days without wind to reduce spray drift among plots. Propiconazole (Tilt 3.6EC) was applied at 252 g a.i./ha (8 fl oz product/acre) or 126 g a.i./ha (4 fl oz product/acre) or as a tank mix with chlorothalonil (Bravo 720) at 585 g a.i./ha (16 fl oz product/acre) at several intervals or frequencies, depending on the experiment.

Disease assessment and seed yields. Stem rust was rated by the modified Cobb scale (9) one or more times during the growing season, depending on the rate of stem rust development and objectives of the experiment. Assessments were made on either the penultimate leaf, flag leaf, or seed spike. Assessment means for each treatment were based on 10 randomly selected spikes or plants per plot. The final stem rust assessment in each experiment was made on the spike a few days before seeds were harvested. In years when stem rust was not observed at harvest, assessments were made on a nonharvested strip remaining on the side of each harvested plot.

Seeds were harvested when moisture content reached 40–45% (dry weight basis). Spikes were cut with a small-plot harvester, threshed, cleaned, air-dried to 10% moisture, and weighed. Seed yield was based on grams of seed per plot, and treatments were compared as seed weight per plot or percent seed yield of the nontreated control. Harvest dates differed each year. In experiment 4, seed yield (grams of seed per plant), thousand seed weight (TSW), and plant growth responses (biomass [seeds and straw] and diameter of crown) were measured.

Disease scores, seed yields, and growth responses were averages of four to six replications, depending on the experiment. Means were subjected to analysis of variance (ANOVA) and compared using either a protected LSD ($P = 0.01$, 0.05, or 0.10) or Duncan's new multiple range test ($P = 0.05$).

Experiments. *Experiment 1.* The effect of the number of propiconazole applications on stem rust control and seed yield was compared in 1986, 1988, and 1989 in a series/omission application schedule using cv. Linn perennial ryegrass. The experiment was done at Hyslop Field Laboratory, and plots were 2.4 × 6.1 m. One field was drill-seeded in fall 1985, and another field, in a different location, was drill-seeded in fall 1987. A mowed strip 1.2 m wide separated plots and replications. The annual date for the first application of propiconazole varied by the maturity of the crop and the stage of plant development. Applications, by methods described previously, were started when 75–100% of the plants had developed first or second nodes in the seed tiller (i.e., "jointing stage") and were continued at 12- to 14-day intervals until anthesis. Propiconazole was applied at 252 g a.i./ha one to six times between 2 April and 16 June 1986 and at 126 g a.i./ha one to six times between 16 April and 23 June 1988 and one to five times between 18 April and 13 June 1989. Each experiment was arranged in a randomized complete block with 12 treatments, with four replications in 1986 and five replications in 1988 and 1989.

In 1986, stem rust assessments were made on the penultimate leaf on 6 June, on the flag leaf on 12 June, and on the seed spike on 3 July; seeds were harvested on 4 July. In 1988, stem rust assessments were made on the seed spikes on 30 June, and seeds were harvested on 1 July. In 1989, stem rust was assessed on seed spikes on 22 June, and seeds were harvested on 26 June.

Experiment 2. In 1989, larger plots of cvs. Linn and Delray were treated with a tank mix of propiconazole and chlorothalonil by methods described previously. Individual plots were drill-seeded at Hyslop Field Laboratory in fall 1988. Plot size of Linn was 3 × 66.7 m and of Delray, 3 × 36.4 m. At harvest, seed weights from Linn plots were converted arithmetically to the plot size of Delray to facilitate cultivar comparisons. The fungicide mixture was applied five times, on 19 April, on 3 and 19 May, and on 3 and 16 June. A mowed strip 1.2 m wide separated plots and replications. Stem rust assessments were made on spikes the day plots were harvested, 25 June for Delray and 26 June for Linn. The study was a randomized complete block with two treatments, a fungicide tank mix and a nontreated control, with six replications.

