INTEGRATED MANAGEMENT OF RHIZOCTONIA ON SUGARBEET WITH RESISTANT VARIETIES, AT-PLANTING TREATMENTS, AND POSTEMERGENCE FUNGICIDES

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Rhizoctonia damping-off and crown and root rot (RCRR) caused by *Rhizoctonia solani* AG 2-2 have been the most common root diseases on sugarbeet in Minnesota and North Dakota for several years (1,2). These disease can occur throughout the growing season and reduces plant stand, root yield, and quality (3-6). Warm and wet soil conditions favor infection by *R. solani*. Disease management options include rotating with non-host crops (cereals), planting partially resistant varieties, planting early when soil temperatures are cool, improving soil drainage, and applying fungicides as seed treatments, in-furrow (IF), or postemergence. An integrated approach involving multiple strategies should help managing Rhizoctonia crown and root rot (4-6).

OBJECTIVES

Field trials were established to evaluate an integrated management strategy consisting of a resistant (R) and a moderately susceptible (MS) variety with at-panting treatments alone and in combination with two different postemergence azoxystrobin application timings for 1) control of early-season damping-off and RCRR and 2) effect on plant stand, yield and quality of sugarbeet.

MATERIALS AND METHODS

The field trial was established at three locations: (1) University of Minnesota, Northwest Research and Outreach Center, Crookston, (2) Minn-Dak Farmers Cooperative, Wahpeton (MDFC), ND, (3) Southern Minnesota Beet Sugar Cooperative (SMBSC), Renville, MN. All locations were fertilized for optimal yield and quality. At each location, a combination of a R and MS variety treated with fluxapyroxad (Systiva), in-furrow azoxystrobin (Quadris) on fluxapyroxad (Systiva), or untreated seed was planted in four replicate plots (Table 1). An additional treatment consisting of in-furrow azoxystrobin on untreated seed was included at the NWROC site. Plots were set up in a split-split plot design at all 3 locations. Main plots were varieties, the first split was at-panting treatments, and the last split was postemergence azoxystrobin timings. Systiva was used at 5 g ai/unit seed and applied by Germains Seed Technology, Fargo, ND. Each variety by at-planting treatment combination was planted in triplicate, so that at the 4- or 8-leaf stage, one plot of each variety by at-planting treatment combination received a postemergence 7-inch band application of azoxystrobin (14.3 fl oz product A^{-1}) while one was left as a stand-alone treatment. Controls for each variety included no at-planting treatment with each postemergence azoxystrobin timing and without postemergence azoxystrobin. Two-year average Rhizoctonia ratings in American Crystal Sugar Company tests for the R and MS varieties were 3.9 and 4.5, respectively (7).

NWROC site. Prior to planting, soil was infested with a mixture of four isolates of *R. solani* AG 2-2-infested whole barley broadcast at 40 kg ha^{-1} and incorporated with a Rau seedbed finisher. The trial was sown in six-row plots (22-inch row spacing, 30-ft rows) on May 16 at 4.5-inch seed spacing. Counter 20G (8.9 lb/A) was applied at planting and Lorsban (2 pt/A) was applied on June 11 for control of root maggot. Sequence (glyphosate + S-metolachlor, 2.5 pt/A) was applied on June 13 and 24) for control of weeds. Postemergence azoxystrobin was applied in a 7-inch band in 10 gallon/A using 4002 nozzles and 34 psi on June 17 (6 leaf stage, ~4.5 weeks after planting) or June 26 (10 leaf stage, ~6 weeks after planting). Cercospora leaf spot (CLS) was controlled by Minerva Duo (16 fl oz/A) on Aug 01 and Super Tin + Topsin M (6 + 10 oz/A) on Aug 21 applied in 20 gallons water/A at 100 psi.

MDFC site. Prior to planting, soil was infested with a mixture of four isolates of *R. solani* AG 2-2-infested whole barley (40 kg ha^{-1}). The trial was sown in six-row plots (22-inch row spacing, 30-ft rows) on May 31 at 4.5-inch seed spacing. Roundup PowerMax (5.5 lb product ae/gallon) tank-mixed with Dual Magnum (0.5 pt/A) was applied on Jun 05 and a tank-mix of Roundup PowerMax (5.5 lb product ae/gallon), N-tense (10 oz/A), Outlook (12 oz/A) and Stinger (4 oz/A) was applied on Jul 02. Postemergence azoxystrobin was applied in a 7-inch band on June 18 (4-leaf stage, 2.5 weeks after planting) or July 01 (8-leaf stage, 4 weeks after planting). Cercospora leaf spot was controlled by application of Super Tin + ManKocide (8 oz/A+ 2.5 lbs/A) on Jul 12, Provysol + Badge SC (5 fl. Oz/A+2 pt/A) on Jul 24, Super Tin + Manzate (8 fl oz/A+1.5 qt/A on Aug 07, and Inspire + Badge SC (2 fl oz/A+2 pt/ A) on Aug 18. All fungicides for CLS control were applied utilizing a 3pt-mounted sprayer dispersing the products in broadcast pattern at a water volume of 15 GPA with TeeJet 8002 flat fan nozzles at 80 psi.

