Powdery Mildew of Sugar Beet: Disease and Crop Loss Assessment

F. J. Hills, L. Chiarappa, and S. Geng

Extension agronomist, University of California, Davis; senior plant pathologist, FAO, Rome, Italy; associate professor of Agronomy and biostatistician, University of California, Davis, respectively.

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ABSTRACT

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Various disease control treatments were used to produce five sequences of disease development in each of three sugar beet field trials. Disease appraisal was accomplished biweekly by evaluating 25 mature leaves per plot as to the extent of leaf area diseased on a scale of 0 to 5 corresponding to 0, 10, 35, 65, 90, and 100% of the leaf area diseased. A season-long disease index was calculated for each disease control treatment as a weighted average of biweekly appraisals from disease onset to 1 October. The weighing factor was the number of weeks from evaluation date to 1 October. Season-long indexes correlated well with crop loss. The estimation of crop loss was improved by combining data over all years and including the yield of healthy plants in addition to the season-long disease index.

Additional key words: Erysiphe betae, E. polygoni.

Sugar beets (*Beta vulgaris* L.) have been severely affected by powdery mildew in California since 1974 (5). This paper discusses a method of disease appraisal that has been used successfully to evaluate various control measures (2). A procedure for computing a season-long disease index is presented along with a method for estimating crop loss based on this index and the yield of nearly disease-free plants.

MATERIALS AND METHODS

Field experiments were done in 1976, 1977, and 1978 at Davis, California. The sugar beet cultivar US H10 was used in all trials and was planted in late April or early May and harvested in October. Experimental designs were randomized complete blocks with four to eight replications. Individual plots consisted of four rows 76-cm apart and 15.2 m long. In each year, nontreated plots plus four different treatments for the suppression of mildew produced five different disease epidemics (Table 1). Sulfur sprays were applied with a CO_2-pressurized back-pack sprayer. Granular triadimefon was applied to the crowns of plants as described by Frate et al (2). Crop yield was determined by harvesting the center two rows of each plot and two random samples of at least 10 beet roots were taken from each plot to determine tare and sucrose concentration. Percent crop loss was calculated as the difference in gross sugar yield between the treatment giving maximum season-long control and the yield resulting from a treatment giving a lesser degree of disease control expressed as a percentage of the yield from protected plants.

Disease assay. Disease was appraised biweekly from its onset, usually around the first of July when foliage was closing the rows, until about 1 October. By 1 October the development of disease on expanding leaves had decreased greatly and the rate of root growth was no longer limited or only slightly limited by disease (F. J. Hills, *unpublished*).

Appraisal was accomplished by examining a recently matured leaf on each of at least 25 plants and rating disease intensity (R_i) as the extent of leaf area covered by fungus mycelium on a scale of 0 to 5 (Fig. 1). Both sides of a leaf were examined and an average rating was given. The disease categories are not equal percentage increments but rather unequal intervals based on one-fifth of the angular transformation range from 0° to 90°. This rating system results in large intervals in the middle of the disease classes and small intervals on both ends, has the advantage of more comfortable visual discrimination, and in our experience results in less error in estimating percent disease than when the disease percentages are used directly (4). The raw data for evaluation are the disease ratings (R_i), not percentages. A disease rating for a plot