Experiment 3. The effect of propiconazole applied at various plant growth stages was evaluated for stem rust control and seed yield. In 1990, propiconazole (126 g a.i./ha) was applied one, two, or three times to cvs. Linn and Delray by methods described previously. Field plots were drill-seeded in fall 1989 at Hyslop Field Laboratory; individual plots were 2.4 × 6.1 m. Propiconazole was applied, as described previously, on 26 April, 9 May, and 29 May when 50% of the plants were at the following growth stages, respectively: boot (flag leaf just emerging), 25% spike emergence, and 100% spike emergence. The experiment contained a nontreated control and the following fungicide treatments: 1) a single application at each stage of plant growth, 2) a double application, one at boot and one at 25% spike emergence, 3) a double application, one at 25% spike emergence and one at 100% spike emergence, and 4) a triple application, one at boot, one at 25% spike emergence, and one at 100% spike emergence. A mowed strip 1.2 m wide separated treatments and replications. Stem rust was assessed on 13 June and 27 June; plots of Delray and Linn were harvested on 28 June and 3 July, respectively.

A portion of the experiment was repeated in 1991, using only cv. Delray. As in 1990, propiconazole was applied with the same frequency and at similar stages of plant growth: boot on 14 May, 25% spike emergence on 24 May, and 100% spike emergence on 11 June. Seeds were harvested on 11 July; stem rust developed 5 days after harvest and was assessed on the remaining plant material on 16 July. The study was arranged in a randomized complete block design with six replications.

Experiment 4. Stem rust severity and plant growth responses were measured in individual plants of six cultivars with and without propiconazole treatment. Twenty seedlings each of cvs. Birdie II, Delray, Linn, Ovation, Palmer, and Yorktown II were first grown in cone-shaped plastic containers (3.8 × 21 cm) in the greenhouse for about 4 mo. Plants were watered daily and fertilized weekly with a solution of N-P-K (Peters 20-20-20, 473 ppm N) to maintain vigorous growth. Excess foliage was removed at 3- to 4-wk intervals by clipping plants to heights of 2–3 cm. Seedlings were hardened off on the north side of a headhouse, and 20 plants per cultivar were transplanted into a field at the Botany Farm in rows on 1-m centers in April 1991. Growth among plants was uneven during the spring and summer of 1991, but the fall and winter provided conditions for vernalization and normal seed development in 1992.

Propiconazole (126 g a.i./ha) was applied to 10 plants per plot of the six cultivars on 1, 14, and 28 April, on 13 May, and on 4 June 1992. Ten plants of each cultivar were left untreated to serve as controls. Stem rust was assessed five times when plants were in different stages of growth: on 29 April, tillering; on 5 May, boot; on 13 May, flag leaf; on 28 May, initiation of spike emergence; and on 8 June, 100% spike emergence. Seeds were harvested on three dates, depending on maturity: on 17 June, nontreated cvs. Palmer, Delray, Linn, and Birdie II; on 23 June, nontreated cvs. Ovation and Yorktown II and propiconazole-treated cvs. Palmer, Delray, Linn, Birdie II, and Ovation; and on 25 June, propiconazole-treated Yorktown II.

Winter survival was based on a count of the living plants for each experimental variable on 1 April 1992 (before treatment with propiconazole had begun) and again on 19 March 1993, the following spring. These values were used to calculate percent plant survival following a severe stem rust epidemic. The study was arranged in a split-split plot design with four replications; whole plots were either treated with propiconazole or left nontreated for a control, split-plots were cultivars, and split-split plots were assessment dates.

RESULTS

The date when stem rust was initially observed differed for each year and was as early as 29 April in 1992 and as late as 16 July in 1991. In other years, infected plants were usually found during the first 2 wk of May. A single stem rust assessment was made for experiments 1 and 2, and multiple stem rust assessments were made for experiments 3 and 4.

Experiment 1. In the series/omission fungicide experiment, stem rust developed during each of the 3 yr in the nontreated controls and was more severe in

Table 1. Stem rust severity and seed yield for perennial ryegrass cultivar Linn treated one to six times with propiconazole in 1986, 1988, and 1989

Application number[x]	Stem rust severity[y] (%)			Seed yield[z] (% of control)		
	1986	1988	1989	1986	1988	1989
Control	57	50	Trace	100	100	100
1	26	34	0	96	98	99
1,2	63	20	0	118	104	97
1,2,3	47	22	Trace	107	97	96
1,2,3,4	24	5	0	102	111	105
1,2,3,4,5	0	0	0	120	97	107
1,2,3,4,5,6	0	0	0	118	123	104
2,3,4,5,6	0	0	0	118	117	104
3,4,5,6	0	0	0	109	111	104
4,5,6	0	0	0	115	87	100
5,6	2	0	Trace	107	105	99
6	17	28	...	110	91	...
LSD ($P = 0.05$)	15.1	14.7	...	NS	NS	NS