Table 1. Application type, product names, active ingredients, and rates of fungicides used at planting in a field trial for control of *Rhizoctonia solani* AG 2-2 on sugarbeet. Each at-plant treatment was used in combination with a Rhizoctonia resistant (2-year average rating = 3.9) and moderately susceptible (2-year average rating = 4.5) variety, and all treatment combinations in triplicate, with one set receiving a postemergence 7-inch band application of azoxystrobin (14.3 fl oz A^{-1}) at 4- or 8-leaf stage. Standard rates of Apron + Thiram and 45 g/unit Tachigaren were on all seed.

Application	Product	Active ingredient	Rate
None	-	-	-
Seed	Systiva	Fluxapyroxad	5 g a.i./unit seed
In-furrow	Quadris	Azoxystrobin	9.5 fl oz product A^{-1}

Table 2. Monthly precipitation in inches at three sites during 2019 crop season based on weather stations.

	Precipitation in inches		
Month	NWROC	MDFC	SMBSC
April	1.56	0.80	-
May	1.38	2.82	4.24
June	1.39	2.65	2.40
July	3.32	6.30	4.34
August	4.72	2.50	2.46
September	6.92	5.79	5.02
October	4.15	2.73	4.01
Total	**23.44**	**23.59**	**22.44**

SMBSC site. Prior to planting, soil was infested with a mixture of four isolates of *R. solani* AG 2-2-infested whole barley (40 kg ha^{-1}). The trial was sown in six-row plots (22-inch row spacing, 30-ft rows) on May 14 at 4.77-inch seed spacing. Inoculum was incorporated using the 8.5 foot cultivator followed by the drag. Weeds were controlled by application of Roundup Powermax (32 oz/A) on Jun 10 followed by Roundup Powermax (22 oz/A) Jul 16. Postemergence azoxystrobin timings were applied on June 10 (4-leaf, ~3.5 weeks after planting), or June 19 (8-leaf, ~5 weeks after planting) as 7 inch bands using 4001E nozzles at 35 psi. Cercospora leaf spot was managed by fungicide application of Dithane on Jul 03, Inspire XT + Dithane on Jul 08, SuperTin + Dithane on Jul 18, Provysol + Champ on Jul 31, Agri-Tin + Dithane on Aug 09, Minerva + Badge on Aug 21, and Super Tin + Badge on Sept 09. All fungicides for CLS control were applied in a water volume of 19.3 GPA with 11002 nozzles at 70 psi.

At NWROC and MDFC stand counts were done beginning 2 weeks after planting through 7 weeks after planting. At SMBSC stand counts were done 1.5, 4, and 6.5 weeks after planting. The trial was harvested on Sept 18 at the NWROC, Oct 09 at Wahpeton and Sept 17 at Renville. Data were collected for number of harvested roots (NWROC only), yield, and quality. Twenty roots per plot also were arbitrarily selected and rated for severity of RCRR using a 0 to 7 scale (0 = healthy root, 7 = root completely rotted and foliage dead). Disease incidence was reported as the percent of rated roots with a root rot rating > 2.

Data were subjected to analysis of variance using SAS Proc GLM (SAS Institute, Cary, NC) for main effects of variety, at-plant treatment, postemergence azoxystrobin application, and all possible interactions. Means were separated by Fisher's Protected Least Significant Difference (P = 0.05).

RESULTS AND DISCUSSION

NWROC site: Early part of the 2019 growing season was dry at the NWROC during the period of May-June resulting in lower early season disease pressure. Rainfall at the NWROC was just 1.38 in. during the month of May and 1.39 in. during the month of June (Table 2) compared to a 30-year average of 2.83 and 4.05 in., respectively. Resistant (R) and moderately susceptible (MS) varieties had similar stands from 2 to 7 weeks after planting (WAP). Untreated and Systiva treatments had higher stands from 3 to 7 WAP compared to Systiva + Quadris in-furrow and Quadris in-furrow treatments (Fig. 1). Dry conditions during early season resulted in some stand reduction (12.6% reduction at 19 days after planting compared to untreated or Systiva treated seed) in treatments with Quadris in-furrow application at this site. Stand reduction with Quadris was also observed in 2017 and 2018 (4,5). Control plants had 182 plants/100 ft. row at 7 WAP indicating very low early season disease pressure. Slight to no root rot severity and incidence were observed for both varieties at harvest. Moderately susceptible variety had significantly higher percent sucrose, less loss to molasses, and higher recoverable sucrose T^{-1} (RST) (Table 3). There were no significant differences between Quadris I-F, Systiva, Systiva + Quadris I-F or control treatment for any harvest parameters. Both 4- and 8-leaf Quadris applications resulted in significant reduction in root rot rating and incidence (Table 3). However, there was no difference in yield, percent sucrose, recoverable sugar A^{-1} (RSA), or RST among treatments (Table 3). There was a significant at-planting by postemergence treatment interaction for root rot rating (Fig. 2); more impact of postemergence Quadris applications was observed on untreated seed or Systiva treated seed compared to treatments involving Quadris in-furrow application.