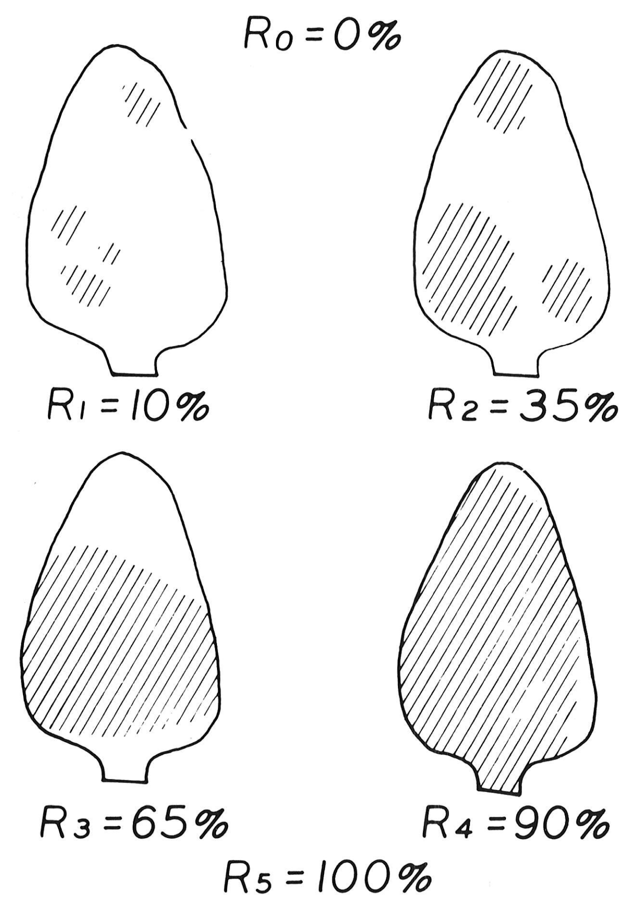

Fig. 1. Leaf diagrams to aid in estimating disease intensity for powdery mildew of sugar beet. Disease intensities (R-0 to R-5) correspond to the indicated percent of the leaf area covered by fungus mycelium. Mycelial coverage > 0 but ⩽ 10% was rated 1; > 10 but ⩽ 35% was rated 2; etc.

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was the mean rating of 25 leaves; ie, $\overline{R} = \Sigma R_i/n$, in which n is the number of leaves rated. An estimate of the effect of a treatment on percent mature leaf area diseased (% MLAD) is obtained by averaging $\overline{R}$ for all replicates ($\overline{\overline{R}}$) then computing: % MLAD = $100[\text{sine}(18° \overline{\overline{R}})]^2$, in which 18° is one-fifth of 90°, the range of the angular transformation.

RESULTS AND DISCUSSION

Table 1 summarized disease appraisal, sucrose yield, and crop loss resulting from the disease control schedules of the three field experiments.

Precision of disease assessment. At peak disease intensity, variances for disease ratings generally were homogeneous, coefficients of variation ranged from 8 to 17%, and it was possible to detect significant treatment differences in mean ratings equivalent to from 7 to 27% MLAD. Disease ratings were reproduced well by different evaluators. Two of us independently evaluated 30 plots in which ratings ranged from 0 to 5. Evaluator means after transformation were 57 and 55% MLAD and there was no interaction of evaluator × disease rating. Thus, the assessment procedure appears to be precise enough and reproducible enough for the evaluation of plant materials for resistance and to compare the effectiveness treatments for disease control.

Crop loss assessment. Regressions of crop loss on % MLAD gave the highest coefficient of determination (r^2) when disease intensity was highest or nearly so. Disease intensity was usually highest in late August or early September. Regressions for 30 August 1976, 22 August 1977, and 11 September 1978 gave r^2 values of 0.968, 0.926, and 0.914, respectively. While these regressions account for a great deal of the variability in crop loss and are similar in slope, they differ considerably in intercept and do not take into consideration the rapidity of disease increase in a given year.

An overall disease rating for a season that gives consideration to the earliness of disease intensity is a weighted average of several appraisal dates: $\overline{\%}\text{ MLAD} = \{\Sigma[W_i(\%\text{ MLAD})_i]\}/\Sigma W_i$, in which W_i are weeks to 1 October for each of several appraisal dates. For example, for the control treatment for 1976 (Table 1): $\overline{\%}$ MLAD = $[10(5)+8(18)+6(75)+4(89)+2(77)]/30 = 38$. In Fig. 2, crop loss is regressed on $\overline{\%}$ MLAD for each experiment. Coefficients of determination are high and the slopes of the regressions are quite similar. The regressions differ principally in intercept values, none

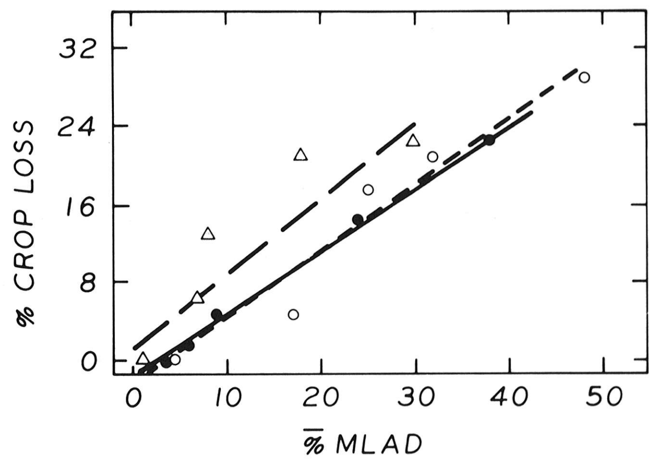

Fig. 2. Regressions of sugar yield on season-long powdery mildew disease indexes ($\overline{\%}$ MLAD of Table 1). 1976: •, $\hat{y} = -2.00 + 0.655X$, $r^2 = 0.987$; 1977: o, $\hat{y} = -3.46 + 0.709X$, $r^2 = 0.930$; 1978: △, $\hat{y} = 2.70 + 0.742X$, $r^2 = 0.829$; in which $\hat{y}$ is a predicted crop loss and X is $\overline{\%}$ MLAD.

