Strobilurin Fungicide Timing for Rhizoctonia Root and Crown Rot Suppression in Sugarbeet

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ABSTRACT

Field experiments were conducted to determine the optimal timing of strobilurin fungicide application to sugarbeet (*Beta vulgaris* L.) for suppression of Rhizoctonia root and crown rot (RRCR) caused by the fungus *Rhizoctonia solani* AG 2-2. Fungicide application timings were made relative to cultivation operations that introduce soil-borne inoculum onto the crown, thus, initiating disease development. Sugarbeet crowns were inoculated with *R. solani* AG 2-2 at times coincident with cultivation in an effort to simulate the natural infection process. Field plots were established near Torrington, Wyoming under sprinkler irrigation in 1999 through 2002 and in Scottsbluff, Nebraska under furrow irrigation in 1999 and 2000. Fungicide application timings most effective for RRCR suppression were those made at the time of inoculation or, alternatively, when a half-rate split application was made at the time of inoculation plus 2 weeks later. Disease incidence decreased 64% to 96% and total root yields increased 67% to 1853% compared to the nontreated control ($P \leq 0.05$). Fungicide applications made at planting were too early and had little effect on disease that developed following inoculation and cultivation. When the application timing was optimal, the different strobilurin fungicides had similar efficacy. However, when the timing was not optimal, azoxystrobin had greater efficacy than did trifloxystrobin and pyraclostrobin applied at similar rates. Thiophanate-methyl

was less effective than the strobilurins for season-long RRCR management ($P \leq 0.05$).

Additional Key Words: in-furrow, foliar broadcast, foliar banded .

[3] This manuscript is published as University of Wyoming Agricultural Experiment Station Journal Series No. 1788 and is a contribution of the University of Nebraska Agricultural Research Division, Lincoln, NE 68583, Journal Series No. 14265. Research was partially funded by the Western Sugar Grower Joint Research Committee.

Rhizoctonia root and crown rot (RRCR) of sugarbeet (*Beta vulgaris* L.) is caused by the soil-borne fungus *Rhizoctonia solani* AG 2-2 (Schneider and Whitney, 1986). A survey of the Western United States sugarbeet production areas revealed that RRCR was problematic on 42% and 30% of the sugarbeet crop in 1998 and 1999, respectively (Jacobsen et al., 2001). Crown rot of maturing sugarbeet plants can occur when *R. solani* infested soil is deposited in sugarbeet crowns during cultivation (Schneider et al., 1982). Infection of the crown is favored by temperatures of 25 to 28 C and moist soil (Parmeter, 1970). In addition to crown and root rot of maturing sugarbeet plants, early-season infection of sugarbeet by *R. solani* causes post-emergence damping-off in young seedlings.

Since *R. solani* is a persistent soil inhabitant and the fungus is endemic to all sugarbeet growing areas, crop rotation is of limited value for control (Rush and Winter, 1990). Cultural management strategies to avoid loss from damping-off and/or crown infection include early spring planting, proper soil fertility, and avoiding the movement of infested soil into the crown during cultivation. Resistant varieties also are available but, in the absence of disease, yields are typically lower than those for adapted more susceptible varieties (Panella and Ruppel, 1996). None of these cultural techniques will totally prevent infection and subsequent RRCR development, but can contribute to RRCR suppression.

Fungicides that suppress *R. solani* potentially offer growers an additional tool for RRCR management. The strobilurin fungicide class (azoxystrobin, Quadris®, SYNGENTA; trifloxystrobin, Gem®, BAYER; pyraclostrobin, Headline®, BASF), is effective against a wide range of fungi, including *R. solani*. For example, research in Montana revealed that azoxystrobin suppressed RRCR following its application to the sugarbeet crown (Kiewnick et al, 2001). Disease suppression was variable, at least in part, due to timing of the fungicide application. The study reported herein was initiated due to the lack of information on proper fungicide application timing for suppression of crown rot. Because most inoculum for crown rot infection is introduced into the crown during cultivation for weed control (Schneider et al., 1982), it is logical to time fungicide applications to coincide with cultivation. Therefore, the primary objective of this study was to determine the optimal time to apply strobilurin fungicide to sugarbeet for RRCR management in relation to the introduction of inoculum during cultivation. Secondary objectives were to determine the relative efficacy of various fungicides and the effects of fungicide rates on disease suppression.

MATERIALS AND METHODS

Field experiments were conducted at Torrington, WY, in 1999 through 2002, and Scottsbluff, NE, in 1999 and 2000. Treatments evolved from year to year based on prior results and also to accommodate changes in manufacturer fungicide use recommendations. Field plots were planted with a *R. solani* susceptible cultivar 'Monohikari' and plants were inoculated with *R. solani* AG 2-2, to increase disease pressure and to reduce in-field variability. These inoculations coincided with the final cultivation pass to simulate the natural infection that occurs following soil movement into the sugarbeet crowns (Schneider et al., 1982). Table 1 summarizes inoculation dates and other relevant dates, environmental conditions, and growth stage at the time of fungicide application for all experiments.