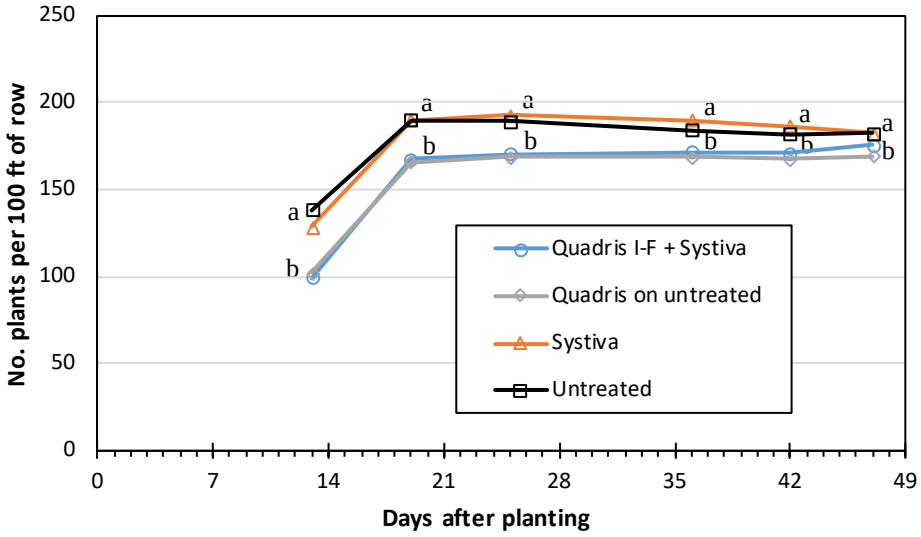

Fig. 1. NWROC site: Emergence and stand establishment for fungicide treatments at planting or untreated control. For each stand count date, values sharing the same letter are not significantly different (P = 0.05). Data shown represents mean of 24 plots averaged across varieties and postemergence treatments.

Table 3. NWROC site: Main effects of variety, at-planting, and postemergence fungicide treatments on Rhizoctonia crown and root rot and sugarbeet yield and quality in a field trial sown May 16, 2019.

Main effect (Apron + Maxim on all seed)	No. harv. roots/100 ft[T]	RCRR (0-7)[TU]	RCRR % incidence[TV]	Yield ton A^{-1}[T]	Sucrose[T] %	Sucrose[T] lb ton^{-1}	Sucrose[T] lb A^{-1}
Variety[W]							
Resistant	142	0.11	1.4	19.9	17.8	336	6690
Moderately Susceptible	154	0.11	1.8	21.0	18.1	344	7211
ANOVA p-value	0.155	0.768	0.308	0.395	**0.001**	**0.004**	0.245
At-planting treatments[X]							
Untreated control	154	0.12	1.9	20.7	17.9	337	6993
Systiva	153	0.20	3.1	19.6	18.1	343	6703
Quadris In-furrow	140	0.04	0.2	19.8	18.0	341	6755
Systiva + Quadris I-F	145	0.08	1.0	21.8	17.8	337	7350
ANOVA p-value	**0.046**	0.061	0.124	0.064	0.222	0.184	0.134
LSD (*P* = 0.05)	10.3	NS	NS	NS	NS	NS	NS
Postemergence fungicide[Y]							
None	145	0.20 a	3.3 a	20.1	17.9	339	6820
4-leaf Quadris	151	0.07 b	0.8 b	20.8	17.9	339	7065
8-leaf Quadris	148	0.06 b	0.6 b	20.4	18.0	341	6966
ANOVA p-value	0.353	**<0.0001**	**0.001**	0.157	0.288	0.325	0.213
LSD (*P* = 0.05)	NS	0.06	1.5	NS	NS	NS	NS
Vty x at-palnt	NS	NS	NS	NS	NS	NS	NS
Vty x Post	NS	NS	NS	NS	NS	NS	NS
At-plant x Post	NS	**0.017**	NS	NS	NS	NS	NS
Vty x At-plant x Post	NS	NS	NS	NS	NS	NS	NS

[T] Numbers followed by the same letter are not significantly different; LSD = Least Significant Difference, *P* = 0.05; NS = not significantly different

