Effect of Fungicides on Sugar Beet Yield, Quality, and Postharvest Respiration Rates in the Absence of Disease

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Abstract
Five fungicides were each applied on sugar beet (Beta vulgaris) three times at about 14-day intervals beginning in July in 2005 through 2008. No foliar disease occurred in the nontreated control or any fungicide treatment. There were no significant differences in root yield, recoverable sucrose, or sucrose concentration among treatments. In 2007 and 2008, postharvest storage respiration rates were determined after 30 and 90 days in storage. There was no significant difference in respiration rates among treatments. There was no apparent benefit in applying these fungicides in seasons when no foliar disease developed.

Introduction
Cercospora leaf spot (CLS), caused by the fungus Cercospora beticola, is one of the most devastating diseases of sugar beet (Beta vulgaris) worldwide (12) and the only foliar disease that has the potential to cause significant economic losses in North Dakota and Minnesota (17,27). In 1998 during a severe CLS epidemic, American Crystal Sugar Company growers paid $45 million for ineffective fungicides (5). Since the 1999 season, tetraconazole, and subsequently, strobilurin fungicides, have provided effective CLS control leading to less disease incidence over the years (6,19,20). Growers in North Dakota and Minnesota now typically apply fungicides two to three times to prevent CLS on the scale of the 1998 season (4). Fungicides are applied if disease symptoms are observed in July, or if symptoms are present and environmental conditions are favorable for disease development later in the season, or on a calendar schedule (27), many times in the absence of disease.

There are reports that strobilurins and triazoles increased crop yields, particularly in cereal crops, beyond any disease control benefits (1,29). Strobilurin applications also have resulted in larger potato (Solanum tuberosum) tubers (25), and triazoles are reported to improve cassava (Manihot esculenta) tuber production and quality (9) and increase yields of barley (Hordeum vulgare) and oilseed rape (Brassica napus) (14).

In North Dakota and Minnesota, sugar beet roots are stored for up to 250 days prior to processing. Therefore, it is in the processors’ interest to promote agronomic practices that have the potential to reduce sugar loss during storage. It is estimated that 80% of the sugar lost during storage is from respiration (2,28). As cooperative owners, all sugar beet growers benefit directly when postharvest losses are minimized. Since fungicides are widely used to control CLS on sugar beet and some fungicides apparently influence basic plant physiological process, questions regarding the impact, if any, of fungicides on the respiration rate of roots during storage have arisen. This study examines the effect of five fungicides on root yield, sucrose concentration, processing quality, and postharvest respiration rate when CLS control is not a contributing factor. This research was previously presented at a scientific meeting (16).
Experimental Design and Field Trials

Field trials were planted near Prosper, ND, on 29 April, and 5, 3, and 6 May in 2005, 2006, 2007, and 2008 with a John Deere Max Emerge II (Deere and Co., Moline, IL) planter. The experimental design was a randomized complete block with four replicates and six treatments. Wheat (*Triticum aestivum*) was always the preceding crop and the site was on a 3 year rotation. Plots were six 0.55-m wide rows and 9.0 m long. Fertilization was in accordance with recommended practice (15). In 2005 through 2007, plots were planted with cv. Beta 3820 treated with hymexazol (Tachigaren, Sankyo Agro Co. Ltd, Tokyo, Japan) at 45 g a.i./kg seed. In 2008, cv. Beta 3820 was unavailable, therefore cv. Beta 1301 treated with hymexazol at 20 g a.i./kg seed was planted. Terbufos (Counter 15G, BASF Corp, Raleigh, NC) was applied at 3.7 kg a.i./ha in-furrow at planting as a preventative treatment for insect pests including sugar beet root maggot (*Tetanops myopaeformis*) and wireworms (*Coleoptera elateridae*).

Weeds were controlled with recommended herbicides (15) and hand weeding. Plots were thinned manually at the four to six-leaf stage to 86,450 plants/ha in all years except 2007, when, as a result of crusting and poor emergence, plots were thinned to 73,522 plants/ha.

**Fungicides evaluated.** The fungicides examined were tetraconazole (Eminent 125 SL, Sipcam AgroUSA, Roswell, GA) at 114 g a.i./ha, pyraclostrobin (Headline 2.09 EC, BASF Corp., Research Triangle Park, NC) at 165 g a.i./ha, trifloxystrobin (Gem 4.17 SC, Bayer CropScience, Research Triangle Park, NC) at 131 g a.i./ha, triphenyltin hydroxide (Super Tin 80 WP, DuPont Crop Protection, Wilmington, DE) at 280 g a.i./ha, and thiophanate-methyl (Topsin M 70 WP, Cerexagri-Nisso LLC, King of Prussia, PA) at 394 g a.i./ha. A non-treated control was included. Each plot received three applications of a single fungicide. Fungicides were applied on 26 July, 9 and 24 August; 18 July, 1 and 15 August; 26 July, 9 and 24 August; and 22 July, and 5 and 25 August in 2005, 2006, 2007, and 2008. Fungicides were applied to the four inner rows of the six row plots with a four-nozzle boom sprayer operating at 690 kPa and calibrated to deliver 187 liter/ha.

