Impact of Cercospora Leaf Spot on Root Weight, Sugar Yield, and Purity of *Beta vulgaris*

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ABSTRACT

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The impact of Cercospora leaf spot, caused by *Cercospora beticola*, on the yield and quality of sugar beets (*Beta vulgaris*) was studied in one field trial in 1982 and two trials in 1983. Fungicides were applied to cultivars of various disease susceptibilities to obtain different levels of disease severity. Plants were rated for disease severity with a spot-percentage scale according to the number of lesions per leaf at intensities <3% and with standard area diagrams at intensities ≥3%. A disease severity of 50% approximately 10 days before harvest corresponded to relative dollar losses of 43, 27, and 27% for trials 1-3, respectively. Reduced payment per hectare was sometimes evident for epidemics of >3% severity by mid-September. Increased concentration of impurities and decreased sugar concentration in beet roots and decreased root weight generally were correlated with disease severity. Beets with higher concentrations of impurities yielded less pure sugar and more unrefined sugar (molasses) in the extraction process. In diseased plots, sugar loss to molasses had a minor impact on dollar return compared with losses attributed to reductions in root weight and sugar content.

Additional keywords: disease management, epidemics

Cercospora leaf spot of sugar beet (*Beta vulgaris* L.), caused by *Cercospora beticola* Sacc., causes significant losses to growers in Minnesota and North Dakota and elsewhere in the United States and the world (6,8,12). Management of Cercospora leaf spot is achieved with the use of resistant cultivars, rotation, sanitation, and fungicides. The net profit for growers in Minnesota and North Dakota often is higher with the use of susceptible cultivars and fungicides than it is when cultivars with more resistance to Cercospora leaf spot but less sugar potential are planted.

Crop loss attributable to Cercospora leaf spot (disregarding disease management and indirect costs) is manifested as a reduction in root weight, reduced sugar content, and increased loss of sugar to molasses due to impurities (16), which include sodium, potassium, nitrate, amino acids, and betaine (2). Losses due to Cercospora leaf spot have gone as high as a 42% reduction in gross sugar and a 32% reduction in root weight (16). A 35% reduction in gross sugar was associated with a leaf spot reading of 3 on a scale of 0–10 (18). Kelber (6) estimated a 0.3% increase in yield loss with each 1% increase in final disease severity. *C. beticola* also predisposes sugar beets to storage rot (17).

Although the ability of *C. beticola* to cause crop loss is not questioned, little information is available on losses attributable to *C. beticola* using a clearly defined rating system. Better definition of the relationship between disease severity and crop loss is crucial to the refinement of disease management strategies. Most researchers have used disease rating scales with broad or imprecisely defined categories. Two rating scales, a scale of 0–10 and the Kleinwanzlebener Saatzucht (KWS) scale, have been used for most measurements of Cercospora leaf spot in the United States and Europe. In the 0–10 scale, 0 = healthy plants and 10 = maximum injury (12,16).

The KWS scale is based on a set of drawings and descriptions distributed by the Kleinwanzlebener Saatzucht Company of Einbeck, Germany, for rating disease intensity (Table 1). The KWS scale can be used to rate individual leaves and whole plants. Descriptions of disease categories are broad, but the KWS scale is used by many plant breeders for rapid assessment of resistance to Cercospora leaf spot in sugar beet breeding lines. The KWS set of descriptions and pictures have been employed in scales with five, six, and nine categories. The nine-category KWS scale is used in Minnesota and North Dakota for evaluation of sugar beet germ plasm (19). Kelber (6) estimated disease severities corresponding to categories of a five-step scale using the KWS diagrams. However, in our preliminary work with the KWS diagrams, our estimations of disease severity did not agree with those of Kelber (6). The 0–10 scale and the various KWS versions were deemed unsuitable for accurate yield loss studies, because the categories are not precisely defined, especially at low disease intensities.

In these studies, our objective was to determine the relationship between Cercospora leaf spot severity and sugar beet root yield, sugar content, and juice purity. To accomplish this goal, it was necessary to develop a rating scale with sufficient precision for severity-loss assessments. Portions of the information presented here were published elsewhere (13–15).

Table 1. Categories of the Kleinwanzlebener Saatzucht scale for rating disease intensity of Cercospora leaf spot in sugar beet

	Description of disease intensity	
Stage[a]	Leaf	Whole plant
1	Healthy leaf	Whole plant healthy
3	Spots on the outer leaves	First symptoms of disease, spots on outer leaves
5	Spots joining together to form areas of dead leaf	Disease spreads, spots joining together to form areas of dead leaf
7	Greater part of leaf brown and dead with only the lower part of the leaf still alive	Whole plant diseased, large parts of the outer leaves dying
9	Leaf and leaf stalk dead and dried up	Whole plant diseased, outer leaves dead, inner leaves severely damaged, regrowth of new leaves

[a]Stages 2, 4, 6, and 8 are derived by interpolation.

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Table 2. Fungicide application dates for Cercospora leaf spot at Rosemount, MN, 1983, and Murdock, MN, 1982

	Day of year of application					
Treatment	**189**	**201**	**215**	**228**	**231**	**240**
Trial 1, 1983						
1	TPTH[a]	TPTH	TPTH	TPTH	—	TPTH
2	TPTH	TPTH	TPTH	—	—	—
3	—	—	TPTH	TPTH	—	TPTH
4	—	—	—	TPTH	—	TPTH
5	TPTH	TPTH	—	—	—	—
6	—	—	—	—	—	—
Trial 2, 1983						
1	TPTH	TPTH	TPTH	TPTH	—	TPTH
2	TPTH	TPTH	—	—	TPTH	TPTH
3	—	—	TPTH	—	TPTH	TPTH
4	—	—	—	—	—	—
Trial 3, 1982[b]						
1	TPTH	TPTH	TPTH	TPTH	TPTH	TPTH
2	MAN	MAN	MAN	MAN	MAN	MAN
3	TBZ	—	TBZ	—	TBZ	TBZ
4	TBZ	TPTH	TBZ	TPTH	TBZ	TPTH
5	MIX	—	MIX	—	MIX	—
6	—	—	—	—	—	—

[a]TPTH = triphenyltin hydroxide (47WP) applied at 700 g of formulated product per hectare; MAN = maneb (80WP) at 2,240 g of product per hectare, TBZ = thiabendazole (42F) at 880 ml of product per hectare; MIX = triphenyltin hydroxide + thiabendazole tank mix, each at rate given above; — = no fungicide applied.
[b]Days of year of application for trial 3, 1982, are 188, 203, 214, 223, 232, and 233.