[U] RCRR = Rhizoctonia crown and root rot; 0-7 scale (adjusted rating), 0 = root clean, no disease, 7 = root completely rotted and plant dead

[V] RCRR = Rhizoctonia crown and root rot; percent of roots with rating greater than two

[W] Values represent mean of 48 plots (4 replicate plots across 4 at-planting treatments and 3 postemergence treatments)

[X] Systiva @ 5 g a.i /unit and Quadris In-furrow @ 9.5 fl oz./A via drip tube; Values represent mean of 24 plots (4 replicate plots across 2 varieties and 3 postemergence treatments)

[Y] Quadris Postemergence @ 14.5 fl oz./A in a 7 inch band; Values represent mean of 24 plots (4 replicate plots across 2 varieties and 3 at-planting treatments)

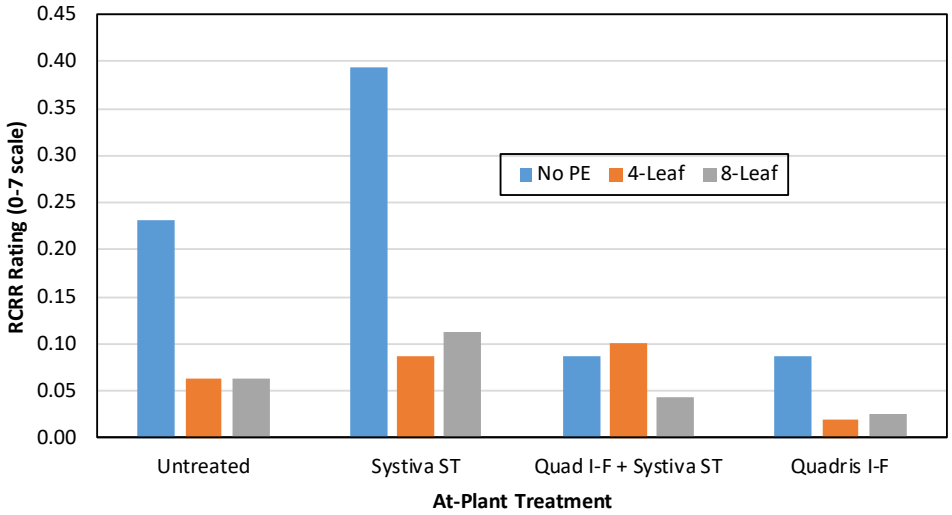

Fig. 2. NWROC site: Effect of at-panting and postemergence (PE) treatment interaction on Rhizoctonia root rot rating. Data shown represents mean of 8 plots averaged across varieties.

MDFC site: Late planting coupled with some moisture (Table 2) resulted in some early season disease pressure at this site. Resistant and moderately susceptible varieties had similar stands from 2 to 5.5 weeks after planting (WAP). Systiva and Systiva + Quadris I-F had significantly higher stands at 4 to 5 WAP compared to untreated control treatment (Fig. 3). At-plant control treatments had 180 plants/100 ft. row at 5.5 WAP indicating very low early season disease pressure at this site and yet Systiva had 201 and Systiva + Quadris had 216 plants/100 ft. row. Late planting (May 31) at this site did not result in stand reduction from Quadris in-furrow application (Fig. 3). However, Quadris in-furrow reduced stands at this site in 2018 (4). Even though July had substantial rainfall, relatively dry August resulted in low end-of the-season root rot development (Table 2). Resistant variety had significantly lower root rot rating and incidence, and lower purity compared to the moderately susceptible variety. Systiva + Quadris I-F had significantly lower root rot followed by untreated control and Systiva treatments (Table 4). No other harvest parameters were significantly different for at-planting treatments (Table 4). Postemergence Quadris application (4- or 8-leaf) significantly reduced root rot severity and incidence and increased yield and RSA compared to no postemergence application (Table 4). There was a significant variety x at-plant x postemergence treatment interaction for root rot rating (Figure 4). For the resistant variety, Quadris postemeregnce application may not be needed with Quadris I-F + Systiva, and 4- and 8-leaf Quadris postmeregence reduced root rot on untreated and Systiva treated seed with 8-leaf application resulting in slightly lower disease compared to 4-leaf post application. Whereas for the moderately susceptible variety, 4- or 8-leaf Quadris post reduced root rot with 4-leaf performing better on untreated and 8-leaf performing better on Quadris I-F + Systiva and Systiva treated seed (Figures 4A and 4B).