**Disease avoidance and evaluation.** The research site was selected because it was usually free of sugar beet diseases. To further avoid common diseases of sugar beet, the cultivars (Beta 3820 and 1301) were selected based on good levels of resistance to Aphanomyces root rot and Cercospora leaf spot (24). Hymexazol seed treatment was added as a precaution to further provide protection from Aphanomyces root rot. Plots were observed weekly for typical symptoms of Aphanomyces root rot, Rhizoctonia root rot, and starting after row closure, for symptoms of Cercospora leaf spot (15).

**Harvest methods, dates and quality analysis.** In 2005 and 2006, plots were harvested on 20 and 26 September, respectively. Two identical trials were planted at the same location in 2007 and 2008 to permit early and late harvests. In 2007 and 2008, the early harvest dates were 26 and 29 September; the late harvest date for both years was 29 October. Except for the late harvest in 2008, all the roots in the middle two rows of each plot were harvested with a mechanical harvester, weighed for root yield, and 12 to 15 representative roots, not including painted roots on the ends of the rows, were analyzed for quality. Because of wet conditions at the time of the late harvest in 2008, 10 roots were hand dug from the middle two rows of each plot, weighed and analyzed for quality at American Crystal Sugar Company Quality Tare Laboratory, East Grand Forks, MN.

**Determining respiration rate.** During the early harvests in 2007 and 2008, 10 additional roots were collected from each plot, washed, placed in perforated polyethylene bags and stored at 4°C and 95% relative humidity. Post harvest respiration rates were determined 30 and 90 days after harvest (DAH). Respiration rates were determined by measuring the CO₂ produced by each 10-root sample using the method described by Campbell et al. (3).

**Statistics.** Data analysis was performed with the ANOVA procedure of Agriculture Research Manager, version 7.5 (Gylling Data Management Inc., Brookings, SD).
Disease, Yield, Sucrose Concentration, and Recoverable Sucrose

None of the plots had visual symptoms characteristic of the sugar beet diseases prevalent throughout the region (15). During the 4-year study there were no significant differences in root yield, sucrose concentration, or recoverable sucrose yield between the non-treated control and any of the fungicide treatments when the early and late harvests were analyzed individually for each year or when combining early harvests, or combining late harvests (Table 1).

Table 1. Effect of fungicides on sugar beet yield and quality at Prosper, ND during early harvest in 2005 through 2008 (combined data), and late harvest in 2007 and 2008 (combined data).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Early Harvest 2005-2008</th>
<th>Late Harvest 2007-2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield (ton/ha)</td>
<td>Sucrose conc. (%)</td>
</tr>
<tr>
<td>Nontreated control</td>
<td>64.5</td>
<td>15.9</td>
</tr>
<tr>
<td>Tetraconazole, 114 g</td>
<td>63.2</td>
<td>15.9</td>
</tr>
<tr>
<td>Pyraclostrobin, 165 g</td>
<td>63.4</td>
<td>16.0</td>
</tr>
<tr>
<td>Trifolxystrobin, 131 g</td>
<td>63.8</td>
<td>15.9</td>
</tr>
<tr>
<td>Triphenyltin hydroxide, 280 g</td>
<td>64.3</td>
<td>16.0</td>
</tr>
<tr>
<td>Thiophanate-methyl, 394 g</td>
<td>64.7</td>
<td>16.1</td>
</tr>
<tr>
<td>Prob(F)</td>
<td>0.94</td>
<td>0.73</td>
</tr>
<tr>
<td>CV</td>
<td>4.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>

x Sucrose conc. = Sucrose concentration.
y Recov. Sucrose = Recoverable sucrose.

Respiration Rates After Different Storage Duration

There were no significant differences in respiration rates between the non-treated control and any of the fungicide treatments as measured by the amount of CO₂ produced by the sugar beet roots 30 and 90 DAH in either 2007 or 2008 (Table 2).