Rhizoctonia inoculum was prepared by culturing four *R. solani* AG 2-2 isolates on potato dextrose agar and then inoculating wheat or rye grain using the procedure described below (E.G. Ruppel, personal communication). Fungal isolates used in the study were provided by the USDA-ARS Sugarbeet Research laboratory in Fort Collins, CO. Three isolates were initially recovered from diseased sugarbeet in Colorado and one isolate was recovered from diseased sugarbeet in Nebraska. For production of inoculum for each fungal isolate, grain (3 kg) was washed in tap water and then placed into a spawn filter-patch bag (Fungi Perfecti, Olympia, WA) along with 1.63 l distilled water. After soaking overnight, the bag was autoclaved for 1.5 hr. Once sufficiently cool, grain was inoculated by thoroughly mixing agar from one of the fungal culture plates into the grain. The top of the bag was sealed by stapling, and the grain culture was incubated 2 to 3 weeks at room temperature with periodic agitation to break up clumps and to encourage fungal growth that permeated the grain. After incubation, grain was poured from the bag into paper trays where it was allowed to air-dry for sever-

Table 1. Inoculation dates and other important environmental conditions, and sugarbeet growth stage at the time of fungicide application for Wyoming and Nebraska experiments.

Location	Year	Planting date	Inoculation date	Application date	Application timing	Air temp. (C)	Wind speed (kph)
Wyoming	1999	6 May	29 June	6 May	at planting	NR†	NR
				9 June	4-6 leaf	17.2	8.0
				7 July	closure within row	28.9	5.6
Wyoming	2000	18 April	7 June	31 May	6-leaf	21.1	5.6
				7 June	6-9 leaf	31.1	5.6
				14 June	8-10 leaf	28.3	8.0
				21 June	closure within row	20.6	0.0
				28 June	closure within row	20.6	0.8
				7 July	closure within row	30.0	8.0
Wyoming	2001	20 April	13 June	20 April	at planting	12.2	4.8
				30 May	6-leaf	21.1	9.7
				6 June	8-10 leaf	21.1	3.2
				13 June	10-12 leaf	16.7	6.4
				20 June	closure within row	14.4	3.2
				28 June	closure within row	33.9	0.0
				4 July	closure between rows	23.9	3.2
Wyoming	2002	14 May	21 June	21 June	6-10 leaf	25.7	1.6
				5 July	15-leaf	27.3	5.6
Nebraska	1999	20 April	3 June	24 May	2-leaf	24.4	4.8
				2 June	4-leaf	26.7	24.1
				16 July	closure between rows	23.4	4.8
Nebraska	2000	24 April	7 June	19 May	2-leaf	16.7	1.6
				2 June	4-leaf	21.7	20.9
				12 June	6-leaf	32.2	4.8
				7 July	closure between rows	21.1	8.0

†NR= Not recorded.

al days. The grain was then pulverized with the aid of a Thomas-Wiley mill to produce a particle size of approximately 1 mm.

Torrington, WY site:

The soil type at Torrington, WY is a Dwyer Mitchell sandy loam soil with pH 7.8 and 1.4 percent organic matter. The experimental design was a randomized complete block design with four replicates. Field plots were two rows wide (0.8 m wide row-centers) by 9.1 m long, with two nontreated rows between each plot. Fungicides were applied to the two center rows of each plot. Sugarbeet 'Monohikari' was planted at a rate of 168,000 seeds/ha on 6 May 1999, 18 April 2000, 20 April 2001, and 14 May 2002. Plots area received 168.3 kg/ha of total N and 56.1 kg/ha of P_2O_5 prior to planting. Plots received overhead irrigation as needed, and weed control was accomplished with standard post emergence herbicide applications plus cultivation.

On 29 June 1999, 7 June 2000, 13 June 2001, and 21 June 2002 Rhizoctonia inoculum (0.8 g/plant) was applied to the crown of each plant in one randomly selected row of each plot except in 2002 when both rows were inoculated. Plots were immediately cultivated after inoculation to introduce soil into the sugarbeet crowns. Immediately after inoculation and cultivation, plots were sprinkler-irrigated with 2 cm, then within 72 hours an additional 2 cm to favor infection. In 1999, 2000, and 2002 sugarbeet in the 6-10 leaf stage were inoculated, and in 2001, inoculations were made in the 10-12 leaf stage.

Azoxystrobin treatments made at planting (in-furrow) in 1999 and 2001 were designed to protect young seedlings from damping-off and to aid in plant establishment. The at-planting treatment effects were determined by measuring early season sugarbeet populations, and by measuring RRCR incidence and severity prior to row closure. Sugarbeet populations were determined by counting the number of plants for 3 m of row for each of the two rows. Disease incidence and severity was determined for a five-root subsample taken from the noninoculated row. The number of roots with RRCR decay symptoms (incidence) and the percentage of root surface-area decayed (severity) was estimated.

Disease data for RRCR development during the remainder of the season and yield data were collected from the inoculated row(s). Non-destructive RRCR disease incidence ratings were determined by counting the plants in 6.1 m of row with wilting leaves, darkened petioles, and/or decayed crowns following infection by *R. solani*. Sugarbeet roots were harvested by hand from the center 1.5 m of the inoculated row(s) and root yields were determined.

The azoxystrobin treatments in 1999 consisted of applications

Table 2. Effects of azoxystrobin treatments on sugarbeet stands, RRCR development, and sugarbeet yield (Torrington, WY; 1999).