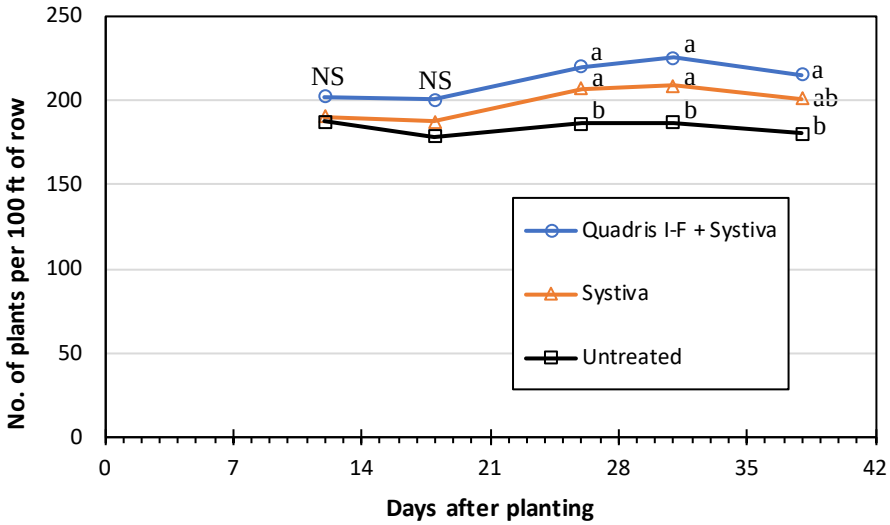

Fig. 3. MDFC site: Emergence and stand establishment for fungicide treatments at planting or untreated control. For each stand count date, values sharing the same letter are not significantly different ($P = 0.05$); NS = not significantly different. Data shown represents mean of 24 plots averaged across varieties and postemergence treatments.

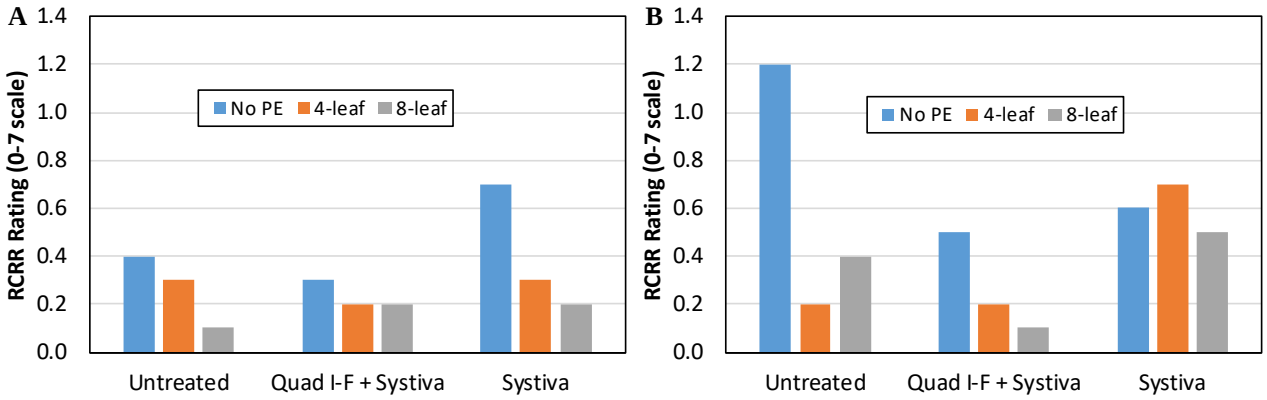

Fig. 4. MDFC site: Three way interaction of variety x at-plant x postemergence treatments for RCRR rating on the (A) resistant variety and (B) moderately susceptible variety. Data shown represents mean of 4 plots.

Table 4. MDFC site: Main effects of variety, at-planting, and postemergence fungicide treatments on Rhizoctonia crown and root rot and sugarbeet yield and quality in a field trial sown May 31, 2019.

Main effect (Apron + Maxim on all seed)	RCRR (0-7) [TU]	RCRR % incidence [TV]	Yield ton A^{-1} [T]	Sucrose [T] %	Sucrose [T] lb ton^{-1}	Sucrose [T] lb A^{-1}
Variety [W]						
Resistant	0.3	2.9	23.6	14.6	231	5434
Moderately Susceptible	0.5	9.0	22.3	14.8	238	5315
ANOVA p-value	**0.023**	**0.025**	0.391	0.434	0.246	0.658
At-planting treatments [X]						
Untreated control	0.4 ab	6.3	23.2	14.6	233	5405
Systiva	0.5 b	8.1	23.0	14.7	235	5395
Systiva + Quadris I-F	0.3 b	3.5	22.7	14.7	235	5324
ANOVA p-value	**0.033**	0.088	0.894	0.590	0.690	0.955
LSD (*P* = 0.05)	0.17	NS	NS	NS	NS	NS
Postemergence fungicide [Y]						
None	0.6 a	10.6 a	21.6 b	14.7	234	5053 b
4-leaf Quadris	0.3 b	4.2 b	24.0 a	14.7	236	5628 a
8-leaf Quadris	0.3 b	3.1 b	23.3 a	14.7	234	5442 a
ANOVA p-value	**<0.0001**	**0.0004**	**0.0006**	0.774	0.869	**0.0008**
LSD (*P* = 0.05)	.016	3.7	1.1	NS	NS	285
Vty x At-plant	NS	NS	NS	NS	NS	NS
Vty x Post	NS	NS	NS	NS	NS	NS
At-plant x Post	NS	NS	NS	NS	NS	NS
Vty x At-plant x Post	**0.022**	NS	NS	NS	NS	NS