Table 2. Effect of fungicides on storage respiration rates of sugar beet roots from Prosper, ND, 2007 and 2008.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Respiration rate x (mg of CO₂/kg/h)</td>
<td>Respiration rate x (mg of CO₂/kg/h)</td>
</tr>
<tr>
<td></td>
<td>30 DAH</td>
<td>90 DAH</td>
</tr>
<tr>
<td>Nontreated control</td>
<td>4.75</td>
<td>4.01</td>
</tr>
<tr>
<td>Tetraconazole, 114 g</td>
<td>5.10</td>
<td>4.63</td>
</tr>
<tr>
<td>Pyraclostrobin, 165 g</td>
<td>4.18</td>
<td>3.99</td>
</tr>
<tr>
<td>Trifolxystrobin, 131 g</td>
<td>4.52</td>
<td>4.32</td>
</tr>
<tr>
<td>Triphenyltin hydroxide, 280 g</td>
<td>4.65</td>
<td>3.78</td>
</tr>
<tr>
<td>Thiophanate-methyl, 394 g</td>
<td>4.47</td>
<td>4.09</td>
</tr>
<tr>
<td>Prob(F)</td>
<td>0.37</td>
<td>0.67</td>
</tr>
<tr>
<td>CV</td>
<td>12.3</td>
<td>17.9</td>
</tr>
</tbody>
</table>

x After 30 and 90 days of root storage at 4°C and 95% relative humidity.
Effect of Fungicide on Protection Against Frost

In 2007 and 2008, the late harvest was delayed until after a frost to determine whether any of the fungicide treatments provided protection against frost. In both years, there were at least 3 days prior to harvest during which the temperature was at, or below 0°C for several hours. The lowest air temperatures attained before harvest during 2007 and 2008 were -6 and -5°C, respectively (23). After the frosts, there were no apparent foliar differences corresponding to the fungicide treatments. The leaves of all plants in all treatments were lying flat on the ground and appeared to be dead.

Conclusion

Growers utilize all the fungicides included in this trial, but tetraconazole, pyraclostrobin, and triphenyltin hydroxide were most frequently chosen over the past 5 years (4). Inoculated trials have consistently demonstrated that these fungicides provide effective CLS control when applied in a rotation with each other (17,21). Fungicide applications have resulted in less than 1% of surveyed growers in 2008 indicating CLS as a major problem compared to 36% in 1998. Annual fungicide applications decreased from an average of 3.74 applications in 1998 to 2.2 applications in 2008 (4,6) and it may be feasible for growers to reduce fungicide usage even further. In the trials summarized in this report, multiple applications of fungicides did not provide any significant increase in sugar beet root yield or quality in the absence of disease. It should be noted that the use of multiple applications of the same fungicides is not recommended since this practice may expedite the development of fungicide-resistant C. beticola strains. Only three fungicide applications were made since most growers who use multiple applications rarely apply more than three (7), and individual fungicides were used so that any treatment effect would be due to one fungicide active ingredient.

The other sugar beet production area in the United States where growers routinely apply fungicides for CLS control is Michigan. Hubbell et al. (13) reported that strobilurin (pyraclostrobin and azoxystrobin) and tetraconazole fungicides, applied at different times prior to harvest, but after other fungicides were used to control CLS, did not enhance yield in Michigan. In Idaho, CLS is not a major problem for growers. However, in a non-disease study where glyphosate was mixed with different fungicides, including azoxystrobin and trifloxystrobin, there was no yield advantage with any of the fungicides (11). Similar trials with soybean (Glycine max), another broadleaf crop widely grown in the Midwest, found that triazole and strobilurin fungicides applied in the absence of disease did not increase soybean yield (26).

In the United Kingdom, a summary of fungicide trials at 16 sites reported sugar beet yield increases at low disease sites, high disease sites, and also at sites with no disease (22). In the absence of disease, it was estimated that yield increased about 5%. Both triazole and strobilurin fungicides increased yield in some, but not all, years. We are not aware of any peer reviewed articles that have associated increased sugar beet yield with fungicide applications in the absence of disease in sugar beet producing countries near the UK. In France and Germany, environmental conditions often are favorable for the development of CLS (12). In the UK, CLS has never been a serious problem because cooler conditions – mean summer temperature of 14.1°C - are unfavorable for the development of CLS, but favorable for powdery mildew (Erysiphe betae) (8,22), whereas this disease is very rarely found on sugar beet in Minnesota and North Dakota. An interaction between environment and fungicide effect on plant response may be responsible for the varied results from trials in different regions.

The respiration rates of sugar beet roots in this study were consistent with other reports involving healthy roots (3,10). In the absence of disease, none of the fungicides had a detectable effect on postharvest respiration rate.

This research indicated that fungicide applications in seasons when no foliar disease developed did not significantly increase sugar beet root yield or quality, or significantly reduce postharvest respiration rate of sugar beet in the environments sampled.
Fungicides that effectively control CLS are now available, but should only be used when there is a need for controlling CLS based on established disease thresholds in conjunction with daily infection values (18,27).

Acknowledgments
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Literature Cited