EVALUATION OF FUNGICIDE SPRAY PROGRAMS TO MANAGE CERCOSPORA LEAF SPOT USING CR+ AND NON-CR+ SUGARBEET VARIETIES

[1]Austin K. Lien, [2]Jeff Nielsen and [3]Ashok K. Chanda

[1]Reasearcher 3 and Graduate Student; [2]Reasearcher 2; [3]Assistant Professor and Extension Sugarbeet Pathologist
University of Minnesota, Department of Plant Pathology & Northwest Research and Outreach Center, Crookston, MN
Corresponding Author: Ashok Chanda, achanda@umn.edu

INTRODUCTION

Cercospora leaf spot (CLS), caused by the fungus *Cercospora beticola*, continues to be a challenge to sugarbeet growers in Minnesota and North Dakota, especially when growing conditions are warm and humid. Management of CLS must incorporate integrated practices such as conventional tillage, crop rotations, and spatial separation from previous sugarbeet fields when possible. Variety selection is also a critical aspect in managing CLS, but each variety has unique characteristics regarding yield, sugar quality, and disease tolerance. Additionally, the use of effective fungicides and proper timing of applications can significantly delay CLS development and reduce the extent of economic losses. However, with the increasing incidence of fungicide-resistant samples of *C. beticola* across sugarbeet growing regions in Minnesota and North Dakota (Secor et al. 2021), the use of highly tolerant sugarbeet varieties (i.e., CR+ varieties) may be vital in managing CLS disease (Mettler and Bloomquist 2021, 2022) as well as managing fungicide resistance (Mettler and Bloomquist 2022).

In 2021, conidia of *C. beticola* had been identified in spore traps as early as May 03 in some growing regions (Secor et al. 2022). Several weeks before leaf spot symptoms were visible, the DNA of *C. beticola* was also detected in sugarbeet leaves in early June of 2020 (Bloomquist et al. 2021) and June of 2021 (Secor et al. 2022). Once the detached conidia contact the leaf or petiole of a sugarbeet, the fungus initiates infection. Results from Rivera-Varas (2021) indicate that conidia can germinate within 2 hours even at 10°C; however, optimal temperatures for germination and infection are 25-35°C (Jacobson and Franc 2009). Following infection, leaf spot symptoms can develop within 5 days (Solel and Minz 1971), and secondary conidia can form after 7 days under favorable conditions (Jacobson and Franc, 2009). Moreover, the development of symptoms and secondary conidia are highly influenced by temperature, humidity, light, leaf age, and disease tolerance of the host; generally, infection cycles are prolonged as CLS tolerance of the host increases (Jacobson and Franc 2009). Additionally, Bhuiyan et al. (2021) showed that infection of *C. beticola* and the hypersensitive response of the host is delayed in a CLS tolerant variety compared to a susceptible variety, implying that the development of conidia is also delayed. In field conditions, Metzger (2021) reported that the final CLS disease severity of CR+ varieties is significantly less compared to susceptible varieties in the 2020 MDFC CLS Nursery near Foxhome, MN. Two trials in separate locations were also conducted in 2020 and 2021 by the SMBSC to determine the best fungicide program to pair with varieties with differing levels of CLS tolerance. Mettler and Bloomquist (2021, 2022) report from the field trials that highly tolerant varieties do not need the same rigorous fungicide program that moderately susceptible varieties need to produce good yields.

Since 2021, CR+ sugarbeet varieties with traits that impart improved tolerance to CLS are now available to growers throughout Minnesota and North Dakota. Promisingly, these newly released varieties are coupled with improved performance and can produce a recoverable sucrose per acre that is comparable to susceptible varieties. Additionally, it is hoped that the cost of fungicide management can be reduced by integrating these varieties and decreasing the number of fungicide applications.

OBJECTIVES

The trial objective is to evaluate a CR+ variety and standard fungicide programs with different timings for 1) the relative control of CLS disease on sugarbeet, and 2) the effect on harvestable root yield and sucrose quality.