[T] Numbers followed by the same letter are not significantly different; LSD = Least Significant Difference, *P* = 0.05; NS = not significantly different

[U] RCRR = Rhizoctonia crown and root rot; 0-7 scale (adjusted rating), 0 = root clean, no disease, 7 = root completely rotted and plant dead

[V] RCRR = Rhizoctonia crown and root rot; percent of roots with rating greater than two

[W] Values represent mean of 36 plots (4 replicate plots across 3 at-planting treatments and 3 postemergence treatments)

[X] Systiva @ 5 g a.i /unit and Quadris In-furrow @ 9.5 fl oz./A via drip tube; Values represent mean of 24 plots (4 replicate plots across 2 varieties and 3 postemergence treatments)

[Y] Quadris Postemergence @ 14.5 fl oz./A in a 7 inch band; Values represent mean of 24 plots (4 replicate plots across 2 varieties and 3 at-planting treatments)

SMBSC site: Low rainfall during June only resulted in slight disease pressure early in the season (Table 2). Resistant variety had higher stands at 2, 4, and 6 WAP compared to moderately susceptible variety (Fig. 5). Systiva and Systiva + Quadris I-F had highest stands at 2, 4, and 6 WAP compared to untreated control treatment. Untreated control had 213 plants/100 ft. row at 7 WAP indicating very low early season disease pressure at this site and hence Systiva and Systiva + Quadris I-F had 222 and 225 plants/100 ft. row, respectively (Fig. 6). In contrary to 2018 observations (4), Quadris I-F did not reduce stands at this site in 2019. Less than normal rainfall during July and some rainfall in Aug (Table 2) resulted in some late season disease pressure at this site. Variety by postemergence interaction was observed for number of harvested roots, root rot rating, incidence, yield and RST (Table 5); (i) postemergence application had significant benefit on the moderately susceptible variety (ii) Both 4- and 8-leaf application were effective on resistant variety, while on the moderately susceptible variety most benefit was seen with the 8-leaf postemergence application (Figs. 7A, 7B and 7C). At-panting by postemergence interaction on yield was observed (Table 5); postemergence applications significantly improved yield parameters in treatments with no Quadris in-furrow application (Fig 8) and 4-leaf Quadris application looked better on untreated and Systiva treated seed compared to 8-leaf application on

Table 5. SMBSC site: Main effects of variety, at-planting, and postemergence fungicide treatments on Rhizoctonia crown and root rot and sugarbeet yield and quality in a field trial sown May 14, 2019.

Main effect	RCRR	RCRR %	Yield	Sucrose[T]		
(Apron + Maxim on all seed)	(0-7) [TU]	incidence[TV]	ton A^{-1}[T]	%	lb ton^{-1}	lb A^{-1}
Variety[W]						
Resistant	0.3	5.8	26.9	15.7	256	6886
Moderately Susceptible	0.8	17.1	27.6	15.8	263	7243
ANOVA p-value	**0.005**	**0.001**	0.465	0.578	0.166	0.095
At-planting treatments[X]						
Untreated control	0.6	13.3	27.0	15.5	253	6842
Systiva	0.7	13.5	26.9	16.0	266	7160
Systiva + Quadris I-F	0.4	7.5	27.8	15.7	259	7191
ANOVA p-value	0.085	0.090	0.099	0.183	0.299	0.291
LSD (P = 0.05)	NS	NS	NS	NS	NS	NS
Postemergence fungicide[Y]						
None	1.1 a	23.5 a	26.2 b	15.3 b	247 b	6468 b
4-leaf Quadris	0.4 b	8.5 b	27.9 a	15.9 a	265 a	7384 a
8-leaf Quadris	0.1 c	2.3 c	27.6 a	16.0 a	266 a	7341 a
ANOVA p-value	<0.0001	<0.0001	<0.0001	0.0004	0.001	<0.0001
LSD (P = 0.05)	0.24	4.9	0.65	0.31	10.8	288
Vty x at-plant	NS	NS	NS	NS	NS	NS
Vty x Post	**0.022**	**0.015**	**0.008**	NS	**0.041**	NS
At-plant x Post	NS	NS	**0.031**	NS	NS	NS
Vty x at-plant x Post	NS	NS	NS	NS	NS	NS

