

Lack of Interaction Between Glyphosate and Fungicide Treatments on Rhizoctonia Crown and Root Rot in Glyphosate-Resistant Sugarbeet

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ABSTRACT

A field experiment was conducted in 2008 and 2009 in the Saginaw Valley region of Michigan to determine if there were potential interactions between applications of glyphosate and the fungicide azoxystrobin and to determine the effectiveness of foliar and in-furrow azoxystrobin applications when *Rhizoctonia solani* is present. Significant differences in disease indices, percentage of harvestable sugarbeet (*Beta vulgaris* L.), and percentage of healthy sugarbeet were evident among the different varieties and azoxystrobin treatments, but herbicide treatment did not significantly affect these parameters. Hilleshög 9027RR and Hilleshög 9029RR had the lowest disease indices and highest percentage of healthy sugarbeet when compared with Crystal RR827 and Hilleshög 9028RR. Foliar applied azoxystrobin resulted in the lowest disease index (2.0) and highest percentage of healthy sugarbeet (42%) when compared with the in-furrow application or no fungicide treatment. In-furrow azoxystrobin reduced the disease index when compared with no fungicide. Similar trends were observed for harvestable sugarbeet, except for Crystal RR827 where there was not a significant difference between in-furrow azoxystrobin and no fungicide. Glyphosate did not affect the efficacy of fungicide treatments, but choosing a *Rhizoctonia*-tolerant variety and applying foliar fungicide applications appear to be the best methods for managing *Rhizoctonia* crown and root rot in glyphosate-resistant sugarbeet.

Additional Key Words: Glyphosate-resistant crops; standard-split; azoxystrobin; *Rhizoctonia solani* Kühn; *Beta vulgaris* L.; disease index; healthy sugarbeet; harvestable sugarbeet.

Glyphosate (*N*-(phosphonomethyl)glycine) is the most widely used herbicide in the world due to its ability to control a broad spectrum of annual and perennial broadleaf and grass weed species (Duke and Powles 2008; Pline-Srnic 2005). The introduction of glyphosate-resistant crops in 1996 changed the way many growers approach weed management. Growers widely adopted glyphosate-resistant crops because glyphosate made weed control easier and more effective with fewer applications, reduced the need for tillage, did not restrict crop rotations, and increased profitability (Green 2009). Currently, there are six commercialized glyphosate-resistant crops: soybean [*Glycine max* (L.) Merr], corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), canola (*Brassica napus* L.), alfalfa (*Medicago sativa* L.) and, most recently in 2008, sugarbeet (*Beta vulgaris* L.). Glyphosate-resistant sugarbeet varieties were quickly adopted by growers in Michigan. Approximately 98% of Michigan's sugarbeet hectares were planted with a glyphosate-resistant variety in 2009 (C. Guza, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication).

The use of glyphosate in glyphosate-resistant sugarbeet provides growers the opportunity to achieve excellent control of many weed species that can affect sugarbeet yield and quality (Kniss et al. 2004). Conventional postemergence (POST) herbicides do not effectively control weeds with more than two leaves, so many herbicide applications are necessary and seldom result in 100% control (Dale et al. 2006; Dale and Renner 2005). Additionally, the time between herbicide applications in glyphosate-resistant sugarbeet may be longer when compared with conventional sugarbeet herbicide programs, because weed height at the time of application is generally not as limiting with glyphosate. Kemp et al. (2009) determined that fewer herbicide applications were required to improve weed control and yields in glyphosate-resistant sugarbeet than with conventional herbicide applications. Glyphosate is less expensive when compared with conventional sugarbeet weed control programs and the potential for greater economic return is possible with fewer herbicide applications, improved weed control, and increased yields (Kniss et al. 2004).