Treatment	Timing and application rate (a.i.)[†]	Stand count (per 6.1 m)	RRCR severity (%)[‡]	RRCR incidence (per 6.1 m)	Sugarbeet yield (Mg/ha)
		26 May	24 Jun	9 Aug	
1. Nontreated Control	NA	48.0 a[§]	1.0 a	16.5 a	25.7 b
2. Azoxystrobin	at planting (2.13 g /304 m)	52.0 a	1.2 a	14.5 a	20.2 b
3. Azoxystrobin	at planting (4.25 g /304 m)	48.5 a	1.3 a	17.3 a	20.8 b
4. Azoxystrobin	3 weeks prior to inoculation (2.13 g /304 m)	52.5 a	1.0 a	15.3 a	31.1 ab
5. Azoxystrobin	3 weeks prior to inoculation (4.25 g /304 m)	46.3 a	1.2 a	16.3 a	21.1 b
6. Azoxystrobin	at planting (2.13 g /304 m) plus 1 week after inoculation (0.17 kg/ha)	49.5 a	1.0 a	2.5 b	44.9 a
7. Azoxystrobin	3 weeks prior to inoculation (2.13 g /304 m) plus 1 week after inoculation (0.17 kg/ha)	54.8 a	0.8 a	5.8 b	43.7 a

[†]The at planting timings were made as banded (18-cm) in-furrow applications on 6 May. Applications made prior to inoculation were made in a 18-cm band. Applications made after inoculation were made as a broadcast. Timings are approximate, actual dates listed in Table 1. Plants were inoculated with *R. solani* on 29 June; NA= not applicable.

[‡]Severity was determined by a visual estimate of the percent surface area of a sugarbeet root affected by rot. Mean percentage data for Rhizoctonia disease symptoms (RRCR) were converted from Horsfall-Barratt ratings (0-11).

[§] Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

made: at planting (in-furrow), 3 weeks prior to inoculation (foliar banded), and 1 week after inoculation (foliar broadcast), compared to a nontreated control for RRCR management. The one week after inoculation treatment timings were preceded by either an at-planting application or a before inoculation banded application (Table 2). The at-planting treatments were applied to open furrows on 6 May with a hand-held spray bottle in a total volume of 0.25 l /49 m of row. Furrows were filled in by hand with a hoe, and then a commercial planter was used to place seed into the treated soil at a depth of 2.5 cm. Band treatments (18 cm wide) were made 3 weeks before inoculation on 9 June with a backpack sprayer (CO_2) in a total volume of 0.5 l /49 m of row at 276 kPa boom pressure. The boom was equipped with a single #730077 flat fan nozzle. Broadcast treatments were made on 7 July using a backpack sprayer in a total spray volume of 402 l /ha at 207 kPa boom pressure (four #8004 flat fan nozzles spaced at 0.5 m). Sugarbeet population counts were taken on 26 May for 6.1 m row. Early season RRCR incidence and severity was measured as described above for five root samples collected on 24 June. Mid-season RRCR incidence ratings were taken on 9 August, and root harvest was on 1 October.

Treatments in 2000 (Table 3) consisted of nine foliar fungicide broadcast applications, including treatments initiated two weeks before inoculation and concluding three weeks after inoculation. A half-rate split application of azoxystrobin at the time of inoculation plus two weeks later was also tested. Additionally, two rates of trifloxystrobin were made at the time of inoculation. All fungicides were applied with a backpack sprayer in a spray volume of 402 l /ha at 207 kPa boom pressure (four #8004 flat fan nozzles spaced at 0.5 m). The mid-season incidence of RRCR was determined on 19 July and root harvest was on 3 October.

Three field studies were conducted in 2001. These studies included an azoxystrobin timing study similar to the one done in 1999, an azoxystrobin and trifloxystrobin timing study similar to that conducted for azoxystrobin in 2000, and a trifloxystrobin rate study which also included azoxystrobin and pyraclostrobin treatments for comparison of efficacy. Fungicide was applied with a backpack sprayer in a total spray volume of 206 l /ha at 345 kPa boom pressure. The boom was equipped with a single #8002 flat fan nozzle with an effective band-width of 18 cm.

The five treatments of the azoxystrobin timing study consisted of two rates banded at planting (in-furrow) and at inoculation, a half-rate split application at planting plus at inoculation, and a nontreated control (Table 4). The at-planting treatments were applied on 20 April as described for 1999. Foliar band treatments were applied just prior to inoculation on 13 June when plants were in the 10-12 leaf stage.

Table 3. Effects of azoxystrobin and trifloxystrobin application timings on RRCR development and sugarbeet root yield (Torrington, WY; 2000).