[T] Numbers followed by the same letter are not significantly different; LSD = Least Significant Difference, P = 0.05; NS = not significantly different

[U] RCRR = Rhizoctonia crown and root rot; 0-7 scale (adjusted rating), 0 = root clean, no disease, 7 = root completely rotted and plant dead

[V] RCRR = Rhizoctonia crown and root rot; percent of roots with rating greater than two

[W] Values represent mean of 36 plots (4 replicate plots across 3 at-planting treatments and 3 postemergence treatments)

[X] Systiva @ 5 g a.i /unit and Quadris In-furrow @ 9.5 fl oz./A via drip tube; Values represent mean of 24 plots (4 replicate plots across 2 varieties and 3 postemergence treatments)

[Y] Quadris Postemergence @ 14.5 fl oz./A in a 7 inch band; Values represent mean of 24 plots (4 replicate plots across 2 varieties and 3 at-planting treatments)

Quadris I-F + Systiva seed (Fig. 8). Variety by at-plant by postemergence interaction was observed for no. of harvested roots (Table 5); postemergence application resulted in higher no. of harvested roots for Quadris I-F + Systiva and untreated control treatments for the moderately susceptible variety, but this trend was not observed for the resistant variety. Similar benefit from postemergence Quadris application at this location was also evident in 2016 thru 2018 (4-6). This clearly demonstrates the importance of choosing a resistant variety for managing Rhizoctonia diseases. In fields with heavy Rhizoctonia pressure, Quadris in-furrow application on treated seed will provide better protection compared to seed treatment only as observed in this trial especially when using a susceptible variety for Rhizoctonia.

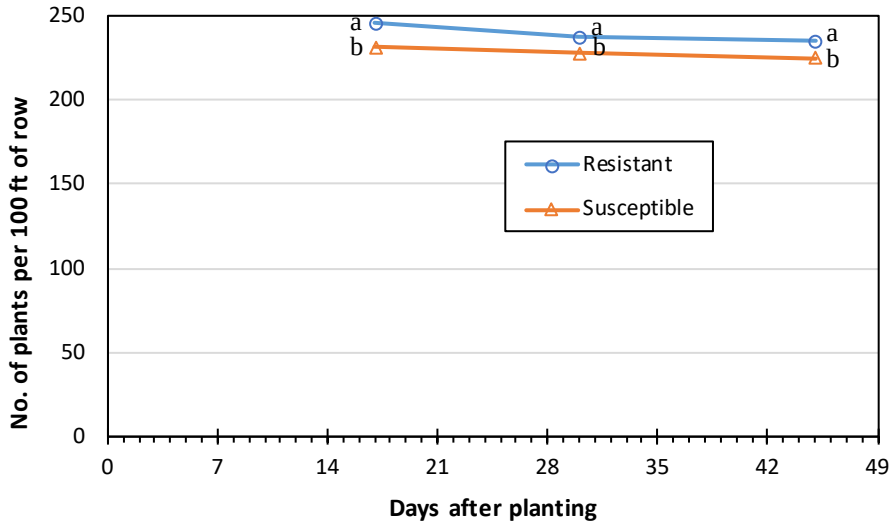

Fig. 5. SMBSC site: Emergence and stand establishment for resistant and moderately susceptible varieties. For each stand count date, values sharing the same letter are not significantly different (P = 0.05). Data shown represents mean of 36 plots averaged across at-planting and postemergence treatments.

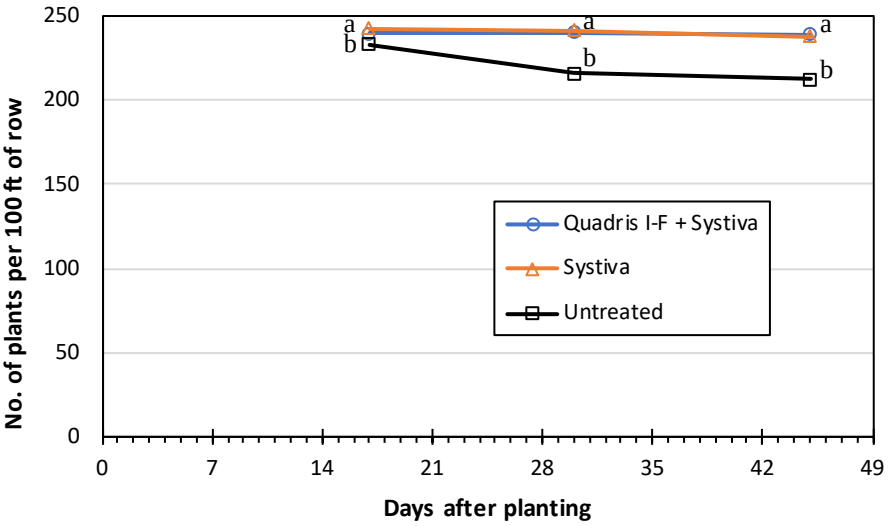

Fig. 6. SMBSC site: Emergence and stand establishment for the at-planting treatments. For each stand count date, values sharing the same letter are not significantly different (P = 0.05). Data shown represents mean of 24 plots averaged across varieties and postemergence treatments.

