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Fungicide Rotations and Host Resistance for Cercospora Leaf Spot Management in Sugar Beet

Abstract

Cercospora leaf spot (CLS), caused by *Cercospora beticola*, is a major foliar disease of sugar beet in North Dakota, Minnesota, and other regions with warm, humid conditions. Intensive fungicide use has driven resistance development across multiple fungicide classes, reducing control efficacy. This study evaluated rotations and mixtures of single- and multi-site fungicides for CLS management. Field trials (2023–2024) in North Dakota and Minnesota tested two sugar beet varieties, one resistant and one susceptible to CLS. Treatments included triazoles, QoI + triazole premix, and multi-site protectants (tin, copper, mancozeb). Both variety and fungicide treatment significantly affected disease severity. Resistant varieties consistently had the lowest disease severity, while in susceptible varieties, rotations achieved control comparable to mixtures. These findings highlight the importance of integrating resistant germplasm with fungicide rotation to sustain CLS management and mitigate fungicide resistance risk.

Keywords: Fungicide, resistance, fungicide rotation, field trials

Introduction

Sugar beet (*Beta vulgaris* L.) is a major source of sucrose and contributes significantly to the U.S. agricultural economy, supporting industries such as food and beverage manufacturing, animal feed, industrial fermentation, as well as supporting equipment manufacturing and transportation (Finkenstadt, 2013) In 2023, Minnesota and North Dakota accounted for over 58% of U.S. sugar beet production, cultivating approximately 656,358 acres and delivering 12.7 million tons to processors (University of Minnesota Extension, 2024; Bailey, 2023). Despite its economic importance, sugar beet production is threatened by *Cercospora beticola*, the causal agent of Cercospora leaf spot (CLS), one of the most damaging foliar diseases in most production areas in the United States and worldwide. CLS is polycyclic, spreading rapidly under warm, humid conditions and causing defoliation, yield losses of up to 40%, and reduced sugar quality (Weiland and Koch, 2004; Khan, 2018).

CLS management relies on integrated strategies, including cultural practices, resistant varieties, and fungicides. However, repeated use of site-specific fungicides such as demethylation inhibitors (DMIs) and quinone outside inhibitors (QoIs) has selected for resistant *C. beticola* populations. QoI resistance, associated with the G143A mutation, and DMI resistance, linked to *cyp51* overexpression, have been reported across production areas (Bolton et al., 2012; Kirk et al., 2012; Secor et al., 2017).

Given these challenges, incorporating multisite fungicides with different modes of action may improve disease control and delay resistance. Triphenyltin hydroxide (FRAC 30) and mancozeb (FRAC M03) are potential alternatives, while copper-based products (FRAC M01) provide additional protectant activity. Although chlorothalonil has been used elsewhere, it is not registered for sugar beet in North Dakota (Branch et al., 2024).

Previous research has demonstrated the value of resistant varieties for reducing CLS severity; however, the relative performance of fungicide rotations versus mixtures remains less clear under field conditions where fungicide resistance is established. This study evaluated fungicide programs in combination with resistant and susceptible sugar beet varieties to determine their impact on CLS severity and yield.

Materials and Methods

Field Sites and Experimental Design

Field trials were conducted at Prosper, North Dakota (2023, 2024), and at Moorhead (2023 and 2024) and Foxhome (2024), Minnesota. Fields were fertilized according to North Dakota State University and University of Minnesota recommendations, followed by conventional tillage. Trials employed a randomized complete block design with four replications. Plots consisted of six rows (55 cm spacing, 9 m length) planted at a seeding rate of 60,875 seeds/acre using a six-row John Deere MaxEmerge planter at 3 cm depth. Planting occurred between late April and late May, depending on site and year (Branch et al., 2024).

Varieties and Inoculation

Two sugar beet varieties were evaluated: ‘Crystal’ (CLS-susceptible) and ‘CR+’ (enhanced CLS resistance). Cercospora leaf spot (CLS) inoculum consisted of ground infected leaves mixed with talc (2:1 ratio) and applied at 600 g/acre foliage in early July each year.

Fungicide Treatments

Fungicides were applied at disease onset, followed by two additional applications at 10–14-day intervals. Treatments included site-specific and multisite fungicides: triphenyltin hydroxide (Agri Tin), prothioconazole (Proline), difenoconazole + propiconazole (Inspire XT), mancozeb (Koverall), and copper hydroxide/oxychloride (Badge SC), applied alone or in combination (Table 1). Applications targeted the center four rows using a CO_2-pressurized sprayer with 11002 TT TwinJet nozzles at 17 gal/acre and 413 kPa.

Table 1. Fungicide treatments were evaluated in the 2023 and 2024 growing seasons at all locations.