TABLE 1. Treatment schedules, disease ratings, and mean sucrose yield of sugar beets naturally infected by powdery mildew in three field trials at Davis, California

Treatment	Rate per application (kg/ha)[a]	Dates applied	Disease rating: Mature leaf area diseased[b] (%)					Disease rating: $\overline{\%}$ MLAD[c]	Gross sucrose (t/ha)	Crop loss (%)
			7/19	8/3	8/17	8/30	9/13			
1976:										
None	...	...	5	18	75	89	77	38	10.2	22
Wettable S	11	7/2	2	3	34	80	70	24	11.2	15
Dusting S	45	7/2	0.5	0	2	37	56	9	12.6	4
Wettable S	11	7/2,7/30	2	1	6	17	20	6	13.0	1
Wettable S	11	7/2,7/30,8/27	2	1	3	14	8	4	13.1	0
LSD, 5%									0.7	
CV[d], %			150	71	37	17	19		4	
1977:			7/11	7/25	8/8	8/22	9/5			
None	...	...	2	54	75	89	60	48	7.3	29
Wettable S	11	6/27	0	13	50	83	67	32	8.2	20
Wettable S	45	6/27	0	4	26	78	72	25	8.4	18
Wettable S	11	6/27,7/25	0	13	20	38	37	17	9.9	4
Wettable S	11	6/27,7/25,8/22	0	4	4	11	6	4	10.3	0
LSD, 5%									1.0	
CV[d], %			110	32	17	16	28		9	
1978:			7/31	8/14	8/28	9/11	9/25			
None	...	...	0.4	13	55	92	98	30	9.0	21
Wettable S	11	7/19	0	0.4	19	85	98	18	9.2	19
Wettable S	11	7/19,8/16	0	0.4	4	31	85	8	10.0	12
Wettable S	11	7/19,8/16,9/11	0	0.4	4	31	64	7	10.8	5
Triadimefon[e]	1.12	7/11	0	0	0	0.7	15	1	11.4	0
LSD, 5%									0.5	
CV[d], %			109	78	30	8	11		4	

[a] All values are active ingredient.
[b] % MLAD = $100[\text{sine}(18\overline{\overline{R}})]^2$, where $\overline{\overline{R}}$ is a mean disease rating per treatment computed from the average rating ($\overline{R}$) of 25 leaves per plot where each leaf was rated (R_i) on the disease intensity scale of Fig. 1.
[c] $\overline{\%}$ MLAD = $\Sigma[W_i(\%\text{ MLAD})_i]\ /\Sigma W_i$, in which W_i are weeks from the first sign of disease to 1 October for each determination of % MLAD.
[d] Coefficient of variation: For a disease rating, CV is based on the analysis of the plot ratings ($\overline{R}$) before transformation to percentages.
[e] 1-(4-chlorophenoxy)-3,3-dimethyl-1-(1 *H*-1,2,4-triaxol-lyl)-2-butanone (2). This material is not registered for use on sugar beets at this time.