Table 3. Spot-percentage scale for assessment of Cercospora leaf spot of sugar beet

Class	**Average number of spots per leaf**	**Disease severity (%)**
1	0	0.00
2	<1[a]	0.01
3	1–5	0.10
4	6–12	0.35
5	13–25	0.75
6	26–50	1.50
7	50–75[b]	2.50
8	. . .	3
9	. . .	6
10	. . .	12
11	. . .	25
12	. . .	50
13	. . .	75
14	. . .	88
15	. . .	94+

[a]This category is used for plants where the disease was seen but the average number of spots per leaf is less than one.
[b]For each plant, a minimum of five leaves were examined for Cercospora leaf spot. At low severities (<3%), each plant was categorized according to spots per leaf as given above; at high disease intensities, disease severity was estimated by comparison of leaves with standard area diagrams.

MATERIALS AND METHODS

Severity-loss relationships for Cercospora leaf spot were determined by analyses of epidemics on sugar beets in two trials (trials 1 and 2) at the University of Minnesota Research Farm in Rosemount, MN, in 1983, and one trial (trial 3) in a commercial field at Murdock, MN, in 1982. Trials 1 and 2 were at sites separated by 0.5 km.

Trial 1 was established 11 May 1983 in a field where sugar beet had not been grown for at least 15 yr. Trial 1 included three cultivars—American Crystal Hybrid (ACH) 14 (moderately resistant to *C. beticola*), Betaseed 1230 (moderately susceptible), and Bush Johnson Monofort (susceptible). Plots consisted of four 10-m rows spaced 56 cm apart. Plants were hand-thinned to a spacing of 25 cm. Two rows of Hilleshog 833 sugar beet (highly susceptible to *C. beticola*) were established as spreader rows between plots. Spreader rows were dusted on 25 June with dried and ground, infected sugar beet leaves collected in the previous season. Infection by *C. beticola* was evident in spreader rows on 10 July, and spreader rows were removed by rototiller on 24 July. Triphenyltin hydroxide (TPTH) (47WP) was used in six different fungicide timing treatments to obtain a range of disease severity (Table 2).

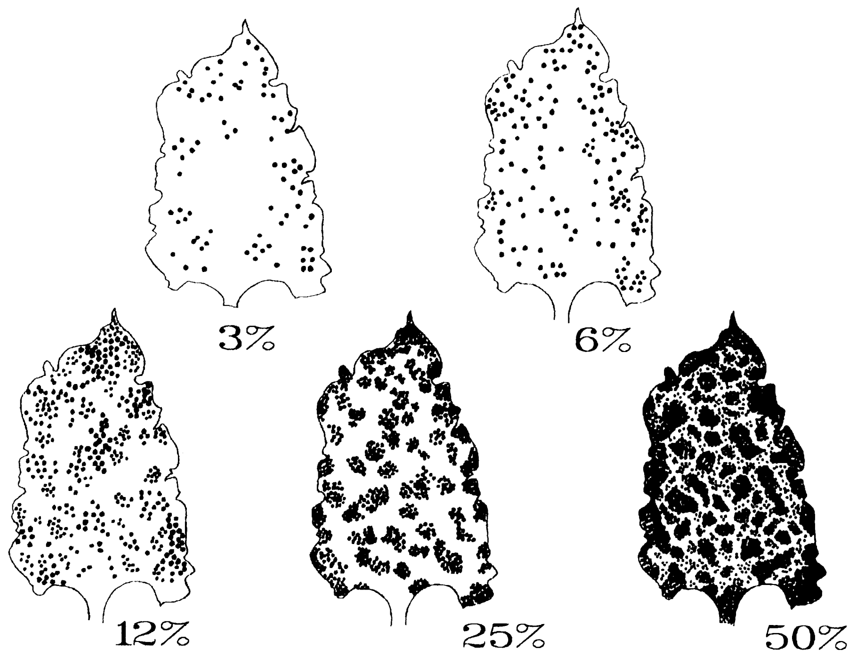

Fig. 1. Standard area diagrams for assessment of disease severity for Cercospora leaf spot of sugar beet.

The same three sugar beet cultivars were used in trial 2, and TPTH was applied in four fungicide timing treatments (Table 2). Trial 2 was planted on 11 May 1983 in a field where sugar beets heavily infected by *C. beticola* had been grown in the previous season. No additional inoculum was provided. Plot size and plant spacing were as described for trial 1, and areas between plots were clean-tilled throughout the season. Symptoms of infection by *C. beticola* were detected in plots on 15 July.

Fungicide sprays at Rosemount (trials 1 and 2) were applied at 700 g of formulated product per hectare. Sprays were applied with a tractor-drawn John Bean sprayer with hollow-cone D2-13 nozzles spaced 25 cm apart with the boom 30 cm above the canopy. Fungicides were applied in 468 L of water per hectare at 1,240 kPa.

Trial 3 was planted 29 April 1982 at Murdock, MN, in a field where sugar beets were grown the previous season. No additional inoculum was used. Trial 3 had 10 sugar beet cultivars and six fungicide treatments. Cultivars used and their susceptibilities to *C. beticola* included Hilleshog 309, very susceptible; Bush Johnson Monofort, ACH 30, Ultra Mono, Betaseed 1230, KW 1132, and ACH 153, susceptible; and GW R2 and