MATERIALS AND METHODS

The trial was established as a randomized complete block design with 4 replicates at the University of Minnesota Northwest Research and Outreach Center in Crookston, MN. Field plots were fertilized for optimal yield and quality. A moderately susceptible variety (Crystal 808RR) with a 2-year average Cercospora rating of 4.9 (Niehaus and Moomjian 2021) and a CR+ variety (BTS 8018) with a 2-year average Cercospora rating of 2.4 (Brantner and Moomjian 2022) was used. All seed was treated with standard seed treatments and were sown in 6-row by 35-feet long plots at 4.5-inch spacing in 22-inch rows on May 24. Plant stands were evaluated June 27 by counting the number of plants in the right four rows of each plot to verify an average plant population of 150 plants per 100 ft of row for BTS 8018 and 191 plants per 100 ft of row for Crystal 808. On July 13 (14 to 16-leaf stage), all rows within each plot were inoculated with a mixture of fine talc and dried ground CLS-infected sugar beet leaves (1:2 weight by weight) using a modified duster created from a power drill and a Nalgene® 1L bottle to deliver a rate of 4.5 lbs. per acre (3 grams of mixture per 35 feet of row). CLS-infected sugar beet leaves used for the inoculum were collected from nontreated rows at the end of 2021 growing season.

Fungicide treatments (see tables) were applied to the right four rows using a tractor-mounted 3-point sprayer with XR TeeJet 11002 VS flat fan nozzles calibrated to deliver 17.1 gallons water/A at 100 psi. Fungicides were applied bi-weekly or approximately every 10 days, depending on weather conditions and the prior treatment. Fungicide applications began when weather was conducive for disease development and coincided with canopy closure, except for the first applications on Jul 08, 5 days prior to inoculation. Fungicide treatments were applied on July 08, July 18, July 27, Aug 04 or Aug 08, Aug 22, and Sept 06. CLS disease severity was evaluated beginning Aug 01 and continued through Sept 22 using the following scale based on infected leaf area: 1=0.1% (1-5 spots/leaf), 2=0.35% (6-12 spots/leaf), 3=0.75% (13-25 spots/leaf), 4=1.5% (26-50 spots/leaf), 5=2.5% (51-75 spots/leaf), 6=3%, 7=6%, 8=12% 9=25%, 10=50; rating scale is outlined by Jones and Windels (1991). Additionally, leaf spots (n = 100) were collected from each variety on Aug 29 and placed in a humidity chamber for 48 hours to identify the causal pathogens; values were then used to adjust each rating to represent the amount of CLS present in each plot. On Sept 27, plots were defoliated, and the two right-most rows of each plot were harvested mechanically and weighed for root yield due to stand establishment issues that occurred early on and negatively impacted the center two rows. Twelve representative roots from each plot were analyzed for sugar quality at the American Crystal Sugar Company Quality Tare Laboratory, East Grand Forks, MN. Statistical analysis was conducted in R (v 4.2.0, R Core Team 2022). CLS severity, sugar, and sucrose per ton were analyzed with the package *stats* (v 4.2.0) using analysis of variance with replication as a random effect, and Fisher's protected least significant difference (LSD) test was used for post hoc analysis at a 0.05 level of significance with the package *agricolae* (v 1.3-5) to separate treatment means. Yield, sucrose per acre, and revenue were analyzed with the package *rstatix* (v 0.7.0) using analysis of covariance with plant stands as the covariate. Pairwise comparisons, partial Eta-squared (η_g^2), and the estimated marginal means of each treatment were produced based on average plant stands for each variety using the package *emmeans* (v 1.8.1-1). Partial Eta-squared is a measure of the strength of association between plant stands and the independent variables (i.e., yield, sucrose per acre, and revenue).