However, one potential issue with glyphosate-resistant sugarbeet is the possible increase in diseases caused by soil-borne pathogens. Glyphosate inhibits the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme, an important component in the shikimate acid pathway (Steinrucken and Amrhein 1980). This pathway produces aromatic amino acids and secondary compounds important for plant growth and protection (Amrhein et al. 1980; Bentley 1990; Dill 2005; Siehl 1997). While glyphosate-resistant crops have a form of

the EPSPS enzyme that is not affected by glyphosate, this enzyme may not be as efficient as native EPSPS when exposed to glyphosate and therefore may result in reduced production of secondary compounds (Pline-Srnic 2005). Studies in glyphosate-resistant crops, including glyphosate-resistant sugarbeet, have indicated a potential for increased susceptibility to some soil-borne pathogens after glyphosate was applied (Larson et al. 2006; Sanogo et al. 2000; Sanogo et al. 2001). Greenhouse and field studies with glyphosate-resistant soybean showed that these plants were more susceptible to sudden death syndrome, caused by *Fusarium solani* (Mart.) Sacc. f. sp. *glycines*, after glyphosate was applied (Sanogo et al. 2000; Sanogo et al. 2001). Larson et al. (2006) determined that at least one of two non-commercial varieties of glyphosate-resistant sugarbeet was more susceptible to certain isolates of both *Rhizoctonia solani* Kühn and *Fusarium oxysporum* Schlecht. f. sp. *betae* Snyder & Hans. after exposure to glyphosate in greenhouse studies.

In contrast, other studies demonstrated that glyphosate applications had no effect, or reduced the severity of diseases caused by soil-borne pathogens (Njiti et al. 2003; Pankey et al. 2005). In glyphosate-resistant soybean, Njiti et al. (2003) determined glyphosate had no effect on soybean yield or disease severity of sudden death syndrome. These results conflicted with greenhouse and field results reported by Sanogo et al. (2000) and (2001). There were differences between these studies concerning variety selection and varietal response to the disease. In addition, there were differences in environmental factors such as planting date, genotype, and other soil factors. This may explain why glyphosate has no effect on *F. solani* disease severity in certain varieties, but increases disease severity in others. In glyphosate-resistant cotton, greenhouse experiments conducted by Pankey et al. (2005) showed that glyphosate had no effect on damping-off or soreshin (caused by the pathogen *R. solani*). Furthermore, in the field, glyphosate actually reduced *Rhizoctonia* induced disease severity in the material tested.

Rhizoctonia crown and root rot, caused by the soil-borne pathogen *Rhizoctonia solani*, is a problematic disease in many crops in Michigan, including sugarbeet (Kirk et al. 2008; Windels et al. 2009). Rhizoctonia crown and root rot reduces economic returns in sugarbeet by as much as 24% in the United States and up to 50% yield loss may result, depending on disease severity (Franc et al. 2001; Windels et al. 2009). *Rhizoctonia solani* has many host crops in addition to sugarbeet, which makes it difficult to control with crop rotation alone (Rush and Winter 1990; Schuster and Harris 1960). Soybean, dry bean (*Phaseolus vulgaris* L.), corn, and many weed species are alternate hosts for *Rhizoctonia*, further increasing the buildup of disease inoculum (Windels et al. 2009). The availability of sugarbeet varieties tolerant to Rhizoctonia crown and root rot provides an additional option to manage this disease, and varieties with varying levels

of tolerance are readily available to Michigan sugarbeet growers. Although these varieties do not completely prevent infection, they certainly limit fungal colonization and disease severity (Ruppel 1973, Panella and Ruppel 1996).

Additional methods for controlling *Rhizoctonia* crown and root rot in sugarbeet include applications of strobilurin fungicides, such as azoxystrobin. Single fungicide treatments are typically applied either in-furrow at planting or postemergence (POST) to sugarbeet at the 4 to 8-leaf stage (Karaoglanidis and Karadimos 2006; Whitney and Duffus 1986). In-furrow applications of azoxystrobin can reduce infection early in the season, but may not prevent later infections (Karaoglanidis and Karadimos 2006; Kiewnick et al. 2001; Jacobsen et al. 1999; Windels and Brantner 2000). If glyphosate-resistant sugarbeet are more susceptible to plant pathogens after glyphosate is applied, then fungicide applications may be important in controlling sugarbeet diseases such as *Rhizoctonia* crown and root rot. Therefore, the objectives of this research were to: 1) investigate potential interactions between glyphosate and fungicide applications of azoxystrobin on management of *Rhizoctonia* crown and root rot in four glyphosate-resistant sugarbeet varieties, and 2) determine the effectiveness of in-furrow and foliar applications of azoxystrobin when *Rhizoctonia solani* is present.