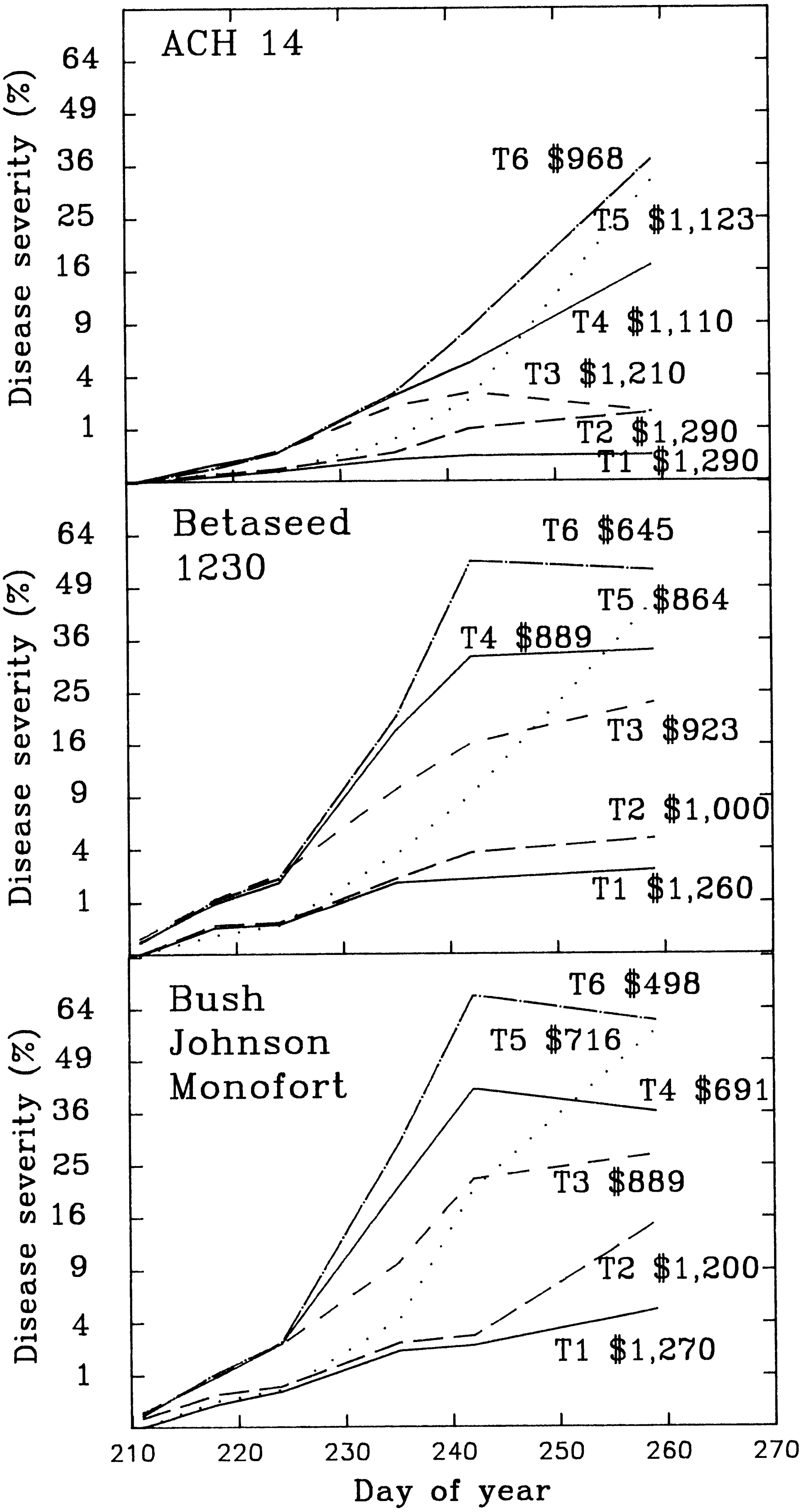

Fig. 2. Disease progress curves and dollar return per hectare associated with Cercospora leaf spot epidemics on three inoculated sugar beet cultivars under six fungicide programs for trial 1 at Rosemount, MN. Treatment and day of year application date for triphenyltin hydroxide (47WP), applied at 700 g of formulated product per hectare, were 189, 201, 215, 228, and 240 for treatment one (T1); 189, 201, and 215 for treatment 2 (T2); 215, 228, and 240 for treatment three (T3); 228 and 240 for treatment four (T4); and 189 and 201 for treatment five (T5). Treatment six (T6) was an untreated control.

ACH 14, moderately resistant. Each plot consisted of six rows, 10.7 m long, with a 25-cm plant spacing. Hilleshog 309 sugar beets were established as spreader rows between blocks and removed by tilling shortly after disease from natural infections became evident on 9 July.

Fungicide treatments for trial 3 were TPTH, maneb, thiabendazole (TBZ), alternating TPTH and TBZ, tank mix (TPTH and TBZ), and untreated controls (Table 2). Fungicides were applied at the following product rates per hectare: TPTH (47WP) at 700 g, maneb (80WP) at 2,240 g, and TBZ (42F) at 880 ml. Fungicides were applied in 560 L of water per hectare at 1,380 kPa with a tractor-mounted boom sprayer. Flat-fan nozzles on the boom were 56 cm apart and 46 cm above the canopy.

Collection of data. A spot-percentage scale was devised at the University of Minnesota for the estimation of Cercospora leaf spot severity of sugar beet plants. In the spot-percentage scale, plants are rated according to the number of spots per leaf for low disease intensities (Table 3), similar to a system developed for peanut (1). The number of spots per leaf was translated into a percent disease severity based on average leaf and lesion sizes. Average leaf size was based on a sample of sugar beet leaves collected from the Betaseed research facility, Shakopee, MN, in September 1981. Twenty fully expanded leaves each were collected from cultivars Bush Johnson Monofort, Betaseed 1230, and ACH 14. The outline of each leaf was traced on paper. The area of each leaf was determined from the weight of the trimmed tracing. The average leaf area for the 60 leaves was 346 cm^2, SE = 15.45. Sugar beet leaves of the three cultivars infected with *C. beticola* were collected at the same field facility. Lesion size was estimated by a single diameter measurement, and area was calculated as πr^2, where r is the radius of the lesion. Average lesion area was 0.134 cm^2, SE = 0.0026, based on a sample of 200 lesions. The corresponding disease severities for classes 3–7 were based on the midpoint of the range of spots per leaf (Table 3). For example, the midpoint of class 4, range of six to 12 spots, is 9. The corresponding disease severity, based on average leaf and lesion area, is 0.35% (Table 3).