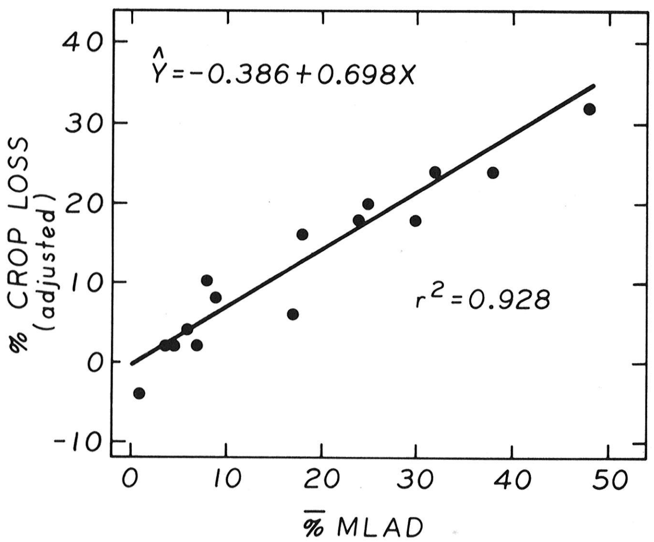

Fig. 3. Adjusted sugar yield losses due to powdery mildew regressed on season-long disease indexes ($\overline{\%}$ MLAD = X of the regression equation). Observed yield losses were adjusted by the year to year variation in the sucrose yield of healthy plants: adjusted % crop loss = Observed % crop loss $-(-454 + 77.970X - 3.318X^2)$, in which X is the sugar yield of the nearly healthy plants for a given year (Table 1).

approaching as close to zero as might be desired. A combined simple regression for the 3 yr gives percent crop loss; % crop loss = $0.238 + 0.636$ ($\overline{\%}$ MLAD), with $r^2 = 0.836$. This regression improves the approach of the intercept to zero at the expense of accounting for less of the variability in crop loss. The discrepancy among intercepts for individual years suggests that % crop loss is affected by environmental components in addition to powdery mildew. A logical index that measures environmental effects not accounted for by powdery mildew is the potential productivity of healthy plants and suggests the following:

% crop loss = a + b ($\overline{\%}$ MLAD) + f(X), in which X is the estimated mean sugar yield (t/ha) of healthy plants for a given year and f(X) is an unknown function of the yield of healthy plants. We have selected the Taylor expansion (1) to approximate f(X) which, in our case, is represented by a quadratic polynomial. Thus, a multiple regression of % crop loss on $\overline{\%}$ MLAD and the estimated yield of healthy plants (X, the yield of plants with minimal disease in Table 1) gives % crop loss = $-454 + 0.698$ ($\overline{\%}$ MLAD) $+ 77.970X - 3.318X^2$, with $R^2 = 0.928$.

To illustrate the improvement in accounting for variability in crop loss by adjusting for year effect, the following steps are taken to construct Fig. 3 from % crop loss and $\overline{\%}$ MLAD of Table 1.

First, compute adjusted % crop loss = observed % crop loss $-(-454 + 77.970X - 3.318X^2)$. Second, regress the adjusted % crop loss on $\overline{\%}$ MLAD to obtain the following, $\hat{y} = -0.386 + 0.698$ ($\overline{\%}$ MLAD), where $\hat{y}$ is the estimated crop loss after adjustment for year effect.

Note that the regression (Fig. 3) now nearly goes through zero and the data points show considerably less variability than in Fig. 2 ($r^2 = 0.928$ versus $r^2 = 0.836$ for the combined regression of the data points of Fig. 2).

In summary, these experiments indicate the following step-wise procedure for estimating percent crop loss.

1. Estimate % MLAD for several appraisal dates.
2. Compute $\overline{\%}$ MLAD = $\{\Sigma[W_i(\%\ \text{MLAD})_i]\} / \Sigma W_i$, where W_i are weeks from evaluation to 1 October.
3. Estimate the yield of healthy plants, X.
4. Estimate % crop loss from the multiple regression proposed above.

Epidemiology and disease management. In California, the first sign of mycelium of powdery mildew on sugar beet leaves usually is not seen until 8–10 wk after emergence—about the time the canopy nearly closes the area between crop rows (5). Subsequently, disease increases rapidly and a delay of 2 wk in implementing control measures may result in serious crop loss (3,6). Under these conditions, the concept of a disease threshold has little practical meaning and control must start at first sign of the disease. In fact, initiating control about 2 wk before first sign allows ground rather than air application of a fungicide, better coverage of foliage, and disease control comparable to that achieved by a first-sign application (F. J. Hills, *unpublished*). Also, a lay-by crown application of triadimefon granules offers the possibility of season-long control from a single application (2, and Table 1). Triadimefon is not registered at this time for use on sugar beets. In other areas, however, where disease does not occur until later in the cropping season, control may not be needed until a certain level of disease has been attained. Our system of disease evaluation may be useful in these situations to quantify meaningful disease thresholds. In California, it appears possible to define a late season disease threshold that the crop can tolerate without serious loss. The definition of such a threshold would be useful in reducing the cost of crop production and in avoiding the excessive use of fungicides. One of our current objectives is to define such a disease threshold below which additional treatment is not needed. At present, the data for 1976 in Table 1 suggest that 20% MLAD might be tolerated at mid-September for an October harvest.

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