Treatment	Timing and application rate (kg a.i./ha)[†]	RRCR incidence (per 6.1 m) 19 Jul	Sugarbeet yield (Mg/ha)
1. Nontreated Control	NA	34.3 a[‡]	0.0 d
2. Azoxystrobin	2 weeks prior to inoculation (0.17)	17.3 bc	9.4 d
3. Azoxystrobin	1 week prior to inoculation (0.17)	19.5 b	16.8 bcd
4. Azoxystrobin	at inoculation (0.17)	1.3 e	51.9 a
5. Azoxystrobin	1 week after inoculation (0.17)	7.0 de	50.7 a
6. Azoxystrobin	2 weeks after inoculation (0.17)	16.5 bc	39.8 ab
7. Azoxystrobin	3 weeks after inoculation (0.17)	21.0 b	34.0 abc
8. Azoxystrobin	at inoculation (0.08) plus 2 weeks after inoculation (0.08)	1.3 e	52.2 a
9. Trifloxystrobin	at inoculation (0.09)	10.8 cd	12.9 cd
10. Trifloxystrobin	at inoculation (0.18)	5.8 de	6.2 d

[†]All applications were made as a broadcast. Plants were inoculated with *R. solani* on 14 June; NA= not applicable.
[‡]Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

Table 4. Effects of azoxystrobin in-furrow and banded treatments on sugarbeet stand establishment, RRCR development, and sugarbeet yield (Torrington, WY; 2001).

Treatment	Timing and application rate (g a.i./304 row m)[†]	Stand count (per 3 m)	RRCR severity (%)[‡]	RRCR incidence (per 6.1 m)	Sugarbeet yield (Mg/ha)
		31 May	3 Jul	8 Aug	
1. Nontreated Control	NA	22.8 a[§]	0.2 a	28.3 a	12.5 b
2. Azoxystrobin	at planting (2.13)	23.8 a	0.1 a	33.0 a	2.2 b
3. Azoxystrobin	at planting (4.25)	26.5 a	0.1 a	34.8 a	4.2 b
4. Azoxystrobin	at inoculation (2.13)	18.8 a	0.0 a	3.0 b	50.0 a
5. Azoxystrobin	at inoculation (4.25)	21.0 a	0.0 a	2.0 b	54.0
6. Azoxystrobin	at planting (2.13) plus at inoculation (2.13)	23.3 a	0.1 a	1.5 b	38.3 a

[†]The at planting timings were made in-furrow on 20 April. All fungicide applications were made in a 18-cm banded spray. Plants were inoculated with *R. solani* on 13 June; NA= not applicable.

[‡]Severity was determined by a visual estimate of the percent surface area of a sugarbeet root affected by rot. Mean percentage data for Rhizoctonia disease symptoms (RRCR) were converted from Horsfall-Barratt ratings (0-11).

[§] Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

Population counts were taken on 31 May. To measure early season RRCR, five sugarbeet roots per plot were collected on 3 July. The mid-season RRCR incidence was rated on 8 August for 6.1 m of row and roots harvested on 24 September.

The azoxystrobin and trifloxystrobin timing study consisted of seven different timings for each fungicide (Table 5). Plants were inoculated on 13 June, and foliar band treatments were applied on 30 May, 6, 13, 20, and 28 June, and 4 July, coinciding with timings that started 2 weeks before inoculation and concluded three weeks after inoculation. Rhizoctonia crown rot incidence was rated on 22 August over 6.1 m of row. Harvest was on 25 September.

The trifloxystrobin rate study consisted of four trifloxystrobin rates compared to one treatment each of azoxystrobin and pyraclostrobin (Table 6). All were applied as foliar band applications (18 cm) made at inoculation plus 2 weeks later (13 and 28 June). The mid-season RRCR incidence was rated on 22 August over 6.1 m of row. Harvest was on 24 September.

Treatments in 2002 included: at inoculation applications of azoxystrobin, pyraclostrobin, and 3 rates of thiophanate-methyl, half-rate split applications made at inoculation plus 2 weeks later of the three strobilurins and thiophanate-methyl, and pyraclostrobin made at 2 weeks after inoculation (Table 7). Mid-season RRCR incidence was rated on 16 July, and harvest was on 3 October.

Scottsbluff, NE site:

The soil type in Nebraska was a Tripp silt loam with 1.0% organic matter and pH of 7.8. The experimental design was a randomized complete block design with five replicates. Plots were three rows wide (0.6 m row-centers) by 13.7 m long. Sugarbeet 'Monohikari' was planted to stand at a rate of 93,898 plants/ha on 20 April 1999 and 24 April 2000. Weed control was accomplished with standard herbicides and cultivation. In 2000, the crop was treated with aldicarb at 1.18 kg/ha on 5 June for sugarbeet root maggot. In mid-July for both years maneb plus triphenyltin hydroxide (1.6 + 0.21 kg a.i./ha) was applied for Cercospora leaf spot (*Cercospora beticola*) management. Plots were watered as needed by furrow irrigation.

On 3 June 1999 and 7 June 2000, *R. solani* AG 2-2 inoculum was applied over each plant in the three rows of each plot at a rate of 12.8 g per 4.3 m of row. Plants were in the 4-leaf stage at the time of inoculation. Plots were cultivated with a rolling cultivator on the day following inoculation. Azoxystrobin treatments were applied post-emergence in a 20.3 cm band with a tractor mounted sprayer calibrated to deliver

Table 5. Effects of strobilurin fungicide timing on RRCR development and sugarbeet yield (Torrington, WY; 2001).