RESULTS AND DISCUSSION

Frequent rainfall early in the spring resulted in delayed planting. Even though the moist soils and slightly above average temperatures in June allowed for the rapid growth of sugarbeets and the production of true leaves, the timing of canopy closure was delayed compared to previous years. Following inoculation, the site received 0.41 in. of rain; additionally, prolonged warm temperatures and high humidity provided conditions that favored the establishment of the Cercospora inoculum. The first leaf spot caused by a *Cercospora* spp. in the trial was identified on July 18. However, abnormally dry conditions and above-average temperatures during August and September resulted in low disease pressure mid to late-season. Macroscopic identification of conidia after Aug 29 indicated that 71%, 13%, and 2% of leaf spots collected from BTS 8018 were caused by *Alternaria* spp., *Cercospora* spp., and *Stemphylium* spp., respectively. Leaf spots collected from Crystal 808 indicated that 1%, 98%, and 1% were caused by *Alternaria* spp., *Cercospora* spp., and *Stemphylium* spp., respectively. Disease pressure progressed in the moderately susceptible nontreated control to a level above the known economic threshold of 3% severity by the end of the season. Standard fungicide programs significantly reduced CLS severity for Crystal 808 ($P < 0.0001$). Disease pressure for BTS 8018 was minimal throughout the season, and CLS severity was not significant (P = 0.7672) and very low regardless of the fungicide spray program. Variable plant stands between treatments significantly correlated with yield (R = 0.89, $P < 0.0001$) and warranted an analysis of covariance and adjustment of treatment means. Based on the analysis of covariance, there were no significant differences for yield, sucrose per acre, and revenue for either of the varieties. However, after transforming treatment means to the estimated marginal means based on the average plant stand for the respective variety, there were numerical differences in the Crystal 808 variety where the nontreated control resulted in the lowest yield, sucrose per acre, and revenue.

Table 1. Effects of fungicide spray programs on CLS disease, harvestable yield, and sucrose quality of sugarbeets in a CLS-infested field trial planted on May 24, 2022 at the University of Minnesota, Northwest Research and Outreach Center, Crookston.

Treatment(s)[z] and timing[y]	CLS Severity (0-10)[x]	Sugar (%)	Sucrose (lbs/ton)	Yield (tons/A)[w]	Sucrose (lb/A)[w]
CR+ Highly tolerant variety (BTS 8018); 2-year Cercospora rating = 2.4					
Provysol **A +** Manzate Pro-Stick **ABDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	0.3	17.2	321	23.6	7539
Provysol **A +** Manzate Pro-Stick **AD** + Super Tin **BF** + Topsin 4.5 FL **B** + Proline 480 SC **D** + Priaxor **F**	0.3	17.4	324	22.5	7262
Provysol **A +** Manzate Pro-Stick **A** + Super Tin **C** + Topsin 4.5 FL **C** + Proline 480 SC **F** + Priaxor **F**	0.3	17.7	332	22.0	7355
Provysol **B +** Manzate Pro-Stick **BDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	0.3	17.4	326	22.0	7181
Provysol **B +** Manzate Pro-Stick **BE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **E** + Priaxor **F**	0.3	17.7	332	22.0	7279
Provysol **B +** Manzate Pro-Stick **B** + Super Tin **C** + Topsin 4.5 FL **C** + Proline 480 SC **F** + Priaxor **F**	0.3	17.4	325	21.9	7106
Provysol **C +** Manzate Pro-Stick **CE** + Super Tin **DF** + Topsin 4.5 FL **D** + Proline 480 SC **E** + Priaxor **F**	0.3	17.2	321	22.7	7284
Provysol **C +** Manzate Pro-Stick **C** + Super Tin **D** + Topsin 4.5 FL **D** + Proline 480 SC **F** + Priaxor **F**	0.3	18.4	345	23.2	7992
Proline 480 SC **C** + Manzate Pro-Stick **C** + Super Tin **F** + Priaxor **F**	0.3	17.6	331	21.6	7129
Proline 480 SC **D** + Manzate Pro-Stick **D** + Super Tin **F** + Priaxor **F**	0.3	17.7	333	21.8	7212
Proline 480 SC **E** + Manzate Pro-Stick **E** + Super Tin **F** + Priaxor **F**	0.3	17.8	333	22.6	7537
Provysol **D +** Manzate Pro-Stick **D** + Super Tin **E** + Topsin 4.5 FL **E** + Proline 480 SC **F** + Priaxor **F**	0.3	17.7	332	22.7	7520
Proline 480 SC **F** + Priaxor **F**	0.3	17.6	329	22.4	7366
Nontreated Control	0.3	17.6	330	21.7	7136
P-value	0.7672	0.5181	0.5190	0.8479	0.6171
η_g^2	-	-	-	0.16	0.21
Moderately susceptible variety (Crystal 808); 2-year Cercospora rating = 4.9					
Provysol **A +** Manzate Pro-Stick **ABDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	1.1 d	16.9	317	27.6	8728
Provysol **B +** Manzate Pro-Stick **BDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	1.4 d	17.8	335	25.1	8412
Provysol **C +** Manzate Pro-Stick **CE** + Super Tin **DF** + Topsin 4.5 FL **D** + Proline 480 SC **E** + Priaxor **F**	2.3 c	16.9	316	27.4	8649
Provysol **D +** Manzate Pro-Stick **D** + Super Tin **E** + Topsin 4.5 FL **E** + Proline 480 SC **F** + Priaxor **F**	2.8 bc	17.6	330	25.4	8392
Super Tin **DF** + Topsin 4.5 FL **D** + Proline 480 SC **E** + Manzate Pro-Stick **E** + Priaxor **F**	3.2 b	17.1	321	26.3	8442
Nontreated Control	6.9 a	16.5	309	24.7	7653
P-value	<0.0001	0.1230	0.1321	0.8713	0.9635
η_g^2	-	-	-	0.1	0.05