[x]Propiconazole applications 1–6 were on 2 April, 17 April, 4 May, 19 May, 2 June, and 16 June 1986; on 16 April, 28 April, 12 May, 26 May, 9 June, and 23 June 1988; and on 18 April, 2 May, 16 May, 30 May, and 13 June 1989. Rates were 252 g a.i./ha in 1986 and 126 g a.i./ha in 1988 and 1989.

[y]Stem rust severity on panicle stem and head was assessed by the modified Cobb scale on 3 July 1986, 1 July 1988, and 22 June 1989.

[z]Seed yields in propiconazole-treated plants were based on percent weight of nontreated controls. Yields in nontreated controls were 188 g harvested 4 July 1986, 353 g harvested 1 July 1988, and 459 g harvetsetd 26 June 1989. NS = not significant.

1986 and 1988 than in 1989 (Table 1). Only trace amounts of stem rust developed in 1989, and the final propiconazole treatment (number 6) was omitted because the crop matured 7–10 days earlier than in 1986 and 1988. In 1986 and 1988, stem rust was controlled in plants receiving three to six applications of propiconazole. Three late-season applications (beginning on 19 May in 1986 and on 26 May in 1988) were more effective than four early-season applications. Two late-season applications of propiconazole in 1988 (9 and 23 June) prevented stem rust development, but a trace amount (2%) of stem rust developed in plots treated twice in 1986 (2 and 16 June). A single late-season application of propiconazole (16 June 1986 or 23 June 1988) did not prevent stem rust development but did lessen its severity significantly ($P = 0.05$) from that in the nontreated control.

Seed yields in propiconazole-treated plants of cv. Linn were not significantly different ($P = 0.05$) from the nontreated controls. In all 3 yr, however, seed yields in plots treated with four to six applications of propiconazole were generally larger than those in the nontreated control, and seed yields were larger in plots treated with late-season applications than in those receiving early-season applications of propiconazole.

Experiment 2. In the large-plot experiment of cvs. Linn and Delray receiving five applications of a tank mix of propiconazole and chlorothalonil, leaf diseases caused by *Drechslera siccans* (Drechs.) Shoemaker and *Rhynchosporium orthosporum* R.M. Caldwell were observed during the first week in April. When the tank-mix applications of fungicides were started on 19 April 1989, neither fungus was observed on newly emerged foliage, both being restricted to leaves near the base of the plant. In June and July, the primary disease in the nontreated controls was stem rust. When plots were harvested (on 25 June for Delray and 26 June for Linn), stem rust was very severe (60–100%) on spikes in plants of nontreated controls and in borders surrounding the plots. No stem rust was observed in plants of either cultivar receiving five applications of the tank mix of fungicides.

Seed yield of fungicide-treated Delray plants was 45% larger than that of nontreated controls (3,639 vs. 2,509 g), and seed yield of fungicide-treated Linn plants was 42% larger than that of nontreated controls (3,276 vs. 2,303 g). The treatment differences for both cultivars were significant ($P = 0.01$).

Experiment 3. When propiconazole was applied at various plant growth stages, no stem rust was observed in any plants of either Linn or Delray on the first assessment date, 13 June 1990. By 27 June, stem rust severity in the nontreated control plots had reached 38% in Linn and 29% in Delray; by 5 July, stem rust in the controls had increased to 85% in Linn and 88% in Delray (Table 2). By 27 June, stem rust had developed in fungicide-treated plots of both cultivars but was significantly less ($P = 0.05$) than in the nontreated control plots. By 5 July, 2 days after harvest of Linn and 7 days after harvest of Delray, one or more applications of propiconazole continued to prevent development of stem rust. Data for both cultivars in both years show that three applications of propiconazole allowed only a trace (1–2%) amount of stem rust to develop in the spike. Data also show that the single application of propiconazole made when plants were in the boot stage of development did not prevent stem rust from developing on the spike at harvest, unless the single application was combined with two later applications. In 1991, two applications of propiconazole (24 May and 11 June) to Delray allowed only a trace (2%) of stem rust to develop by 16 July, 5 days beyond harvest (11 July). Seed yield and disease differences due to propiconazole applications were less obvious in a year like 1991, when stem rust development was less severe than in 1990.