Treatment	Timing and application rate (g a.i./304 row m)[1]	RRCR incidence (per 6.1 m) 22 Aug	Sugarbeet yield (Mg/ha)
1. Nontreated Control	NA	28.8 ab[2]	10.5 de
2. Azoxystrobin	2 weeks before inoculation (4.25)	26.8 abc	7.6 e
3. Azoxystrobin	1 week before inoculation (4.25)	24.8 a-d	33.4 a-d
4. Azoxystrobin	at inoculation (4.25)	6.5 fg	49.3 a
5. Azoxystrobin	1 week after inoculation (4.25)	15.3 d-g	54.4 a
6. Azoxystrobin	2 weeks after inoculation (4.25)	17.8 b-e	45.2 a
7. Azoxystrobin	3 weeks after inoculation (4.25)	17.8 b-e	39.6 abc
8. Azoxystrobin	at inoculation (2.13) plus 2 weeks after inoculation (2.13)	5.3 g	52.4 a
9. Trifloxystrobin	2 weeks before inoculation (4.25)	26.0 a-d	0.0 e
10. Trifloxystrobin	1 week before inoculation (4.25)	32.3 a	17.9 b-e
11. Trifloxystrobin	at inoculation (4.25)	12.8 efg	41.4 ab
12. Trifloxystrobin	1 week after inoculation (4.25)	24.0 a-d	19.7 b-e
13. Trifloxystrobin	2 weeks after inoculation (4.25)	18.8 b-e	15.9 cde
14. Trifloxystrobin	3 weeks after inoculation (4.25)	19.5 b-e	9.0 e
15. Trifloxystrobin	at inoculation (2.13) plus 2 weeks after inoculation (2.13)	17.0 c-f	49.1 a

[1] All applications were made in a 18-cm band, NA= not applicable. Plants were inoculated with *R. solani* on 13 June.
[2] Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

Table 6. Effects of varied trifloxystrobin rates on RRCR development and sugarbeet yield (Torrington, WY; 2001).

Treatment	Timing and application rate (g a.i./304 row m)[†]	RRCR incidence (per 6.1 m) 21 Aug	Sugarbeet yield (Mg/ha)
1. Nontreated Control	NA	27.8 a[‡]	12.1 b
2. Trifloxystrobin	at inoculation (3.12) plus 2 weeks after inoculation (3.12)	9.5 bc	41.9 a
3. Trifloxystrobin	at inoculation (4.54) plus 2 weeks after inoculation (4.54)	8.3 bc	60.5 a
4. Trifloxystrobin	at inoculation (5.95) plus 2 weeks after inoculation (5.95)	4.0 c	56.4 a
5. Trifloxystrobin	at inoculation (7.65) plus 2 weeks after inoculation (7.65)	3.3 c	57.3 a
6. Azoxystrobin	at inoculation (5.39) plus 2 weeks after inoculation (5.39)	3.8 c	53.1 a
7. Pyraclostrobin	at inoculation (5.39) plus 2 weeks after inoculation (5.39)	15.8 b	51.3 a

[†]All applications were made in a 18-cm band, NA= not applicable. Plants were inoculated with *R. solani* on 13 June.
[‡]Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

Table 7. Effects of banded fungicide applications on RRCR development and yield (Torrington, WY; 2002).

Treatment	Timing and application rate (g a.i./304 row m)[†]	RRCR incidence (per 6.1 m) 16 Jul	Sugarbeet yield (Mg/ha)
1. Nontreated Control	not applicable	39.6 a[‡]	0.7 c
2. Thiophanate-methyl	at inoculation (6.65)	19.4 b	6.7 bc
3. Thiophanate-methyl	at inoculation (10.32)	12.5 bc	13.7 b
4. Thiophanate-methyl	at inoculation (13.30)	14.3 b	9.4 bc
5. Azoxystrobin	at inoculation (4.25)	2.1 d	50.7 a
6. Thiophanate-methyl	at inoculation (6.65) plus 2 weeks after inoculation (6.65)	17.8 b	11.2 bc
7. Azoxystrobin	at inoculation (2.13) plus 2 weeks after inoculation (2.13)	2.5 d	52.2 a
8. Trifloxystrobin	at inoculation (2.13) plus 2 weeks after inoculation (2.13)	3.3 d	42.6 a
9. Pyraclostrobin	at inoculation (2.13) plus 2 weeks after inoculation (2.13)	5.8 cd	41.9 a
10. Pyraclostrobin	at inoculation (4.25)	2.8 d	42.1 a
11. Pyraclostrobin	2 weeks after inoculation (4.25)	36.1 a	4.0 bc

[†]All applications were made in a 18 cm banded spray. Plants in the two center rows of each treatment plot were inoculated with *R. solani* AG 2-2 on 21 June, 2002 immediately after the first fungicide application.

[‡] Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

390 l/ha of spray solution at 248 kPa using #40015E flat fan nozzles.

Sugarbeet stand loss due to RRCR was evaluated by comparing the number of dead plants to the initial plant population. All plant populations and root yields were based on three rows by 13.7 m long.

Treatments in 1999 and 2000 compared azoxystrobin rates and timing. Complete treatment descriptions for 1999 and 2000 are summarized in Tables 8 and 9, respectively. In 1999, sugarbeet stand loss due to RRCR was evaluated on 12 September. Sugarbeet roots were harvested on 8 October. Additionally, a random subsample of 10 harvested roots was evaluated for RRCR disease severity using the procedure of Harveson and Rush (1994) to calculate a sugarbeet root disease index. In 2000, sugarbeet stand loss due to RRCR was evaluated on 9 August. Sugarbeet roots were harvested on 27 October.