Treatment No.	Treatment Name	Active Ingredient	Application Rate	[a]Application Code
1	Untreated	-		
2	Agri Tin Proline Koverall	triphenyltin hydroxide prothioconazole mancozeb	8 fl oz/a 5.7 fl oz/a 2 lb/a	A B C
3	Agri Tin Badge SC Proline Koverall Agri Tin Badge SC	triphenyltin hydroxide copper hydroxide and oxychloride prothioconazole mancozeb triphenyltin hydroxide copper hydroxide and oxychloride	8 fl oz/a 2 pt/a 5.7 fl oz/a 2 lb/a 8 fl oz/a 2 pt/a	A A B B C C
4	Proline Agri Tin Inspire XT	prothioconazole triphenyltin hydroxide difenoconazole and propiconazole	5.7 fl oz/a 8 fl oz/a 7 fl oz/a	A B C
5	Proline Koverall Agri Tin Badge SC Inspire XT Koverall	prothioconazole mancozeb triphenyltin hydroxide copper hydroxide and oxychloride difenoconazole and propiconazole mancozeb	6.7 fl oz/a 2 lb/a 8 fl oz/a 2 pt/a 7 fl pz/a 2 lb/a	A A B B C C

[a]The application codes indicate the grouping of fungicides applied together during a single spray. Fungicides with the same letter were applied in the same treatment pass. For example, fungicides labeled with **"A"** were applied together, followed by those labeled **"B"**, and then those labeled **"C"** in subsequent applications.

Disease Assessment and Yield

CLS severity was rated weekly using the 1–10 scale of Jones and Windels (1991), beginning at disease onset, with assessments restricted to the two center rows (3^{rd}

and 4th rows), which were also harvested. Beets were defoliated with a four-row Standard Alloway defoliator and harvested with a two-row harvester during August and September in both years at all locations. Harvested roots were weighed, and subsamples were analyzed for sugar content at the American Crystal Sugar Company Quality Lab (East Grand Forks, MN).

Data Analyses

Data was analyzed using SAS software (version 9.4; SAS Institute, Cary, NC). Disease severity ratings were converted to percentage values and used to calculate the area under the disease progress curve (AUDPC) with the formula: AUDPC = $\Sigma [(y_i + y_{i+1}) / 2] * (t_{i+1} - t_i)$, where y_i= disease severity at the ith observation, t_i= time (days) at the ith observation and, Σ = The sum of the areas of all trapezoids is the AUDPC. AUDPC values were normalized by the total assessment period to obtain relative AUDPC (rAUDPC). Levene's test was used to evaluate variance homogeneity for rAUDPC and sugar yield across locations. When variances were homogeneous ($P > 0.05$), data were combined across sites. A mixed-model ANOVA was conducted using PROC GLIMMIX, with treatment, variety, and interaction as fixed effects and location as a random effect. Mean comparisons were performed using the Tukey-Kramer test ($\alpha = 0.05$).

Results

Levene's test indicated unequal variances for rAUDPC between years ($P = 0.02$), so 2023 and 2024 were analyzed separately. Variances were homogeneous across 2024 locations ($P = 0.95$), allowing combined analysis.

A mixed-model ANOVA revealed significant variety × treatment interactions in both years ($P < 0.05$). Disease pressure was low in 2023, and fungicide programs did not differ significantly in rAUDPC within either variety (Table 2). In 2024, untreated susceptible plots had the highest rAUDPC (11.4), while fungicide programs reduced disease to 2.3–4.8. Resistant varieties maintained consistently low rAUDPC (0.3–1.6) across all treatments

Table 2. Relative Area Under the Disease Progress Curve (rAUDPC) for the variety × treatment interaction in 2023 and 2024 for the resistant and susceptible varieties.

Variety	Treatment	[a]rAUDPC (Prosper 2023)	[b]rAUDPC (Combined 2024)
Resistant	Untreated	0.1 b	1.6 cd
	Agri Tin Proline Koverall	0.1 b	0.3 d
	Agri Tin + Badge SC Proline + Koverall Agri Tin + Badge SC	0.1 b	0.4 d
	Proline Agri Tin Inspire XT	0.1 b	0.3 d
	Proline + Koverall Agri Tin + Badge SC Inspire XT + Koverall	0.1 b	0.3 d
Susceptible	Untreated	0.5 a	11.4 a
	Agri Tin Proline Koverall	0.1 b	4.8 b
	Agri Tin + Badge SC Proline + Koverall Agri Tin + Badge SC	0.1 b	3.3 bc
	Proline Agri Tin Inspire XT	0.1 b	2.9 bc
	Proline + Koverall Agri Tin + Badge SC Inspire XT + Koverall	0.1 b	2.3 cd

[a]Values sharing the same letter are not statistically different ($p > 0.05$), based on the Tukey-Kramer post hoc test.
[b]Values sharing the same letter are not statistically different ($p > 0.05$), based on the Tukey-Kramer post hoc test.