When data obtained for Delray in 1990 and 1991 were compared, plant growth and stem rust development were about 1 wk later in 1991. Fungicide applications were also delayed by the same length of time. When seeds of Delray were harvested on 11 July 1991, no stem rust was observed. Sufficient stem rust had developed 5 days after harvest (on 16 July 1991) to allow comparison of the various fungicide treatments for stem rust control. The results obtained for Delray in 1990 and 1991 were generally in agreement. Three applications of propiconazole reduced the severity of stem rust from that in nontreated controls. One application of propiconazole at the boot stage (i.e., before seedhead emergence) was the least effective treatment.

In 1990, seed yields of Linn receiving several different fungicide treatments were not statistically different ($P = 0.05$) from those of the nontreated control. These results were similar to observations made for Linn in 1986, 1988, and 1989 (Table 1), namely, rust was controlled by propiconazole but seed yields did not differ statistically ($P = 0.05$) from those of nontreated controls. Linn maintained seed yields when exposed to moderately severe stem rust.

When seed yields of Delray in the nontreated control were compared with seed yields in the fungicide-treated plots, yields were significantly ($P = 0.05$) higher (17–20% increase) in the propiconazole-treated plants in 1990 and also significantly ($P = 0.10$) higher in propiconazole-treated plants in 1991. In a 2-yr comparison of seed yields for Delray, three applications of propiconazole increased yields as did two applications of propiconazole, one when spikes were emerging and the second when spikes were fully emerged. One application of propiconazole at the boot stage was the least effective treatment for increasing seed yield.

Table 2. Stem rust severity and seed yield for perennial ryegrass cultivars Linn and Delray treated one to three times with propiconazole in 1990 and 1991

Growth stage at application[x]	Stem rust severity[y] (%)					Seed yield[z] (g/plot)		
	Linn		Delray			Linn	Delray	
	27 June 1990	5 July 1990	27 June 1990	5 July 1990	16 July 1991	3 July 1990	28 June 1990	11 July 1991
Control	38	85	29	88	23	458	499	371
Boot (B)	16	64	12	83	9	422	509	396
Spikes emerging (S)	6	44	2	64	10	516	544	424
100% Emergence (100)	1	5	1	31	2	504	552	397
B + S	7	55	3	49	8	414	544	422
S + 100	0	3	1	13	2	420	582	445
B + 100 + S	0	2	0	0	1	462	599	436
LSD ($P = 0.05$)	11.1	21	6.8	13.8	...	NS	54.9	...
($P = 0.10$)	...	...	...	...	12.6	...	...	42.5

[x] Propiconazole (126 g a.i./ha) applied in 1990 on 26 April (boot), 9 May (spikes emerging), and 29 May (100% emergence) and in 1991 on 14 May (boot), 24 May (spikes emerging), and 11 June (100% emergence).

[y] Assessed by the modified Cobb scale. No stem rust was observed on Delray in 1991 at harvest (11 July) but was present on 16 July. Final stem rust assessments in 1990 were made on Linn and Delray 2 and 7 days after harvest, respectively.

[z] Plots were harvested on dates indicated.

Experiment 4. When stem rust severity and plant growth responses were measured for six cultivars treated with propiconazole, stem rust developed very early in the year in nontreated controls (Table 3). Stem rust was observed first on 29 April in some plants of all six cultivars and continued to increase until the final assessment on 8 June.

Stem rust assessments for whole plots were significantly ($P = 0.01$) lower in propiconazole-treated plots (0.8%) than in nontreated controls (45%). Stem rust assessments among the six cultivars were not significantly different, and no significant fungicide treatment (whole plot) × cultivar (split plot) interaction was observed. The stem rust severity ratings among the five assessment dates (split-split plot) were significantly ($P = 0.01$) different, with no significant date × cultivar interaction. When stem rust severity assessments were compared for each of the six cultivars on each of the five dates within the no-fungicide treatment, assessments on 29 April and 5 May were not significantly different from each other, but assessments from 5 May to 8 June showed a significant ($P = 0.05$) increase in stem rust.