MATERIALS AND METHODS

A field experiment was conducted in 2008 and 2009 in the Saginaw Valley region of Michigan. The 2008 experiment was located in St. Charles, Michigan on a Misteguay silty clay (fine, mixed, semiacative, calcareous, mesic Aeric Endoaquepts) soil with a pH of 7.8 and 3.0% organic matter. The 2009 experiment was located in Frankenmuth, Michigan and the soil type was a Tappan-Londo complex (fine-loamy, mixed, active, calcareous, mesic Typic Endoaquolls) with a pH of 7.7 and 2.4% organic matter. Experiments followed dry bean in both 2008 and 2009. Fields were fall-chisel plowed followed by spring field cultivation twice prior to planting. Fertilizer applications were standard for sugarbeet production in Michigan. The glyphosate-resistant sugarbeet varieties Crystal RR827 (BetaSeed, Inc., Shakopee, MN), Hilleshög 9027RR, Hilleshög 9028RR, and Hilleshög 9029RR (Syngenta Seeds Inc., Longmont, CO) were planted 2.5-cm deep in 76-cm rows at a population of 122,000 seeds/ha on April 25, 2008 and April 16, 2009. Plots were six rows wide by 9.1 m in length. Each variety was planted, one per row, in rows two through five. Rows one and six served as border rows. Commercial sugarbeet varieties selected for this experiment were approved by Michigan Sugar Company and were thought to have varying degrees of *Rhizoctonia* crown and root rot tolerance.

The experimental design was a split-split-plot with four replica-

tions. The main plot was variety, the sub-plot herbicide treatment, and the sub-sub-plot was fungicide treatment. Herbicide treatments consisted of a glyphosate program, a standard-split program (used in non-glyphosate-resistant sugarbeet), and a hand-weeded control (no herbicide). The glyphosate program consisted of glyphosate (Roundup WeatherMAX, Monsanto Co., St. Louis, MO) at 0.84 kg ae ha⁻¹ plus ammonium sulfate at 2% v/v, applied three times at 2 to 4-leaf, 4 to 6-leaf, and 6 to 8-leaf sugarbeet. The standard-split program consisted of a combination of desmedipham plus phenmedipham (Betamix, Bayer CropScience AG, Monheim am Rhein, Germany) each at 180 g ai ha⁻¹, triflusaluron (UpBeet, E.I. du Pont de Nemours and Co., Crop Protection, Wilmington) at 9 g ai ha⁻¹, clopyralid (Stinger, Dow AgroSciences, Indianapolis, IN) at 104 g ai ha⁻¹, and non-ionic surfactant at 0.25% v/v, applied twice when sugarbeet was at the cotyledon to 2-leaf and 2 to 4-leaf stages. The rates of desmedipham plus phenmedipham were each increased to 270 g ai ha⁻¹ for the second application. All plots were maintained weed-free by hand-weeding throughout the growing season. Individual varieties were evaluated for herbicide injury 7 days after the last herbicide application timing on a scale from 0 (no injury) to 100 (plant death). Fungicide treatments consisted of azoxystrobin (Quadris, Syngenta International AG, Basel, Switzerland) applied in-furrow at planting at 140 mg ai m⁻¹ of row, broadcast foliar applications of azoxystrobin at 0.82 kg ai ha⁻¹ to 4 to 6-leaf sugarbeet, and a no-fungicide control. Foliar applications of azoxystrobin were tank-mixed and applied with glyphosate for the glyphosate program. POST herbicide and fungicide treatments were applied with a tractor-mounted compressed-air sprayer calibrated to deliver 178 L ha⁻¹ at 207 kPa through 11003 AirMix (AirMix 11003, Greenleaf Technologies, Covington, LA) nozzles. Nozzles were spaced 51 cm apart and were positioned approximately 56 cm above the sugarbeet canopy.