Severities of 3% and greater were estimated by reference to standard area diagrams developed in our laboratory (Fig. 1). Cercospora leaf spot severities were assessed on 10 plants selected at random in the center two rows of each plot. Assessments were done every 7–10 days beginning the last week in July. Plots were rated six times at each of the two trials at Rosemount and eight times at Murdock. Areas under the disease progress curves were calculated for all trials.

Beets in the center two rows of each plot were defoliated mechanically, harvested, and weighed on 20 and 30 September (day of year 263 and 273) for the Murdock and Rosemount trials, respectively. Sugar analyses were done at the American Crystal Sugar Company quality lab, East Grand Forks, MN. Percent sugar was determined by polarization. Sodium, potassium, and amino-nitrogen (aN) were determined by standard tare laboratory procedures used by the American Crystal Sugar Company (4).

Analyses of data. Randomized complete block designs were used, with five replicates in trial 1 and four replicates in trials 2 and 3. Percent impurities was estimated as follows with Na, K, and aN expressed as micrograms per milliliter (2): percent impurities = [(Na × 3.5) + (K × 2.5) + (aN × 9.5)]/11,000.

Recoverable sugar (kilograms per hectare) was calculated as the estimated sugar produced minus sugar not extractable due to impurities. For each kilogram of impurities, an estimated 1.5 kg of sugar could not be extracted during processing and remained in the molasses fraction (2). Return (dollars per hectare) was calculated according to 1982 American Crystal grower payment figures for recovered sugar, by-products, estimated storage losses, and processing costs per unit weight of roots. Profit did not take into consideration costs for beet production.

To determine treatment effects, analyses of variance were performed on root yield (kilograms per hectare), recoverable sugar (kilograms per hectare); dollar return per hectare; percent sugar content; percent sugar lost; impurities Na, K, and aN (micrograms per milliliter); and area under the disease progress curve (AUDPC). Linear regression was used to determine the relationship between dollar return per hectare and disease severity, including the AUDPC. Statistical analyses were done with the GLM and REG procedures (SAS Institute Inc., Cary, NC).

RESULTS

Cultivars differed greatly in their resistance to *C. beticola* (Figs. 2–4). Resistance alone was not sufficient to control leaf spot on any cultivar. Maximum leaf spot severities reached approximately 60% in trial 1 and 80% in trials 2 and 3 in plots of the most susceptible cultivars not treated with fungicide. At a severity of 80%, corresponding to a KWS scale value of 9 (Table 1), most outer leaves were brown and the newer inner leaves had few lesions. No plants were observed with a disease severity of 100%.

Fungicide treatments in all trials resulted in a wide range of Cercospora leaf spot severities (Figs. 2–4). Treatments at Murdock with TBZ alone or

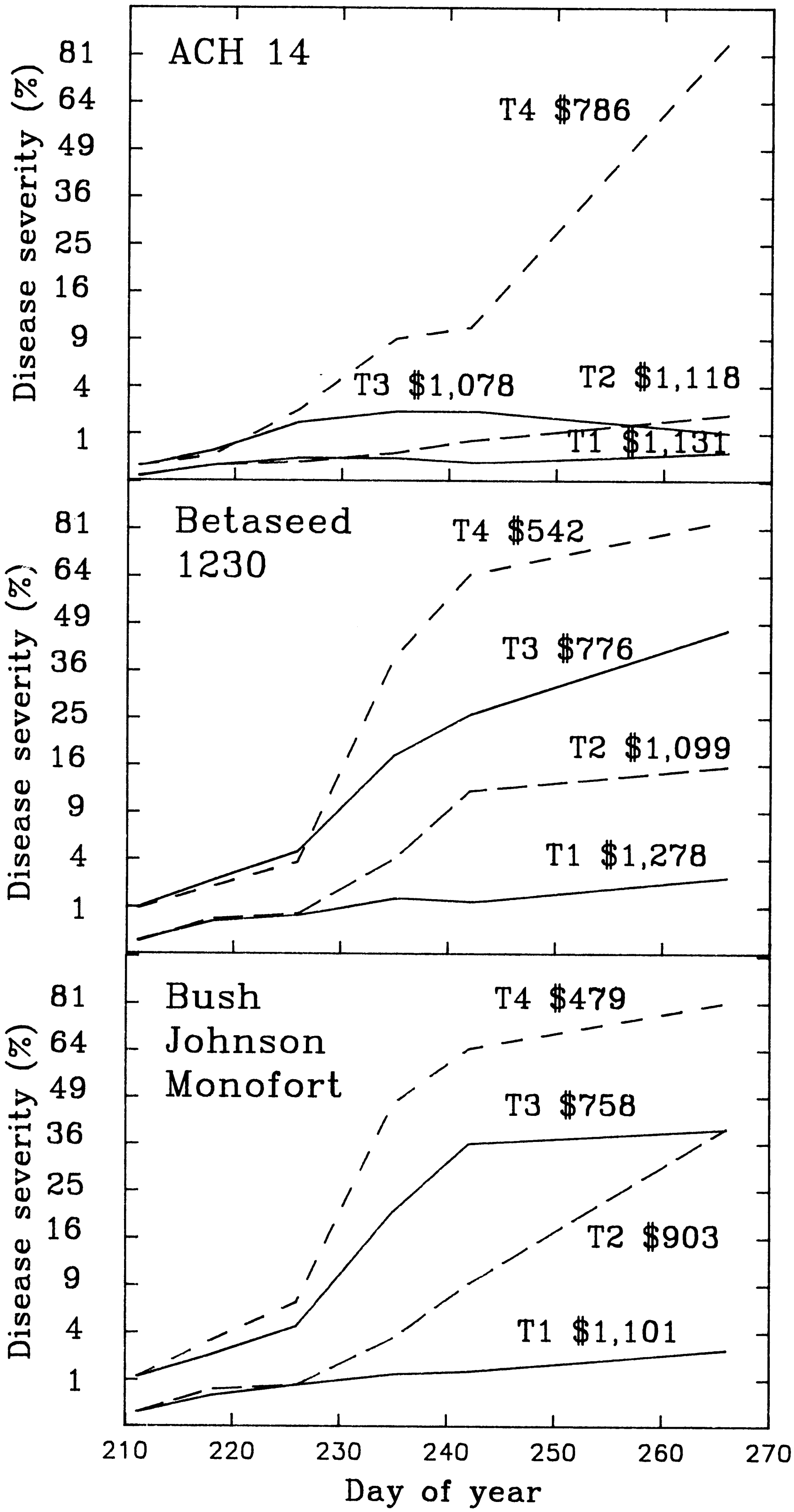

Fig. 3. Disease progress curves and dollar return per hectare associated with Cercospora leaf spot epidemics on three naturally infected sugar beet cultivars under four fungicide programs for trial 2 at Rosemount, MN. Treatment and day of year application dates for triphenyltin hydroxide (47WP), applied at 700 g of formulated product per hectare, were 189, 201, 215, 228, and 240 for treatment one (T1); 189, 201, 231, and 240 for treatment two (T2); and 215, 231, and 240 for treatment three (T3). Treatment four (T4) was an untreated control.