When plant growth responses were compared, seed weight per plant was significantly different between fungicide treatments ($P = 0.01$) and among cultivars ($P = 0.01$), with a significant ($P = 0.05$) treatment × cultivar interaction (Table 3). Birdie II and Linn produced the largest seed yields in both fungicide-treated and nontreated plots. When the mean seed yield per plant for each cultivar was compared for the propiconazole-treated and nontreated control plots, seed yields from fungicide-treated plants were about 10-, eight-, eight-, seven-, four-, and threefold larger than those from nontreated control plants of Palmer, Delray, Yorktown II, Ovation, Birdie II, and Linn, respectively.

Significant differences occurred in TSW between fungicide treatments ($P = 0.05$) and among cultivars ($P = 0.01$), with no significant interaction. TSWs of Linn and Delray were significantly larger ($P = 0.05$) than those of the other cultivars for the propiconazole-treated plants. In the nontreated controls, TSW of Linn was significantly ($P = 0.05$) larger than those of the other cultivars tested. In propiconazole-treated plants, TSW of Yorktown II, Palmer, Ovation, and Birdie II were 63, 65, 76, and 76%, respectively, of the TSW of Linn, and these differences were significant ($P = 0.05$).

When plant biomass (seeds and straw) was compared, propiconazole-treated plants produced significantly ($P = 0.01$) more than did nontreated controls. Also, biomass differed significantly ($P = 0.01$) among cultivars, with no significant treatment × cultivar interaction. Plants of Linn produced the largest, and those of Yorktown II and Ovation the smallest, biomass dry weights. When crown diameters were measured, no significant differences were found between treatments or among cultivars.

The mean percent survival of plants (Table 3) treated with propiconazole (87%) was significantly larger ($P = 0.05$) than that for nontreated control plants (62%). Mean percent plant survival among the six cultivars was also significantly different ($P = 0.05$), with no significant treatment × cultivar interaction. When cultivar plant survival means were compared by Duncan's new multiple range test, that of Birdie II (92.5%) was significantly larger than that of Linn (78.9%), Yorktown II (74.4%), Palmer (72%), Ovation (71.4%), and Delray (58.6%); the percent survivals of plants among the latter five cultivars were statistically similar to each other.

DISCUSSION

Stem rust is a serious disease of perennial ryegrass grown for seed. In most years, grass seed producers control stem rust by one to four applications of a fungicide. The yearly cycle of stem rust begins following seed harvest in mid-July. After seed and straw removal, plants resume growth and stem rust is maintained on summer and fall regrowth and survives winter in infected plants. During most winters, weather conditions allow slow growth of the host but prevent stem rust from increasing, i.e., low temperatures limit growth and sporulation and urediospores that form are often washed from air by rain, or low temperatures are unfavorable for germination, infection, and incubation. During late winter and early spring, epidemics of stem rust appear as a sigmoid, or S-shape, progression when disease is graphed against time (16). Fungicides must be applied before the appearance of stem rust lesions to obtain optimum

Table 3. Stem rust severity and growth responses of plants treated with propiconazole among six cultivars of perennial ryegrass

Treatment Cultivar	Stem rust severity[v] (%) 29 April	5 May	13 May	28 May	8 June	Growth responses[w]: Seed per plant (g)	Thousand seed weight (g)	Biomass per plant (g)	Crown diameter (cm)	Plant survival[x] (%)
Control										
Birdie II	15	22	30	62	87	6.2 a	1.248 bc	242.2 b	39.7	90
Delray	9	12	34	59	84	2.4 b	1.346 b	195.1 bc	37.4	45
Linn	9	16	32	80	94	8.0 a	1.830 a	327.1 a	37.4	75
Ovation	13	13	29	53	88	3.4 b	1.185 cd	154.0 bc	40.8	48
Palmer	27	27	45	73	92	2.2 b	1.161 cd	201.0 bc	39.9	54
Yorktown II	24	36	49	53	88	1.7 b	1.089 d	128.0 c	37.4	60
Mean[y]	16 a	21 a	37 b	63 c	88 d	4.0 a	1.310 a	208.0 a	35.3 a	62 a
Propiconazole[z]										
Birdie II	0	0	0	0	3	26.9 a	1.619 bc	381.9 a	35.3	95
Delray	0	0	0	0	5	19.7 c	1.938 ab	289.0 b	35.4	72
Linn	0	0	0	0	4	25.4 ab	2.119 a	416.4 a	36.0	81
Ovation	0	0	0	0	5	23.1 abc	1.604 bc	265.9 b	35.1	95
Palmer	0	0	0	0	9	21.9 bc	1.373 c	374.9 a	36.0	90
Yorktown II	0	0	0	0	0	13.2 d	1.344 c	240.2 b	34.2	89
Mean	0	0	0	0	4	21.7 b	1.666 b	328.0 b	38.7 a	87 b