[z] Treatment rates per acre are as follows: Provysol = 4 fl oz, Manzate Pro-Stick = 2 lb, Super Tin = 8 fl oz, Topsin 4.5 FL = 10 fl oz, Proline 480 SC = 5.7 fl oz, Priaxor = 6.7 fl oz; Non-ionic surfactant (NIS; Permeate) was used at a rate of 0.125% v/v with Provysol and Proline 480 SC.

[y] Application letter code for the following dates: **A**= Jul 08, **B**= Jul18, **C**= Jul 27, **D**= Aug 04 or Aug 08, **E**= Aug 22, **F**= Sept 06

[x] Values within a column followed by the same letter are not significantly different

[w] Values are estimated marginal means based on average plant stands for the respective variety

Table 2. Revenue associated with fungicide spray programs to manage CLS of sugarbeets in a CLS-infested field trial planted on May 24, 2022 at the University of Minnesota, Northwest Research and Outreach Center, Crookston.

Treatment(s)[z] and timing[y]	Gross Rev. ($/ton)[x,v]	Gross Rev. ($/A)[w,x,v]	Fung. Cost ($/A)[w]	Net Rev. ($/A)[v]
CR+ Highly tolerant variety (BTS 8018); 2-year Cercospora rating = 2.4				
Provysol **A +** Manzate Pro-Stick **ABDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	61.2	1430	107	1323
Provysol **A +** Manzate Pro-Stick **AD** + Super Tin **BF** + Topsin 4.5 FL **B** + Proline 480 SC **D** + Priaxor **F**	62.4	1389	94	1295
Provysol **A +** Manzate Pro-Stick **A** + Super Tin **C** + Topsin 4.5 FL **C** + Proline 480 SC **F** + Priaxor **F**	65.2	1447	81	1366
Provysol **B +** Manzate Pro-Stick **BDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	63.1	1384	101	1284
Provysol **B +** Manzate Pro-Stick **BE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **E** + Priaxor **F**	64.9	1423	94	1329
Provysol **B +** Manzate Pro-Stick **B** + Super Tin **C** + Topsin 4.5 FL **C** + Proline 480 SC **F** + Priaxor **F**	62.5	1364	81	1284
Provysol **C +** Manzate Pro-Stick **CE** + Super Tin **DF** + Topsin 4.5 FL **D** + Proline 480 SC **E** + Priaxor **F**	61.0	1384	94	1290
Provysol **C +** Manzate Pro-Stick **C** + Super Tin **D** + Topsin 4.5 FL **D** + Proline 480 SC **F** + Priaxor **F**	69.6	1615	81	1534
Proline 480 SC **C** + Manzate Pro-Stick **C** + Super Tin **F** + Priaxor **F**	64.6	1390	59	1331
Proline 480 SC **D** + Manzate Pro-Stick **D** + Super Tin **F** + Priaxor **F**	64.9	1410	59	1351
Proline 480 SC **E** + Manzate Pro-Stick **E** + Super Tin **F** + Priaxor **F**	65.4	1484	59	1426
Provysol **D +** Manzate Pro-Stick **D** + Super Tin **E** + Topsin 4.5 FL **E** + Proline 480 SC **F** + Priaxor **F**	65.1	1471	81	1390
Proline 480 SC **F** + Priaxor **F**	63.6	1429	46	1383
Nontreated Control	64.0	1387	0	1387
P-value	0.2367	0.3963	-	0.1703
η_g^2	0.3	0.26	-	0.32
Moderately susceptible variety (Crystal 808); 2-year Cercospora rating = 4.9				
Provysol **A +** Manzate Pro-Stick **ABDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	59.2	1638	107	1531
Provysol **B +** Manzate Pro-Stick **BDE** + Super Tin **CF** + Topsin 4.5 FL **C** + Proline 480 SC **D** + Priaxor **F**	66.0	1658	101	1558
Provysol **C +** Manzate Pro-Stick **CE** + Super Tin **DF** + Topsin 4.5 FL **D** + Proline 480 SC **E** + Priaxor **F**	59.0	1618	94	1524
Provysol **D +** Manzate Pro-Stick **D** + Super Tin **E** + Topsin 4.5 FL **E** + Proline 480 SC **F** + Priaxor **F**	64.3	1639	81	1558
Super Tin **DF** + Topsin 4.5 FL **D** + Proline 480 SC **E** + Manzate Pro-Stick **E** + Priaxor **F**	61.0	1603	69	1534
Nontreated Control	57.1	1410	0	1410
P-value	0.9583	0.9803	-	0.9925
η_g^2	0.06	0.04	-	0.03