in alternation with TPTH resulted in poor control of leaf spot due to the presence of strains of *C. beticola* resistant to TBZ (10) (Fig. 4). Treatment with TBZ alone resulted in disease severities nearly as high as those for the untreated control.

A significant block effect was evident for most variables in trial 1 (Table 4). The block effect corresponded to a soil and texture gradient evident on the slight incline over the test area; however, no block × treatment interactions were detected on inspection of the data. No significant block effects were detected in trial 2 (Table 5) or trial 3 (*data not shown*).

Simple linear regression analyses were made of the relationships between dollar return and disease severities from the final three assessments in trials 1 and 2 (Table 6). The coefficients of determination (r^2) were relatively lower for trial 1 (Table 6), which had a significant block effect, compared with trial 2, where no block effect was detected (Table 4). The final assessment date, approximately 11 days before harvest, provided the highest r^2 values in four of six cases (Table 6). The power of AUDPC and severity at the last two assessment dates were examined as predictors of dollar return. Neither AUDPC nor the final two assessment dates were consistently better predictors of dollar return than the final assessment date alone (Table 6), as indicated by coefficients of determination adjusted for the number of predictor variables.

Dollar return was expressed as relative dollar return on a scale of 0–100%, so that data for cultivars with different yield potentials could be combined (Fig. 5).

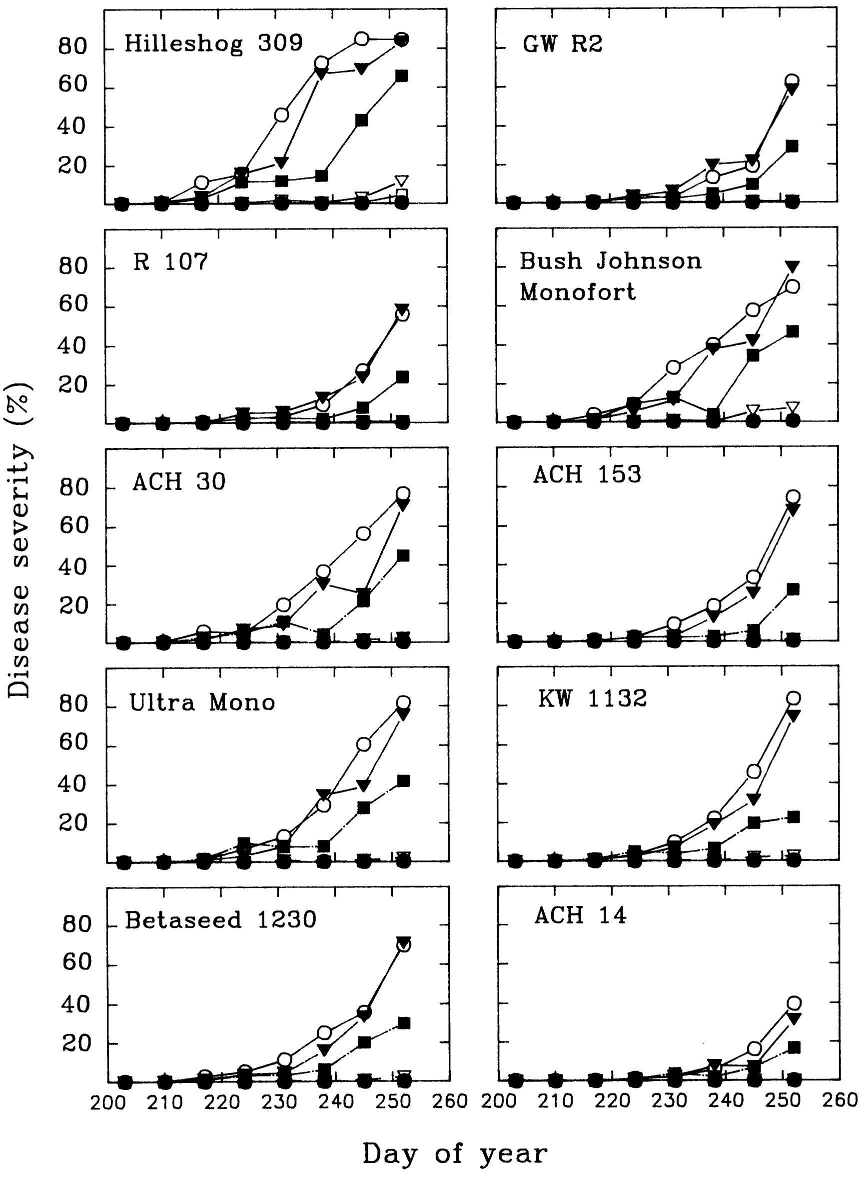

Fig. 4. Disease progress curves associated with 10 naturally infected sugar beet cultivars under six fungicide programs for trial 3 at Murdock, MN: triphenyltin hydroxide (TPTH) protectant (●); maneb protectant (▽); thiabendazole (TBZ) systemic (▼); alternating TPTH and TBZ (■); TPTH + TBZ tank mix (□); and untreated control (○).

The impact of Cercospora leaf spot on relative dollar return differed among the three trials. A disease severity of 50% approximately 11 days before harvest corresponded to relative dollar losses of 50, 27, and 27% for trials 1–3, respectively.