All data were analyzed by analysis of variance (ANOVA) using the statistical program SAS. Mean separations were based on Fisher's protected LSD (P=0.05); for the sugarbeet root disease index (Table 7), mean separations were done at P=0.10 because of the small and variable sample sizes. Where applicable, linear contrasts were constructed at P=0.05 to compare treatment timings and fungicide efficacy.

RESULTS

Torrington, WY site:

Azoxystrobin applications at planting and 3 weeks prior to inoculation had no significant effect on plant populations and early season root decay (Table 2, P=0.05). Following artificial inoculation of sugarbeet crowns on 29 June, disease development substantially increased. However, azoxystrobin applied prior to inoculation still had no effect on mid-season RRCR incidence (P=0.05). The split treatments with the 1 week after inoculation broadcast applications (treatments 6 and 7) reduced mid-season RRCR incidence compared to the nontreated control ($P \leq 0.05$). Total root yields for these treatments were increased by an average of 72%, compared to the nontreated control ($P \leq 0.05$).

In 2000, RRCR was evident on 19 July and all fungicide treatments reduced disease incidence from 39% to 96% compared to the nontreated control (Table 3, $P \leq 0.05$). Azoxystrobin applied at the time of inoculation, one week after inoculation, or as a half-rate split application, were better than azoxystrobin applications made either earlier or later ($P \leq 0.05$).

Disease destroyed all or most plants in the nontreated control

Table 8. The effects of azoxystrobin rates and timings on RRCR development and sugarbeet yield (Scottsbluff, NE; 1999).

Treatment	Timing and application rate (g a.i./304 row m)[†]	Sugarbeet stand loss due to RRCR (%)	Sugarbeet root disease index[‡]	Root yield (Mg/ha)
		12 Sep	8 Oct	
1. Nontreated Control	NA	36.6 a[§]	1.88 a[¶]	32.3 d[§]
2. Azoxystrobin	1 week prior to inoculation (2.13)	22.6 b	1.38 a	46.4 c
3. Azoxystrobin	1 week prior to inoculation (4.25)	10.9 cd	0.74 b	59.1 a
4. Azoxystrobin	at inoculation (2.13)	12.9 c	0.90 b	47.9 c
5. Azoxystrobin	at inoculation (4.25)	11.4 c	1.16 ab	49.7 bc
6. Azoxystrobin	1 week prior to inoculation (2.13) plus 2 weeks after inoculation (4.25)	8.6 cd	0.72 b	48.8 c
7. Azoxystrobin	at inoculation (2.13) plus 2 weeks after inoculation (4.25)	3.5 d	0.59 b	58.0 ab

[†]All azoxystrobin applications were made in a 20.3 cm band. Plants were inoculated with *R. solani* on 3 June, NA= not applicable.

[‡]A weighted average of 10 sugarbeet roots were rated individually for Rhizoctonia using the procedure of Harveson and Rush (1994). Greater values indicate increased disease development.

[§]Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

[¶]Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.10).

Table 9. Effects of azoxystrobin rates and timing on RRCR development and sugarbeet yield (Scottsbluff, NE; 2000).

Treatment	Timing and application rate (g a.i./304 row m)[†]	Sugarbeet stand loss due to RRCR (%)	Root yield (Mg/ha)
		9 Aug	27 Oct
1. Nontreated Control	NA	23.7 ab[‡]	60.0 bc
2. Azoxystrobin	2.5 weeks prior to inoculation (2.13)	34.6 a	56.4 c
3. Azoxystrobin	2.5 weeks prior to inoculation (4.25)	12.5 bc	75.0 a
4. Azoxystrobin	1 week prior to inoculation (2.13)	14.8 bc	71.7 ab
5. Azoxystrobin	1 week prior to inoculation (4.25)	15.4 bc	73.2 a
6. Azoxystrobin	1 week after inoculation (2.13)	10.4 c	78.6 a
7. Azoxystrobin	1 week after inoculation (4.25)	16.8 bc	70.6 ab
8. Azoxystrobin	2.5 weeks prior to inoculation (2.13) plus 4 weeks after inoculation (4.25)	13.3 bc	76.6 a
9. Azoxystrobin	1 week prior to inoculation (2.13) plus 4 weeks after inoculation (4.25)	14.5 bc	78.6 a
10. Azoxystrobin	1 week prior to inoculation (2.13) plus 4 weeks after inoculation (2.13)	12.2 bc	72.4 ab
11. Azoxystrobin	4 weeks after inoculation (4.25)	15.0 bc	73.7 a

[†]All azoxystrobin applications were made in a 20.3 cm band. Plants were inoculated with *R. solani* on 7 June, NA= not applicable. Timings are approximate, actual dates are listed in Table 1.

[‡]Treatment means followed by different letters differ significantly (Fisher's protected LSD, P=0.05).

plots and no root harvest was possible. Azoxystrobin applied at time of inoculation, up to 3 weeks later, or as a half-rate split application, improved the average sugarbeet root yield compared to the nontreated control and azoxystrobin application 2 weeks before inoculation ($P \leq 0.05$). Although trifloxystrobin treatments applied at the time of inoculation reduced mid-season disease, compared to the nontreated control ($P \leq 0.05$), trifloxystrobin treatments resulted in an average of 82% reduction in root yield compared to the similarly-timed azoxystrobin treatment ($P \leq 0.05$).