[z] Treatment rates per acre are as follows: Provysol = 4 fl oz, Manzate Pro-Stick = 2 lb, Super Tin 4L = 8 fl oz, Topsin 4.5 FL = 10 fl oz, Proline 480 SC = 5.7 fl oz, Priaxor = 6.7 fl oz; Non-ionic surfactant (NIS; Permeate) was used at a rate of 0.125% v/v with Provysol and Proline 480 SC.

[y] Application letter code for the following dates: **A**=8 Jul, **B**=18 Jul, **C**=27 Jul, **D**=4 Aug or 8 Aug, **E**=22 Aug, **F**=6 Sept

[x] Values within a column followed by the same letter are not significantly different

[w] Revenue is based on the November 2022 ACSC beet payment; fungicide cost is based on 2022 prices and does not include application costs

[v] Values are estimated marginal means based on average plant stands for the respective variety

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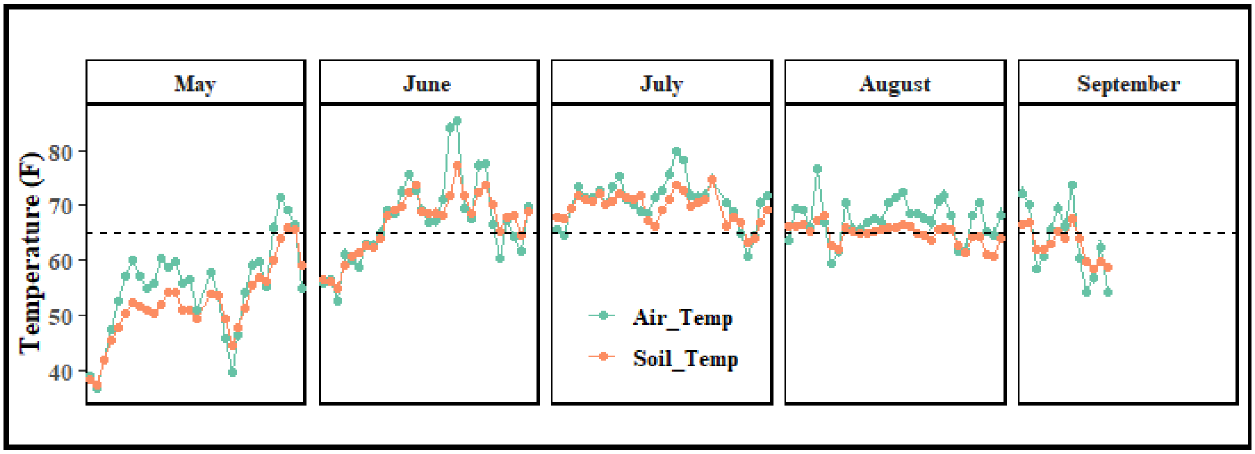

Figure. 1. Daily mean air temperature and 4-inch soil temperature collected at the NWROC weather station in Crookston, MN for the 2022 growing season. The dotted line represents 65°F.