All plots were inoculated with *R. solani* AG-2-2-IIIB when sugarbeet was at the 6 to 8-leaf stage. Subgroup AG-2-2-IIIB is the most common and virulent *R. solani* subgroup found on sugarbeet in Michigan (Kirk et al. 2008). *R. solani* inoculum was produced in bulk on barley medium. Pans of barley, saturated with water overnight, were autoclaved for 2 h. Nine plugs (7 mm) of *R. solani* grown on potato dextrose agar for 7 d were placed into the pans. The pans were sealed with parafilm and incubated at 28 + 2°C for 3 wks. Once the barley was colonized, it was air dried for 5 d and ground into fine flour. Inoculum was applied in two directions directly over each sugarbeet row at 2 g m⁻¹ using a modified drop spreader (Gandy Company, Owatonna, MN). The rate of inoculum was confirmed by determining the amount of leftover inoculum and calculating the g applied per m of row. All plots were cultivated following inoculation to put soil and inoculum in the sugarbeet crown for increased disease severity (Ruppel et al. 1979).

Sugarbeet stand counts were recorded for each variety at 4 wks after planting and at harvest. Approximately 8 wks after inoculation, sugarbeet were lifted from the soil using a modified lift harvester. Each sugarbeet root was rated for disease severity using the 0 to 7 *Rhizoctonia* crown and root rot rating scale as follows: 0 = no visible signs of disease; 1 = inactive lesions on less than 5% of the root area; 2 = less than 5% of the root area having active lesions; 3 = 6 to 25% of the root rotted; 4 = 26 to 50% of the root rotted; 5 = 51 to 75% of the root rotted; 6 = greater than 75% of the root rotted, but some living tissue; and 7 = roots completely rotted and dead (Ruppel et al. 1979). Stand counts were used to determine how many sugarbeet were missing from each plot due to advanced disease severity. Values were adjusted by assigning each of the missing sugarbeet a disease severity rating of 7. An average disease index was determined for each variety in each plot. The disease index was calculated as a weighted average based on the number of sugarbeet in each of the eight disease classes (Ruppel et al. 1979). Healthy sugarbeet were determined by calculating the percentage of sugarbeet that had a disease severity rating of 0 or 1. Harvestable sugarbeet were determined by calculating the percentage of sugarbeet with a disease severity rating of 3 or less.

Data were analyzed using the PROC MIXED procedure in SAS 9.1 (SAS Institute, Inc., Cary, NC). An analysis of variance was performed and treatment means for disease index, percentage of healthy sugarbeet, and percentage of harvestable sugarbeet were compared using Fisher's Protected LSD at the $p < 0.05$ significance level. Interactions between main effects were analyzed using the SLICE option in the LSMEANS statement. Data were combined across year, variety, herbicide treatment, or fungicide treatment when interactions were not significant.

RESULTS AND DISCUSSION

Herbicide injury

The glyphosate-resistant sugarbeet varieties did not show visible signs of damage from glyphosate treatments. However, applications of the standard-split herbicide program uniformly caused 13% injury for each of the four glyphosate-resistant sugarbeet varieties evaluated (data not shown). Injury symptoms consisted of yellowing and stunting when compared with the non-treated control, which are consistent with what others have observed with this combination (Wilson 1994, 1995). Approximately 4 wks after the standard-split applications sugarbeet recovered from this damage. In-furrow or foliar applications of azoxystrobin neither significantly increased nor decreased herbicide injury. An increase in herbicide injury was a potential concern with the glyphosate and azoxystrobin tank-mixture, since previous research has indicated an increase in sugarbeet injury

from tank-mixtures of azoxystrobin and other sugarbeet herbicides (Sprague et al. 2005).

Effect of variety, herbicide, and fungicide on *Rhizoctonia* crown and root rot

Overall environmental conditions were sufficient for disease development in the plots inoculated with *Rhizoctonia solani* subgroup AG-2-2-IIIB. The non-fungicide controls inoculated with *R. solani* resulted in an average disease index of 5.9 which provided a good basis for treatment separation.