[v] Assessed by the modified Cobb scale.

[w] Seeds were harvested on 17 June for nontreated Birdie II, Delray, Linn, and Palmer; on 23 June for nontreated Ovation and Yorktown and for treated Birdie II, Delray, Linn, Ovation, and Palmer; and on 25 June for treated Yorktown. Seeds were cleaned and blown before weighing.

[x] Means were based on viable plants on 1 April 1992 and 19 March 1993.

[y] Means for stem rust severity among columns and for growth responses within columns between treatments and among cultivars followed by the same letter are not significantly different ($P = 0.05$) by Duncan's new multiple range test.

[z] Applications of 126 g a.i./ha on 1, 14, and 28 April, on 13 May, and on 4 June 1992.

plant protection. If applications are delayed, fungicides do not adequately control the disease. The cost of one application of propiconazole, at 189 g a.i./ha [6 fl oz product/acre], a common rate used by seed producers, plus the cost of application to treat all fields of perennial ryegrass in the Willamette Valley in 1991 was estimated to be $2.1 million (M. A. Mellbye, *personal communication*). Judicious application of fungicides could reduce production costs by $2 to $6 million, depending on the number and the concentration of the fungicide sprays eliminated.

Data from experiment 1 (Table 1) indicated that disease control is most effective when three applications of a fungicide are started in mid-May and continued at 14-day intervals. Data also indicated that applications started in early April, unless continued through May, do not protect plants from stem rust. Likewise, two applications in June did not prevent stem rust from developing.

When propiconazole application was based on the stage of plant development (experiment 3, Table 2), the most effective fungicide treatments were either three applications (at boot, initial spike emergence, and full spike emergence) or two applications (when spikes were beginning to emerge and when spikes were fully emerged). Application of propiconazole at the boot stage of growth was the least effective treatment; this was generally true for both years and both cultivars.

Considerable variation occurred among data obtained for seed yield comparisions among fungicide treatments. In experiments 1 and 2, seed yields of cv. Linn for a given treatment could vary by as much as 24% within a replication, with a coefficient of variation of over 20%. This observation has been made with other open-pollinated grass species when evaluating the effect of treatments on seed yield in small plots. In order to measure the effect of stem rust on seed yield in cvs. Linn and Delray, plot size was increased for experiment 2. In 1989 (experiment 2), when plots received five applications of the tank mix of propiconazole and chlorothalonil, stem rust was controlled and seed yields of Linn and Delray were 43 and 45% higher, respectively, than those of nontreated controls.

In 1992, stem rust was very severe throughout the Willamette Valley. Propiconazole application started on 1 April controlled stem rust during the critical period of April and May. In field tests in this year (experiment 4, Table 3), a threefold to 10-fold increase in seed yield was observed among cultivars treated with propiconazole applied at the lowest labeled rate (126 g a.i./ha), compared with nontreated controls. Mean seed weight per plant for six cultivars in propiconazole-treated plots was 5.4 times larger than that for nontreated controls (21.7 vs. 4 g). A significant ($P = 0.05$) response was observed also among cultivars for seed yield per plant, TSW, plant biomass, and plant survival, with or without stem rust control.