Cercospora leaf spot had a profound effect on the estimated beet payment per hectare for nearly all cultivars in the three trials, depending on the resultant disease severities (Figs. 2 and 3, Table 7). The impact of Cercospora leaf spot on dollar return was not evident on the most resistant cultivar, ACH 14, in trial 3. Cercospora leaf spot significantly suppressed root weight for all cultivars except ACH 14, the most resistant cultivar, in trials 2 and 3. Sugar content was suppressed for some of the most susceptible cultivars, such as Bush Johnson Monofort, Betaseed 1230, ACH 30, and Hilleshog 309 (Tables 4, 5, and 7). A significant increase in Na concentration in connection with Cercospora leaf spot was noted for two of three cultivars in trial 1 and approximately half of the cultivars in trial 3. An increase in aN due to Cercospora leaf spot was noted only for ACH 14 in trials 1 and 2 and for seven of 10 cultivars in trial 3 (Tables 4, 5, and 7).

Under the current payment plan for Minnesota and North Dakota growers, the primary impact of Cercospora leaf spot was a reduction of root yield and sugar concentration. Sugar loss to molasses due to impurities had a minor impact on dollar return compared with losses attributed to reductions in root weight or sugar content.

Several treatments generated epidemics with markedly different midseason severities but similar final severities, e.g., treatments two and three for ACH 14 in trial 1, treatments five and six for Bush Johnson Monofort in trial 1, and treatments two and three for Bush Johnson Monofort in trial 2 (Figs. 2 and 3). Early-season epidemics resulted in an additional loss of estimated revenue.

Of interest is the contrast between treatments four and five for all cultivars in trial 1 (Table 4). Treatment four had a relative high severity early, followed by a flattening of the disease progress curve (Fig. 2). Treatment five had relatively low severities early, followed by late-season epidemics. Root weight was higher for treatment four (early-season epidemic) than it was for treatment five (late-season epidemic) (Table 4). Percent sugar content generally was higher for treatment five (late-season control) than for treatment four (late-season epidemic).

DISCUSSION

Previous investigators have shown decreased root weight and sugar content and increased impurities, especially Na and aN, in association with Cercospora leaf spot epidemics (3,6,9,12,16). We also have shown increased impurity concentrations in sugar beets affected by Cercospora leaf spot and have shown that the primary economic impact was on root yield and sugar content. Further, increased impurities may be a result of reduced root size associated with Cercospora leaf spot, rather than an enhanced production of impurities.

Early-season epidemics resulted in reduced root yields, whereas late-season

Table 4. Yield and quality data for three sugar beet cultivars under six fungicide programs at Rosemount, MN, in 1983—trial 1

Cultivar	Treatment	Root weight (kg/ha)	Sugar (%)	Impurities (μg/ml) Na	K	aN[a]	Recovered sugar (kg/ha)	Sugar lost[b] (%)	Return ($/ha)	AUDPC[c]
ACH 14	1	39,200	15.2	328	2,019	825	4,290	1.9	1,290	8
	2	38,500	15.2	312	1,946	824	4,260	1.9	1,290	31
	3	35,600	15.3	304	2,010	846	3,970	1.9	1,210	72
	4	34,047	15.0	314	2,068	846	3,670	1.9	1,100	223
	5	35,600	15.0	342	1,995	922	3,790	2.0	1,123	309
	6	32,900	14.6	349	1,943	950	3,370	2.1	968	433
Treatment		**[d]	NS	NS	NS	**	*	*	**	**
Block		**	NS	**	***	***	***	**	**	*
Betaseed 1230	1	44,800	14.4	399	2,109	841	4,480	2.0	1,260	67
	2	34,700	14.3	416	2,036	804	3,520	1.9	1,000	116
	3	36,300	13.8	488	2,044	920	3,430	2.1	923	521
	4	35,400	13.8	448	2,124	876	3,320	2.1	889	883
	5	36,500	13.4	482	2,008	877	3,320	2.0	864	544
	6	29,600	13.1	466	1,907	856	2,580	2.0	645	1,327
Treatment		***	***	*	NS	NS	***	NS	***	***
Block		***	NS	***	**	***	***	**	***	*
Bush Johnson Monofort										
	1	45,500	14.4	411	2,153	878	4,530	2.1	1,270	98
	2	44,300	14.2	432	2,136	908	4,340	2.1	1,200	198
	3	39,000	13.4	502	2,124	962	3,480	2.2	889	616
	4	33,600	13.1	452	2,248	986	2,850	2.3	691	1,024
	5	36,500	12.8	468	2,090	971	3,030	2.2	716	779
	6	27,300	12.5	528	1,938	960	2,190	2.1	498	1,620
Treatment		***	***	*	NS	NS	***	NS	***	***
Block		NS	**	***	***	***	*	*	**	*

[a]Amino-nitrogen.
[b]Calculated recovered sugar, sugar lost, and dollar return was based on the 1982 American Crystal Cooperative payment scheme. Dollar return does not include costs for beet production.
[c]Area under the disease progress curve (AUDPC).
[d]F test for significance of treatment and block effects. NS = not significant, * = $P = 0.05$, ** = $P = 0.01$, and *** = $P = 0.001$.

Table 5. Yield and quality data for three sugar beet cultivars under four fungicide programs at Rosemount, MN, in 1983—trial 2

Cultivar	Treatment	Root weight (kg/ha)	Sugar (%)	Impurities (μg/ml) Na	K	aN[a]	Recovered sugar (kg/ha)	Sugar lost[b] (%)	Return ($/ha)	AUDPC[c]
ACH 14	1	32,353	15.6	217	2,547	910	3,641	2.1	1,131	9
	2	30,786	15.9	232	2,327	917	3,545	2.1	1,118	28
	3	32,465	15.4	252	2,417	927	3,543	2.1	1,078	72
	4	26,644	15.1	243	2,527	1,230	2,714	2.6	786	915
Treatment		NS[d]	NS	NS	NS	*	*	NS	*	**
Block		NS	NS	NS	NS	NS	NS	NS	NS	NS
Betaseed 1230	1	41,253	14.8	292	2,500	850	4,321	3.1	1,278	54
	2	36,551	14.8	290	2,490	995	3,763	2.3	1,099	314
	3	31,943	13.8	296	2,757	990	2,928	2.4	776	949
	4	23,677	13.6	305	2,617	1,005	2,105	2.3	542	1,824
Treatment		*	NS	NS	NS	NS	***	NS	**	***
Block		*	NS	NS	NS	NS	NS	NS	NS	NS
Bush Johnson Monofort										
	1	36,887	14.9	277	2,717	987	3,782	2.3	1,101	57
	2	35,152	14.1	312	2,675	1,002	3,318	2.3	903	441
	3	30,898	14.0	327	2,790	1,125	2,846	2.6	758	802
	4	22,334	13.4	382	2,537	1,110	1,923	2.5	479	1,906
Treatment		**	**	NS	NS	NS	***	NS	***	***
Block		NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Amino-nitrogen.
[b]Calculated recovered sugar, sugar lost, and dollar return was based on the 1982 American Crystal Cooperative payment scheme. Dollar return does not include costs for beet production.
[c]Area under the disease progress curve (AUDPC).
[d]F test for significance of treatment and block effects. NS = not significant, * = $P = 0.05$, ** = $P = 0.01$, and *** = $P = 0.001$.