Interactions between the years were not significant, therefore all data were presented as a combination of the 2008 and 2009 experiments. The three-way interaction of variety x herbicide x fungicide was not significant for any of the parameters evaluated (Table 1). All two-way interactions were not significant for any of the parameters measured, except for the variety x fungicide interaction for the percentage of harvestable sugarbeet. Therefore, data were discussed as the main effects of variety, herbicide, and fungicide, except for the variety x fungicide interaction for the percentage of harvestable sugarbeet.

Variety. There was a difference in how the four glyphosate-resistant sugarbeet varieties responded to inoculation of *R. solani*. Averaged across herbicide and fungicide treatments, Hilleshög 9027RR and Hilleshög 9029RR were the most tolerant varieties to *R. solani* subgroup AG-2-2-IIIB with disease index evaluations of 3.6 and 3.7,

Table 1. P-values for main effects and interactions of herbicide and fungicide treatments on *Rhizoctonia solani*[†] AG-2-2-IIIB impact on disease index, harvestable, and healthy sugarbeet of four glyphosate-resistant sugarbeet varieties. Data are combined across years.

	Disease index	Harvestable sugarbeet	Healthy sugarbeet
	<i>p</i> -value		
Variety	<0.0001	<0.0001	0.0248
Herbicide	0.6361	0.5194	0.9533
Fungicide	0.0003	0.0006	<0.0001
Variety x herbicide	0.9514	0.9729	0.9326
Variety x fungicide	0.4919	0.0045	0.4484
Herbicide x fungicide	0.7364	0.5717	0.5662
Variety x herbicide x fungicide	0.9999	0.9971	0.9966

[†] *Rhizoctonia solani* inoculum was prepared on barley medium.

respectively (Table 2). Crystal RR827 was the most susceptible glyphosate-resistant variety with a disease index of 4.7 and Hilleshög 9028RR showed moderate tolerance with a disease index of 4.0. The percentage of healthy sugarbeet, based on disease severity ratings of 1 or less, followed a similar trend. The percentage of healthy sugarbeet was less than 25% for all four glyphosate-resistant sugarbeet varieties. However, the percentage of healthy sugarbeet for the most susceptible variety, Crystal RR827 (14%), was considerably lower than the more *Rhizoctonia* tolerant varieties, Hilleshög 9027RR and Hilleshög 9029RR (Table 2). As observed with other studies, varieties have varying levels of *Rhizoctonia* crown and root rot susceptibility and tolerance (Ruppel 1973). Although Hilleshög 9027RR and Hilleshög 9029RR do not completely prevent *R. solani* infection, they exhibited more tolerance and are more effective at managing *Rhizoctonia* crown and root rot when compared with Crystal RR827.

Herbicide. One of the objectives was to determine if there were interactions between glyphosate and fungicide applications on *Rhizoctonia* crown and root rot. There were no significant interactions with herbicide and the main effect of herbicide was not significant (Table 1). This indicated that glyphosate had no influence on the disease index, the percentage of harvestable sugarbeet, or percentage of healthy sugarbeet when compared with the standard-split or no her-

Table 2. Disease index ratings and percent healthy sugarbeet of four glyphosate-resistant sugarbeet varieties inoculated with *Rhizoctonia solani*.[†] Data are combined across herbicide treatments, fungicide treatments, and years.

Variety	Disease index [‡]	Healthy sugarbeet [§]
	— 0 to 7 scale —	— % —
Hilleshög 9027RR	3.6 a*	20 a
Hilleshög 9028RR	4.0 b	19 ab
Hilleshög 9029RR	3.7 a	22 a
Crystal RR827	4.7 c	14 b

[†] *Rhizoctonia solani* inoculum was prepared on barley medium.

[‡] Disease is rated based on a 0 to 7 scale (0 = no disease and 7 = completely rotted, see text) and the disease index is calculated by determining a weighted average based on the number of sugarbeet in each of the eight disease classes.

[§] Healthy sugarbeet is determined by calculating the percent of sugarbeet that have a disease severity rating of 0 or 1.