Main effects confirmed these patterns: resistant varieties consistently had lower rAUDPC than susceptible varieties in both 2023 and 2024. In 2023 at Moorhead, resistant varieties showed an rAUDPC of 0.2 compared to 0.6 in susceptible varieties, while the combined 2024 data showed 0.6 for resistant and 4.9 for susceptible varieties. Fungicide treatments significantly reduced rAUDPC relative to the untreated control in both years. For example, in 2023, treated plots had rAUDPC values of 0.1 compared with 0.3 in untreated plots, and in 2024, treated plots ranged from 1.3 to 2.6 versus 6.5 for the untreated control. The benefit of fungicide application was most pronounced in susceptible varieties under high disease pressure, indicating that management practices have the greatest impact when varietal resistance is low.

Sugar yield responses varied by site and year. Resistant varieties generally outperformed susceptible ones, though the advantage was smaller at low-disease sites. Fungicide treatment effects were inconsistent across environments: significant yield gains were observed in Foxhome and Moorhead 2024, but not at Moorhead 2023 or Prosper 2024 (Table 3).

Table 3. Effect of Variety ×Treatment on Recoverable Sugar (lb)/Acre across locations.

Variety	Treatment	Moorhead 2023	Foxhome 2024	Moorhead 2024	Prosper 2024
Resistant	Untreated	13419 a	10164 d	13107 ab	10409 a
	Agri Tin Proline Koverall	13315 a	10828 cd	12242 bc	10409 a
	Agri Tin + Badge SC Proline + Koverall Agri Tin + Badge SC	13231 a	12383 abc	13072 ab	9877 a
	Proline Agri Tin Inspire XT	12869 ab	13129 ab	12590 ab	9875 a
	Proline + Koverall Agri Tin + Badge SC Inspire XT + Koverall	13688 a	13389 a	13342 a	10214 a
Susceptible	Untreated	11569 b	11876 abc	9536 e	9522 a
	Agri Tin Proline Koverall	11740 b	12316 abc	9771 e	10350 a
	Agri Tin + Badge SC Proline + Koverall Agri Tin + Badge SC	12725 ab	12852 ab	11070 d	10211 a
	Proline Agri Tin Inspire XT	12310 ab	11737 acd	11285 cd	9614 a
	Proline + Koverall Agri Tin + Badge SC Inspire XT + Koverall	12392 a	12565 ab	10575 e	10614 a

Values sharing the same letter are not statistically different ($P > 0.05$), based on the Tukey-Kramer post hoc test.

Economic analysis showed wide differences in program costs (Table 4). The lowest-cost rotation and the fungicide combination Agri Tin (triphenyltin hydroxide) + Proline (prothioconazole) + Koverall (mancozeb), achieved disease control comparable to that of higher-cost mixtures. The most expensive program, costing $198.42/acre and $238.42/acre with Cr+, which included the fungicide combinations Proline (prothioconazole) + Koverall (mancozeb), Agri Tin (triphenyltin hydroxide) + Badge SC (copper hydroxide), and Inspire XT (pyraclostrobin + difenoconazole) + Koverall (mancozeb), did not provide proportionally greater disease suppression

Table 4. Cost of Fungicide Application/Acre.

Treatment	Application Code	Fungicide Cost/acre	Total Cost/acre with Cr+ Variety
Agri Tin Proline Koverall	A B C	$98.67	$138.67
Agri Tin Badge SC Proline Koverall Agri Tin Badge SC	A A B B C C	$170.85	$210.85
Proline Agri Tin Inspire XT	A B C	$132.09	$172.09
Proline Koverall Agri Tin Badge SC Inspire XT Koverall	A A B B C C	$198.42	$238.42

Discussion

This study demonstrates the complementary importance of host resistance and fungicide programs for Cercospora leaf spot (CLS) management. Resistant varieties consistently maintained low disease levels across environments, confirming their central role in integrated management (Madden et al., 2017). Fungicides provided clear benefits primarily in susceptible varieties and under high disease pressure, whereas their contribution was minimal in resistant germplasm.

The significant interaction between variety and fungicide treatment highlights the need to tailor programs to crop resistance levels. In susceptible varieties, fungicides substantially reduced disease severity, while in resistant varieties, disease suppression was already strong, making additional fungicide benefits marginal. Similar variety × fungicide interactions have been reported in other pathosystems, emphasizing the importance of integrating host resistance with chemical management (Vitale, 2023, (Bradshaw, 2016).

Rotations of single-site fungicides were as effective as mixtures in suppressing CLS, supporting previous evidence that rotations reduce resistance risk without sacrificing control. This finding is particularly relevant given widespread resistance to QoIs and DMIs. Using rotations rather than mixtures may slow resistance development while also lowering input costs (Khan, 2018; Secor et al., 2017).