Table 6. Coefficients of determination (r^2) from linear regression of return (dollars per hectare) on Cercospora leaf spot severity measured on three dates and area under disease progress curve (AUDPC) in two field trials

	Day of year									
	Trial 1					Trial 2				
Cultivar	260	242	235	260, 242[a]	AUDPC	266	242	235	266, 242	AUDPC
ACH 14	0.377	0.117	0.286	0.352	0.279	0.668	0.324	0.107	0.599	0.551
Betaseed 1230	0.515	0.461	0.412	0.834	0.687	0.631	0.731	0.648	0.677	0.710
Bush Johnson Monofort	0.633	0.519	0.410	0.790	0.668	0.495	0.788	0.548	0.753	0.749

[a]Coefficients of determination were calculated for the least squares estimates for a linear combination of severities from the last two assessment dates.

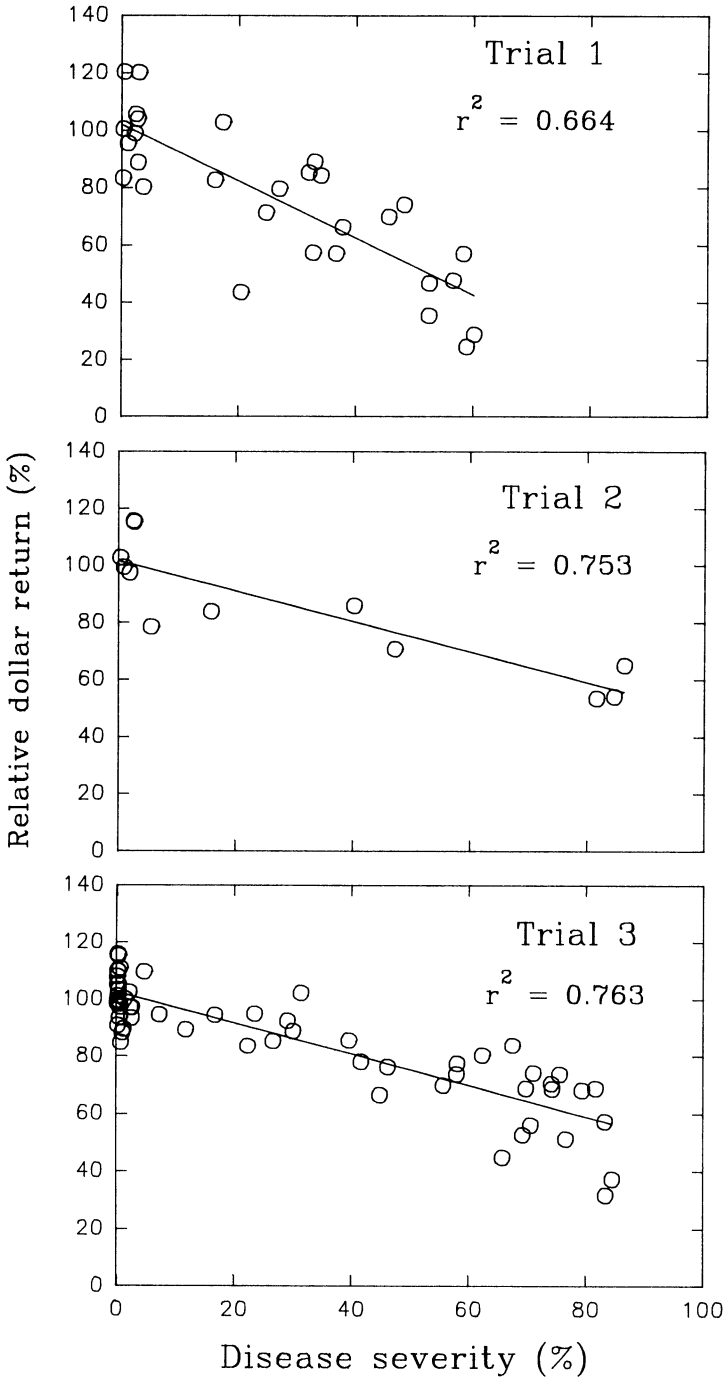

Fig. 5. Relationship between relative dollar return for sugar beets and Cercospora leaf spot severity as measured on 19 September 1983 (day of year 262) in trials 1 and 2 at Rosemount, MN, and on 9 September 1982 (day of year 252) in trial 3 at Murdock, MN. Each point represents the data for one treatment and cultivar combination. Relative dollar return was calculated as return per hectare for an individual plot multiplied by 100 and divided by the estimated average return for disease-free beets of the same cultivar. Regression lines were forced through the 100% y-intercept. Regression equations were: trial 1, $Y = 100 - 0.992X$; trial 2, $Y = 100 - 0.534X$; and trial 3, $Y = 100 - 0.548X$.

epidemics generally resulted in lower sugar concentrations. This corresponds well with observations that sugar beet root weight increases over the last half of the season, and sugar concentration increases markedly during cooler temperatures shortly before harvest (20).

Sugar beet plants display remarkable recuperative capacities once the plants have developed past the delicate seedling stage. Jones et al (5) showed no appreciable effect on sugar beet root weight and sugar content when 25% of green foliage was removed by mechanical defoliation at the eight-leaf stage. Additionally, defoliated plants were allowed to regrow leaves and, thus, restore the photosynthetic capacity. Unlike defoliated leaves, affected leaves on diseased plants block sunlight to remaining healthy leaves. We showed that estimated payments per hectare were 1.3- to 2.5-fold greater for the full fungicide treatments than for the sugar beets receiving no fungicides. Further, appreciable losses in estimated dollar return were detected at end-of-season Cercospora leaf spot severities less than 10%.