* Means followed by the same letter are not significantly different according to Fisher's Protected LSD at $p < 0.05$.

bicide treatments. This is in contrast to what Larson et al. (2006) observed in greenhouse experiments with non-commercial glyphosate-resistant sugarbeet varieties. Their results indicated that a glyphosate-resistant sugarbeet variety with tolerance to *Rhizoctonia* crown and root rot demonstrated increased susceptibility to the disease after glyphosate was applied. The increased disease severity did not appear to be a fungal response because there was not a significant difference in the growth rate of *Rhizoctonia solani* or in the production of sclerotia after exposure to glyphosate. They concluded that differences in disease severity were explained by a particular cultivar or isolate pathogen response. Only one of the glyphosate-resistant varieties demonstrated a significant increase in disease severity with *R. solani* subgroup AG-2-2-IIIB (not AG-2-2-IV) after glyphosate application. In addition, other studies suggest the timing of glyphosate application in relation to disease infection is important. In our field experiment, sugarbeet were inoculated 7 days after the last herbicide application. However, if sugarbeet were inoculated prior to herbicide applications, it may have influenced disease severity differently than what was observed in our study. In addition, the Larson et al. (2006) study observed a significant effect only for one beet variety. Other studies have shown varying responses to herbicide and pathogen interactions depending upon the crop variety involved (Nelson et al. 2002). This may explain why differences between herbicide treatments were not observed in our field experiment, while greenhouse studies by Larson et al. (2006) indicated that glyphosate applications could increase disease severity in some variety by isolate interactions.

Herbicides may synergize or antagonize fungicide activity against different diseases in different crops. Kataria and Gisi (1990) found that when used alone in wheat, the herbicides DNOC, dicamba, ioxynil, and bromoxynil had a low to moderate effect on reducing the disease severity of *Rhizoctonia cerealis* Van der Hoeven and *Pseudocercospora herpotrichoides* (Fron) Deighton. However, herbicide combinations with the fungicide cyproconazole were synergistic and effective in reducing the disease severity. Hill and Stratton (1991) concluded from *in vitro* tests, that the herbicide metribuzin, when used in combination with the fungicide chlorothalonil, was antagonistic and reduced efficacy on *Alternaria solani* (Ell. And Martin) Sor. Unlike these examples, the herbicide treatments in our field experiments did not synergize nor antagonize *Rhizoctonia* crown and root rot management with azoxystrobin.

Fungicide. The main effect of fungicide was significant for *Rhizoctonia* disease indices and the percentage of healthy sugarbeet (Table 1). Combined across all varieties and herbicide treatments, a foliar application of azoxystrobin to 4 to 6-leaf sugarbeet provided the greatest suppression of *Rhizoctonia* crown and root rot (Table 3). Foliar applications of azoxystrobin resulted in a disease index rating

of 2.0 and 42% of the sugarbeet were considered healthy (disease severity rating of one or less). This was in contrast to the no fungicide treatment where the disease index rating was 4.0 and only 1% of the sugarbeet were considered healthy. In-furrow applications of azoxystrobin also provided some protection against *Rhizoctonia* crown and root rot. However, in-furrow applications were not as effective as foliar applied azoxystrobin (Table 3). Others have reported that in-furrow applications of azoxystrobin were just as effective as foliar applications to 4 to 6-leaf sugarbeet in reducing *Rhizoctonia* crown and root rot in naturally infested fields (Kirk et al. 2008). Differences in the results of our experiment may be related to the timing of *R. solani* inoculation, which occurred when sugarbeet was at the 6 to 8-leaf stage. In-furrow azoxystrobin applications may be more effective against earlier infections of *R. solani* and may not last long enough to prevent later infections. In addition, Stump et al. (2004) determined that fungicide treatments applied at the time of inoculation resulted in the lowest disease severity.

Harvestable sugarbeet

There was a fungicide by variety interaction for the percentage of harvestable sugarbeet. Sugarbeet that were considered harvestable have a disease severity rating of 3 or less, which means that less than

Table 3. Disease index ratings and percent healthy sugarbeet for fungicide treatments applied to glyphosate-resistant sugarbeet inoculated with *Rhizoctonia solani*.[†] Data are combined across varieties, herbicide treatments, and years.