Results for the 2001 azoxystrobin timing study are shown in Table 4. Similar to the 1999 study, applications of azoxystrobin made at planting had no significant effect on plant populations or on early season RRCR disease severity when measured on 3 July ($P = 0.05$). Root infection due to natural inoculum was low and inoculation of sugarbeet crowns on 13 June resulted in substantial RRCR development. Banded azoxystrobin treatments made at the time of inoculation suppressed disease incidence on 8 August compared with RRCR incidence for the at-planting treatments and the nontreated control ($P \leq 0.05$).

Root yields of treatments that included at inoculation applications of azoxystrobin were higher than those of the nontreated control ($P \leq 0.05$). Average yield increased 279% compared to the nontreated control. Treatment applications made at planting had no effect on root yields, compared to the nontreated control ($P = 0.05$).

The results for the 2001 azoxystrobin and trifloxystrobin timing study are shown in Table 5. Treatment applications made one to two weeks before inoculation as well as those made two or more weeks after inoculation resulted in disease incidence levels similar to the nontreated control ($P = 0.05$). The data suggests that these treatments were made either too early or too late. The most effective treatments were those made at the time of inoculation or as a split-application compared to treatments made after inoculation for all data collection dates ($P \leq 0.05$). At the same use rates, azoxystrobin treatments overall resulted in an average of 24% less RRCR incidence and 84% greater root yields compared with trifloxystrobin treatments ($P \leq 0.05$).

All fungicide treatments suppressed RRCR development compared to the nontreated control in 2001 (Table 6, $P \leq 0.05$). The two lowest rates of trifloxystrobin (treatments 2 and 3) had disease incidence equivalent to pyraclostrobin ($P = 0.05$). With increasing rates of trifloxystrobin there appeared to be a corresponding decrease in disease incidence, however, this trend was not significant ($P = 0.05$). At harvest, all treatments increased total sugarbeet root yield compared to the nontreated control ($P \leq 0.05$).

Results for the 2002 study are shown in Table 7. On 16 July, most fungicide treatments reduced RRCR incidence compared to the nontreated control, however thiophanate-methyl treatments generally had greater disease incidence than did most strobilurin fungicide class treatments ($P \leq 0.05$). Disease suppression afforded by split (half-rate) applications of a fungicide made at inoculation and 2 weeks later did not differ from the single full-rate application of the same fungicide made at the time of inoculation ($P=0.05$). Disease suppression by pyraclostrobin applied 2 weeks after inoculation (treatment 11) did not differ from the nontreated control, in sharp contrast to the same rate of pyraclostrobin applied at the time of inoculation (treatment 10: $P \leq 0.05$). Therefore, results for treatments 10 and 11 reveal that most infection occurred shortly after inoculation and that fungicide applications made 2 weeks after inoculation (on 5 July) contributed very little to season-long disease suppression.

Strobilurin fungicide treatments that included a fungicide application made at the time of inoculation resulted in the greatest yields ($P \leq 0.05$). Thiophanate-methyl treatments generally improved yields compared to the nontreated control but only thiophanate-methyl at 10.32 g ai/304 row m (treatment 3) increased yields compared to the nontreated control ($P \leq 0.05$).

Scottsbluff, NE site:

In the nontreated control, stand loss due to RRCR was 36.6% on 12 September (Table 8). Stands were improved an average of 25% following azoxystrobin treatment compared to the nontreated control. Azoxystrobin (2.13 g a.i./304 m) applied one week prior to inoculation (treatment 2) was less effective in protecting against stand loss and disease development on harvested sugarbeet than the other azoxystrobin treatments ($P \leq 0.10$). However, when the rate was doubled for this timing, there was 52% less stand loss than with the lower rate treatment ($P \leq 0.05$) and this difference was statistically equivalent to the other timings for protecting against stand loss ($P=0.05$). By harvest, most fungicide treatments had a reduced sugarbeet root disease index compared to the nontreated control ($P \leq 0.10$). All fungicide treatments resulted in greater sugarbeet root yields compared to the nontreated control ($P \leq 0.05$).

Disease pressure in 2000 was less than that observed in 1999, and azoxystrobin (2.13 g a.i./304 m) applied one week after inoculation (treatment 6) was the only treatment that significantly suppressed stand loss due to RRCR compared to the nontreated control (Table 9, $P \leq 0.05$). There was a trend for all azoxystrobin treatments to have improved stands compared to the nontreated control, with the exception of azoxystrobin (2.13 g a.i./304 m) 2.5-weeks before inoculation (treatment 2). However, when the rate was doubled for this timing there was a 65% reduction of stand losses due to RRCR and a 33% higher sugarbeet yield than the 2.13 g a.i./304 m treatment applied at the same time ($P \leq 0.05$). All azoxystrobin treatments except treatment 2 had higher root yields than the nontreated control, but not always statistically so.