We estimated dollar loss associated with Cercospora leaf spot as measured with the spot-percentage scale. A 1% increase in disease severity corresponded with 1.0, 0.5, and 0.5% decrease in profit for trials 1–3, respectively. In contrast, Kelber (6) estimated only a 0.3% decrease in profit associated with each 1% increase in Cercospora leaf spot disease severity as measured at the end of the season. Kelber (6,7) noted that the severity-loss relationship may differ from year to year.

In our studies, the impact of Cercospora leaf spot generally was obvious with end of August disease severities greater than 9% (trials 1 and 2). Reduced payment per hectare sometimes was evident for epidemics exceeding approximately 3% severity by the end of August. The precision of these experiments was not sufficient to determine whether or not damage occurs at disease severities below 3% on the spot-percentage scale. Based on our results, we recommend that growers in Minnesota and North Dakota maintain Cercospora leaf spot severities below 3% through the end of August. In North Dakota and Minnesota from 1982 to 1985, Cercospora leaf spot severities have exceeded 3% in many commercial fields at the end of August (W. W. Shane, *unpublished*). Cercospora leaf spot epidemics develop rapidly under favorable environmental conditions. Up to 10-fold increases in disease severity in commercial fields over the span of 1 wk were detected in North Dakota and Minnesota between 1982 and 1985 (W. W. Shane, *unpublished*).

Table 7. Linear regression of root yield (kg/ha), sugar content (%), sodium and amino-nitrogen (μg/ml), and return (dollars/ha) on Cercospora leaf spot severity measured on 9 September at Murdock, MN—trial 3[a]

Cultivar and variable measured	b_0	b_1	Adjusted r^2
Hilleshog 309			
Root yield	64,400	−243***[b]	0.631
Sugar	14.1	−0.027***	0.569
Na	516	2.81*	0.206
Amino-nitrogen	491	2.95***	0.433
Return	2,035	−15.7***	0.712
Great Western Mono-Hy R2			
Root yield	60,500	−185***	0.384
Sugar	13.6	NS	0.032
Na	352	NS	0.040
Amino-nitrogen	578	NS	0.089
Return	1,730	−6.8**	0.270
Great Western Mono-Hy R107			
Root yield	58,300	−207***	0.396
Sugar	14.1	NS	−0.044
Na	420	NS	−0.037
Amino-nitrogen	485	2.90**	0.241
Return	1,872	−7.5*	0.202
Bush Johnson Monofort			
Root yield	60,800	−173***	0.411
Sugar	14.5	NS	0.099
Na	470	NS	0.048
Amino-nitrogen	478	2.45*	0.169
Return	2,041	−10.0***	0.398
ACH 30			
Root yield	54,300	−223***	0.569
Sugar	15.0	−0.014*	0.183
Na	432	2.25**	0.261
Amino-nitrogen	429	2.60***	0.397
Return	2,023	−12.3***	0.604
ACH 153			
Root yield	65,600	−187***	0.335
Sugar	14.2	NS	0.001
Na	492	NS	0.030
Amino-nitrogen	493	NS	0.157
Return	1,931	−6.4*	0.194
Maribo Ultramono			
Root yield	60,400	−180***	0.495
Sugar	14.8	NS	0.013
Na	455	1.36*	0.179
Amino-nitrogen	513	2.01*	0.215
Return	1,975	−7.3**	0.297
KW 1132			
Root yield	64,200	−187***	0.487
Sugar	15.3	−0.0116*	0.166
Na	387	1.95*	0.214
Amino-nitrogen	444	2.36**	0.348
Return	2,307	−10.9***	0.579
Betaseed 1230			
Root yield	67,100	−181***	0.556
Sugar	14.7	NS	0.027
Na	391	NS	0.075
Amino-nitrogen	455	2.25*	0.153
Return	2,186	−8.1**	0.288
ACH 14			
Root yield	55,500	NS	0.004
Sugar	15.2	NS	0.049
Na	366	NS	0.042
Amino-nitrogen	403	NS	0.004
Return	2,218	NS	0.012

[a]Linear regressions of sugar beet potassium (μg/ml) concentration on Cercospora leaf spot severity were not significant for all 10 cultivars.
[b]F test for significance of slope coefficient b_1. NS = not significant; * = $P = 0.05$; ** = $P = 0.01$; and *** = $P = 0.001$.

We have found the spot-percentage scale to be useful for monitoring commercial fields, because it allows measurement of disease at intensities below those depicted by most other rating systems (6,11,12). We could find no precise definitions of the USDA 0–10 scale in the literature. Furthermore, in our preliminary studies, we found that the KWS scale is poorly defined. For example, a KWS rating of 1 corresponded with the range of severities from 0.05 to 0.50% (13). Most spray decisions for Cercospora control are made at average field severities well below 0.50%, where the KWS scale is unsuitable. On the other hand, the spot-percentage scale is less appropriate than the KWS scale for evaluation of inoculated trials of sugar beet breeding lines where the need is for very rapid assessments of plants with relatively high severities.

The spot-percentage categories are sufficiently broad to allow rapid assessment by growers and consultants, yet narrow enough for accuracy required for disease management decisions. A hand calculator aids in the calculation of plot or field averages. A programmable hand calculator or microcomputer is helpful for the calculation of averages for large studies. The spot-percentage scale is based on the assumptions that sizes of lesions and sugar beet leaves are adequately represented by average values. Because environment and the genetics of host and pathogen will influence both lesion and leaf sizes, these assumptions may not be appropriate for all situations.

It was our goal in these studies to develop a useful rating scale and define the relationship between severity and sugar beet performance. Costs of fungicide applications were not included in our estimation of dollar return because the need for fungicide applications is highly dependent on the geographical location, site, cultivar, and year (W. W. Shane, *unpublished*). Refinement of tactics for management of Cercospora leaf spot must take into consideration not only the severity-loss relationship and costs of application but also the factors affecting pathogen activity in the site under consideration.

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