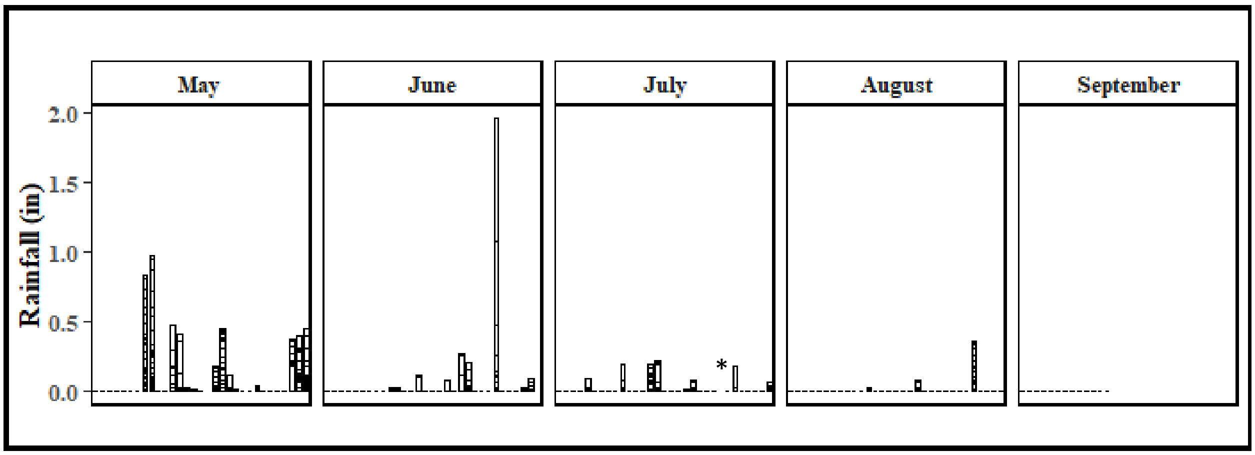

Figure 2. Daily rainfall totals collected at the NWROC weather station in Crookston, MN for the 2022 growing season. *Missing Data: 0.65 in received on June 24, 2022.

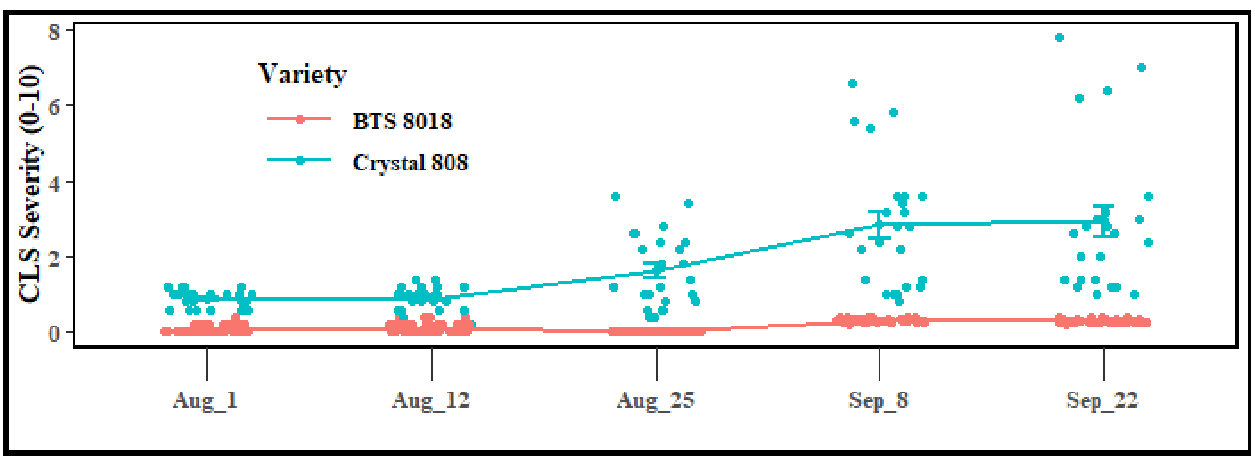

Figure 3. CLS disease severity ratings throughout the 2022 growing season for sugarbeet varieties sown in an CLS inoculated field trial at the University of Minnesota, NWROC, Crookston, MN.