Yield responses reflected these trends. Fungicide applications improved sugar yield mainly in susceptible varieties at high-disease sites, while resistant varieties consistently produced stable yields with limited fungicide input. These results suggest that fungicide programs should be adapted to disease pressure and variety resistance level, rather than applied uniformly across production fields.

Economic analysis further supports this conclusion: low-cost fungicide rotations provided equivalent disease suppression compared to high-cost mixtures. Since expensive programs did not deliver proportionally greater yield or disease reduction, growers may optimize returns by prioritizing resistant varieties and cost-efficient rotations. In wet summers, timely fungicide applications by tractor may be difficult, and aerial applicators may not always be available. Frequent rainfall can also wash off fungicides, most of which act as protectants, leading to reduced efficacy, increased disease pressure, and lower yields (Schilder, 2010). Under such conditions, planting more resistant varieties, such as CR+ types, provides a valuable “insurance policy,” helping to ensure acceptable disease control and maintain crop performance even during wet growing seasons. CR+ cultivars, developed by KWS, carry the BvCR4 gene derived from Beta maritima, which confers enhanced tolerance to Cercospora leaf spot (CLS). These improved varieties, released since 2021, are selected through rigorous field trials and standardized evaluations using the Klein Wanzlebener Saatzucht (KWS) scale, providing producers with a reliable tool to complement cultural and chemical disease management strategies (Törjék et al., 2020).

Conclusion

Resistant varieties remained the most effective strategy for suppressing CLS, reducing both disease severity and reliance on fungicides. Fungicide programs are most valuable in susceptible varieties and under high disease pressure, but rotations of single-site fungicides provide control equivalent when compared to more costly mixtures. Integrating resistant varieties with strategic fungicide rotations offers a sustainable and economically efficient framework for CLS management. This approach reduces disease risk, slows fungicide resistance development, and avoids unnecessary production costs.

Conflict of Interest

The authors declare that there is no conflict of interest.

Literature Cited

Bailey, A. 2023. American Crystal has a record breaking 2023 sugarbeet crop. AgWeekly. Available at: https://agweek.com/ [Accessed on: February 3, 2025].

Bolton, M. D., K. Birla, V. Rivera-Varas, K. D. Rudolph, G. A. Secor. 2012. Characterization of CbCyp51 from field isolates of *Cercospora beticola.* Phytopathology. 102:298-305.

Bradshaw, J. 2016. Plant breeding: Past, present and future. Cham: Springer International Publishing.

Branch, E., D. Kaiser, M. Boetel, A. Chanda, T. Peters. 2024. 2024 Sugarbeet Production Guide. NDSU Extension. Available at: https://www.ndsu.edu/agriculture/sites/default/files/2024-01/a1698-24.pdf [Accessed on: September 12, 2025].

Jones, R. K., Windels, C. E. 1991. A management model for Cercospora leaf spot of sugarbeets. University of Minnesota. Agricultural Extension Service. 5643:1-8

Khan, M. F. R. 2018. Success and limitations of using fungicides to control cercospora leaf spot on sugar beet. Agricultural Research and Technology. 14: 555909.

Kirk, W.W., L. E. Hanson, G. D. Franc, W. L. Stump, E. Gachango, G. Clark, J. Stewart. 2012. First report of strobilurin resistance in *Cercospora beticola* in sugar beet (*Beta vulgaris*) in Michigan and Nebraska, USA. New Disease Reports. 26:3.

Madden, L. V., G. Hughes, F. Bosch. 2017. The study of plant disease epidemics. St. Paul, MN: APS Press.

Secor, G.A., V. Rivera, M.D. Bolton. 2017. Sensitivity of *Cercospora beticola* to foliar fungicides in 2017. Sugarbeet Research and Extension Report. Available at: https://www.sbreb.org/wpcontent/uploads/2018/ [Accessed on: February 3, 2025].

University of Minnesota Extension. 2024. Staying on top of sugarbeets. Magazine. Available at: https://extension.umn.edu/source-magazine/staying-top-sugarbeets [Accessed on: February 3, 2025].

Schilder, A. 2010. Fungicide Properties and Weather Conditions. Michigan Stante University. Available at: https://www.canr.msu.edu/news/fungicide_properties_and_weather_conditions#:~:text=The%20question%20sometimes%20comes%20up,to%20wash%2Doff%20by%20rain [Accessed on: September 12, 2025].

Törjék, O., Borchardt, D., Rekoske, M., Mechelke, W., Schulz, B., and Lein, J.C. 2020. Gene 758 conferring resistance to *Cercospora beticola* in beets.

Vitale, A. 2023. Epidemiology and control of plant diseases. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC9962675/ [Accessed on: March 6, 2025].

Weiland, J., G. Koch. 2004. Sugarbeet leaf spot disease (*Cercospora beticola* Sacc.). Molecular Plant Pathology. 5:157-166.