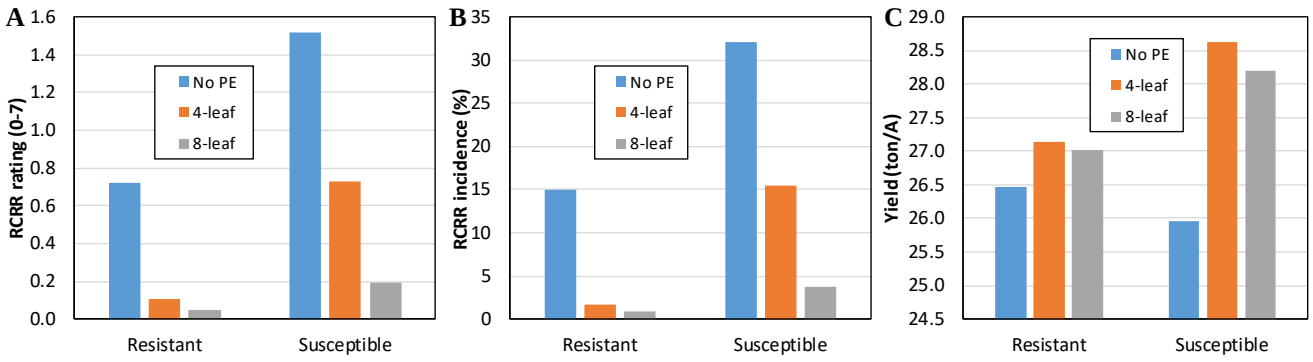

Fig. 7. SMBSC site: Effect of variety and postemergence treatments on **A)** RCRR rating (0 to 7 scale, 0 = root clean, no disease, 7 = root completely rotted and plant dead), **B)** RCRR incidence (% roots with rating > 2) and **C)** yield. Data shown represents mean of 12 plots averaged across at-planting treatments.

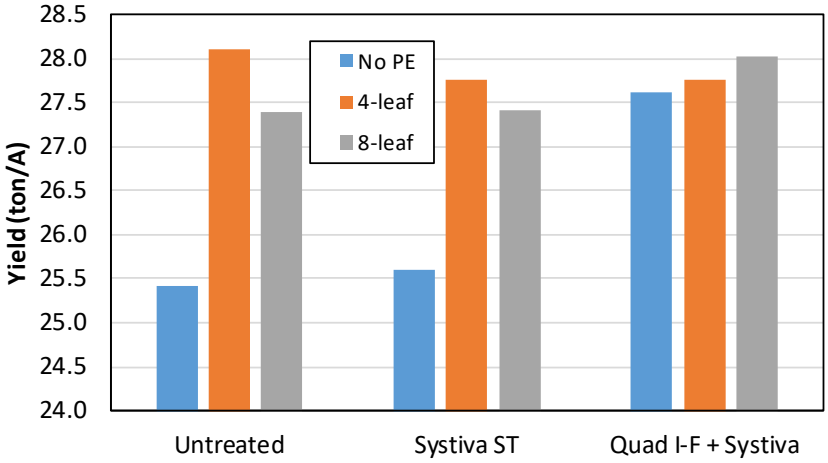

Fig. 8. SMBSC site: Effect of at-planting and postemergence treatments on root yield. Data shown represents mean of 8 plots averaged across varieties.

ACKNOWLEDGEMENTS

We thank the Sugarbeet Research and Education Board of Minnesota and North Dakota for funding this research; BASF and Syngenta for providing products; Crystal Beet Seed for providing seed; Germains Seed Technology for treating seed; staff from the Minn-Dak Farmers Cooperative for plot maintenance and harvest at the Wahpeton site; staff from the Southern Minnesota Beet Sugar Cooperative for plot maintenance and harvest at the Renville site; the University of Minnesota, Northwest Research and Outreach Center, Crookston for providing land, equipment and other facilities; Jeff Nielsen for plot maintenance; Hal Mickelson, Derefaa Cline and Muira MacRae for technical assistance; Minn-Dak Farmers Cooperative, Wahpeton, ND for the Wahpeton site sugarbeet quality analysis; Southern Minnesota Beet Sugar Cooperative, Renville, MN for the Renville site sugarbeet quality analysis; and American Crystal Sugar Company, East Grand Forks, MN for NWROC site sugarbeet quality analysis.

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