DISCUSSION

Properly timed strobilurin fungicide applications are effective in reducing RRCR losses even under severe disease pressure. In-furrow applications of azoxystrobin made at the time of planting had no effect on crown rot development of maturing sugarbeet plants, presumably because they were made too early ($P \leq 0.05$). Azoxystrobin is effective for reducing sugarbeet seedling losses due to Rhizoctonia damping-off (Brantner and Windels, 1999 and 2003); however no seedling loss was detected in the study reported herein. Stobilurin applications made at the time of inoculation, or made as a split half-rate application at inoculation and 2 weeks later, provided the most consistent and effective RRCR management. Therefore it appears that the most effective fungicide applications would coincide with cultivation operations that deposit soil into the crown, thus, initiating infection that can be suppressed with fungicide up to two weeks after. In production areas where several cultivation operations are necessary, split half-rate applications may provide greater flexibility and better season-long disease suppression than a single application of fungicide.

Differences in fungicide efficacy were detected. At approximately the same use rates and under severe disease pressure, azoxystrobin was more effective than trifloxystrobin for RRCR management when averaged over the various application timings ($P \leq 0.05$). However, when applied at inoculation in 2001 or as a split application during 2002, trifloxystrobin provided equivalent suppression of mid-season RRCR incidence and had equivalent root yields compared to azoxystrobin. Pyraclostrobin was not always as effective as the other strobilurins for disease suppression but final yields were equivalent to azoxystrobin and trifloxystrobin (P=0.05). Thiophanate-methyl provided initial disease suppression but by the time of harvest, yields were not different from the nontreated control (P=0.05).

When applied at inoculation or as a split application, increasing the rate of strobilurin fungicide did little to improve efficacy. In the 2001 placement study, doubling the foliar banded application of azoxystrobin did not affect RRCR control or root yields (P=0.05). In the 2001 trifloxystrobin rate study, there was no significant improvement of disease suppression or yield with increased rates (P=0.05). However, for applications made before inoculation, a time not optimal for disease suppression, azoxystrobin efficacy improved with increased rates for the 1999-2000 Nebraska studies. These results suggest that for azoxystrobin applications that are made before cultivation events that introduce inoculum onto sugarbeet crowns, disease management efficacy may increase with higher use rates.

The RRCR pressure reported herein was greater than that experienced by growers. In the recent work by Kiewnick et al. (2001), sugarbeet yield results from their Sidney, MT site indicate marginal returns with azoxystrobin applications under low Rhizoctonia disease pressure. Additional work is needed to address the use of the various strobilurin fungicides in an integrated management approach to Rhizoctonia management. The economics of fungicide use needs to be explored when fungicides are integrated with other methods for RRCR suppression, such as crop rotation and resistant varieties.

ACKNOWLEDGMENTS

This work was supported in part by the Western Sugar Joint Grower Research Committee and the University of Wyoming Agricultural Experiment Station. We also thank Stephan Briere for preparation of inoculum.

LITERATURE CITED

Brantner, J.R., and C.E. Windels. 1999. In-furrow and postemergence application of Quadris for control of Rhizoctonia damping-off and root and crown rot. 1998 Sugarbeet Res. Ext. Rep., Coop. Ext. Serv., North Dakota State Univ. 29:275-277.

Brantner, J.R., and C.E. Windels. 2003. Band and broadcast applications of azoxystrobin for control of *Rhizoctonia solani* on sugar beet. J. Sugar Beet Res. 40: 151.(abstr.).

Harveson, R.M., and C.M. Rush. 1994. Evaluation of fumigation and Rhizomania-tolerant cultivars for control of a root disease complex of sugarbeets. Plant Dis. 78:1197-1202.

Jacobsen, B.J., A.G. Dexter, and L.J. Smith, and M.B. Mikkelson. 2001. Survey of pesticide use, IPM practices and pests of sugarbeet in the U.S.A. for 1998 and 1999. J. Sugar Beet Res. 38:76 (abstr.).

Kiewnick, S., B.J. Jacobsen, A. Braun-Kiewnick, J.L.A. Eckhoff, and J.W. Bergman. 2001. Integrated control of Rhizoctonia crown and root rot of sugar beet with fungicides and antagonistic bacteria. Plant Dis. 85:718-722.

Panella, L., and Ruppel, E.G. 1996. Availability of germplasm for resistance against Rhizoctonia spp. p. 515-527. In B. Sneh, S. Jabaji-Hare, S. Neate, and G. Dijat (eds.) Rhizoctonia Species: Taxonomy, Molecular Biology, Ecology, Pathology and Disease Control. Kluwer Academic Publishers, Dordrecht, Netherlands.

Parmeter, J.R. Jr. (Ed.). 1970. Biology and Pathology of *Rhizoctonia solani.* Univ. Of California Press, Berkeley. 255pp.

Rush, C.M., and S.R Winter. 1990. Influence of previous crops on Rhizoctonia root and crown rot of sugar beet. Plant Dis. 74:421-425.

Schneider, C.L., E.G. Ruppel, R. J. Hecker, and G. J. Hogaboam. 1982. Effects of soil deposition in crowns on development of Rhizoctonia root rot in sugar beet. Plant Dis. 66:408-410.

Schneider, C.L., and E.D. Whitney. 1986. Rhizoctonia root and crown rot. p. 21. In E.D. Whitney and J.E Duffus (eds.) Compendium of Beet Diseases and Insects. APS Press. St. Paul, MN, USA.