Fungicide	Rate	Disease index [‡]	Healthy sugarbeet [§]
		— 0 to 7 scale —	— % —
Foliar azoxystrobin	0.8 kg ha ⁻¹	2.0 a*	42 a
In-furrow azoxystrobin	140 g m row ⁻¹	4.0 b	13 b
No fungicide	—	5.9 c	1 c

[†] *Rhizoctonia solani* inoculum was prepared on barley medium.

[‡] Disease is rated based on a 0 to 7 scale (0 = no disease and 7 = completely rotted, see text) and the disease index is calculated by determining a weighted average based on the number of sugarbeet in each of the eight disease classes.

[§] Healthy sugarbeet is determined by calculating the percent of sugarbeet that have a disease severity rating of 0 or 1.

* Means followed by the same letter are not significantly different according to Fisher's Protected LSD at $p < 0.05$.

25% of the sugarbeet is rotted and there are no deep penetrating cracks. Regardless of variety, fewer than 20% of sugarbeet were harvestable when a fungicide was not applied (Table 4). In-furrow and foliar applications of azoxystrobin increased the number of harvestable sugarbeet for all varieties, excluding the in-furrow azoxystrobin treatment on the most susceptible variety, Crystal RR827. A foliar application of azoxystrobin was the only treatment that improved the percentage of harvestable sugarbeet for this variety (73%). In contrast, Hilleshög 9027RR, Hilleshög 9028RR, and Hilleshög 9029RR benefited from both in-furrow and foliar applications of azoxystrobin for the percentage of harvestable sugarbeet (Table 4), although the foliar azoxystrobin application resulted in the greatest percentage of harvestable sugarbeet (88% or greater).

In summary, the four glyphosate-resistant sugarbeet varieties that we investigated had a range of responses to *R. solani*. Hilleshög 9027RR and Hilleshög 9029RR were most tolerant, Hilleshög 9028RR was moderately tolerant, and Crystal RR827 was the most susceptible variety to *Rhizoctonia* crown and root rot. Herbicide treatment, whether it was the glyphosate program or the standard conventional herbicide program, did not affect *Rhizoctonia* crown and root rot development or management in the field. This is in contrast to a greenhouse study by Larson et al. (2006) where applications of glyphosate

Table 4. Percent harvestable[†] sugarbeet for fungicide treatment applied to four glyphosate-resistant sugarbeet varieties inoculated with *Rhizoctonia solani*.[‡] Data are combined across herbicide treatments and years.

Variety	Fungicide		
	Foliar azoxystrobin	In-furrow azoxystrobin	No fungicide
	_____ harvestable sugarbeet (%) _____		
Hilleshög 9027RR	95 a*	62 bcd	15 f
Hilleshög 9028RR	88 abc	46 e	9 f
Hilleshög 9029RR	92 ab	57 cd	12 f
Crystal RR827	73 de	25 fg	2 g

[†] Harvestable sugarbeet is determined by calculating the percent of sugarbeet that have a disease severity rating of 3 or less.

[‡] *Rhizoctonia solani* inoculum was prepared on barley medium.

* Means followed by the same letter are not significantly different according to Fisher's Protected LSD at $p < 0.05$.

increased the disease severity of *Rhizoctonia* crown and root rot in a single *Rhizoctonia*-tolerant glyphosate-resistant sugarbeet variety. Across the four glyphosate-resistant sugarbeet varieties, a foliar application of azoxystrobin provided the most protection against *Rhizoctonia* crown and root rot. However, both foliar and in-furrow applications of azoxystrobin reduced the disease index and resulted in more healthy and harvestable sugarbeet than treatments lacking a fungicide application. The exception was Crystal RR827, the variety most susceptible to *R. solani*, where harvestable sugarbeet did not differ between the in-furrow fungicide treatment and no fungicide application. Choosing varieties that exhibit some tolerance to *Rhizoctonia* crown and root rot and timely application of a fungicide such as azoxystrobin will be the key factors to help growers manage this disease.

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