In an earlier report (16), incidence and severity of stem rust were lower in cvs. Birdie II, Linn, and Ovation than in Delray, Palmer, and Yorktown II. These differences were attributed to slow-rusting characteristics in Birdie II, Linn, and Ovation. Birdie II was previously selected for stem rust resistance in field test plots by backcrossing two sources of stem rust resistance into Birdie (7). Linn, a common cultivar, was field-selected for forage production and seed yield (14), and Delray, Ovation, Palmer (4), and Yorktown II (3) were not selected for stem rust resistance. Differences in stem rust reactions among these cultivars observed in the field in 1991 (16) were not observed in 1992. Environmental conditions were more favorable for stem rust in 1992 than in 1991. Stem rust was observed first on 12 June 1991 and 29 April 1992; the stem rust epidemic started 44 days earlier in 1992 than 1991. Perhaps stem rust resistance in Birdie II perennial ryegrass is similar to stem rust resistance in wheat; when inoculum density is high and environmental conditions are ideal for stem rust development, resistant wheat cultivars can fail (10).

Data obtained in these experiments indicate that: 1) two applications of propiconazole at 126 g a.i./ha, one at spike emergence and one when spikes were fully emerged, controlled stem rust; 2) seed yield losses by stem rust varied among years but reached 90% reduction in years when the disease was severe; 3) epidemics of stem rust started at different times each year and seed yield losses were larger when epidemics started in early spring; and 4) plant growth responses (seed yield components and biomass) varied among cultivars and cultivars responded differently to stem rust severity.

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LITERATURE CITED

1. Anonymous. 1982. Fertilizer guide, perennial ryegrass—FG 46. Oreg. State Univ. Ext. Serv.
2. Faar, D. F., Bills, G. F., Chamuris, G. P., and Rossman, A. Y. 1989. Fungi on Plants and Plant Products in the United States. American Phytopathological Society, St. Paul, MN.
3. Funk, C. R., Cickson, W. K, Ledeboer, F. B., and McVeigh, K. J. 1981. Registration of 'Yorktown II' perennial ryegrass. Crop Sci. 21:144-145.
4. Hurley, R. H., Loft, P. S., Pompei, M. E., and Funk, C. R. 1983. Registration of 'Palmer' perennial ryegrass. Crop Sci. 23:401.
5. Koepsell, P. A., and Pscheidt, J. W. 1991. Pacific Northwest plant disease control handbook. Oreg. State Agric. Ext. Serv.
6. Meyer, W. A. 1982. Breeding disease-resistant cool-season turfgrass cultivars for the United States. Plant Dis. 66:341-344.
7. Meyer, W. A., and Rose-Fricker, C. 1990. Registration of 'Birdie II' perennial ryegrass. Crop Sci. 30:1158-1159.
8. Miles, S. D. 1991. 1990 Oregon county and state agricultural estimates. Spec. Rep. 790. Oreg. State Univ. Ext. Serv.
9. Peterson, R. F., Campbell, A. B., and Hannah, A. E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems of cereals. Can. J. Res. Sect. C 26:496-500.
10. Roelfs, A. P., McVey, D. V., Long, D. L., and Rowell, J. B. 1972. Natural rust epidemics in wheat nurseries as affected by inoculum density. Plant Dis. Rep. 56:410-414.
11. Rose-Fricker, C. A., Meyer, W. A., and Kronstad, W. E. 1986. Inheritance of resistance to stem rust (*Puccinia graminis* subsp. *graminicola*) in six perennial ryegrass (*Lolium perenne*) crosses. Plant Dis. 70:678-681.
12. Smiley, R. W. 1983. Compendium of Turfgrass Diseases. American Phytopathological Society, St. Paul, MN.
13. Smith, J. D., Jackson, N., and Woolhouse, A. R. 1989. Fungal Diseases of Amenity Turf Grasses. 3rd ed. E. & F.N. Spon, New York.
14. U.S. Department of Agriculture. 1972. 'Linn'. Page 74 in: Grass Varieties in the United States. A. A. Hansen, ed. Agric. Handb. 170. U.S. Government Printing Office, Washington, DC.
15. Welty, R. E. 1989. Incidence and severity of stem rust *Puccinia graminis* subsp. *graminicola* in *Lolium perenne* 'Linn' treated with propiconazole. (Abstr.) Phytopathology 79:912.
16. Welty, R. E., and Barker, R. E. 1992. Evaluation of resistance to stem rust in perennial ryegrass grown in controlled and field conditions. Plant Dis. 76:637-641.