Predicting Yield Losses in Corn from Southern Corn Leaf Blight

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ABSTRACT

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The effect of southern corn leaf blight caused by *Helminthosporium maydis* race T on corn in Texas male-sterile cytoplasm was investigated in the field in 1975 and 1976. Losses in yield of grain due to infection initiated late in the season were 9.7 to 11.7%. There was no significant difference ($P = 0.05$) between yield in the delayed-inoculation treatment and controls in 1975 but there was a significant difference in 1976. Losses observed in treatments inoculated prior to anthesis were about 30%. Regression analysis was used to determine the relationship of percent yield loss and disease severities recorded at different stages in the growth of the crop. The best regression equation was derived from disease severities assessed at the dough stage in each year. Regression coefficients were 0.69 in 1975 and 0.70 in 1976 (R^2 = 86.3 and 87.0%, respectively). Values for y-intercepts for these equations were not significantly different from zero (P = 0.05). Various transformations and multiple regression techniques were attempted but they did not enhance precision in the analysis. A generalized equation to predict yield loss was presented; $\hat{y} = 0.69x_d$; where $\hat{y}$ is the percent yield loss and x_d is the percent diseased tissue at the dough stage. A method to estimate losses from disease assessments made prior to the dough stage using projected disease severities is presented.

Additional key words: *Zea mays, Helminthosporium maydis, Cochliobolus heterostrophus.*

The 1970 epidemic of southern corn leaf blight (SCLB) caused by race T of *Helminthosporium maydis* Nisikado and Miyake (*Cochliobolus heterostrophus* Drechs.) demonstrated that this disease has the potential to inflict heavy losses on corn (*Zea mays* L.) cultivars with Texas male-sterile cytoplasm (T-cms) (6, 13).

Previous research has been undertaken to determine the influence of cultivars, planting dates, and fungicide application on yield loss due to SCLB (4, 8, 9, 11, 12). Ayers et al. (1) determined a simple linear relationship between disease and yield using disease severities assessed on day 75 of the epidemic as an independent variable.

The objectives of this research were to determine the effect of time of disease onset on yield and to determine the growth stage of the crop at which yield-loss estimates could best be made. Furthermore, for yield-loss research to be applicable it is necessary to predict losses with adequate time to undertake control measures to prevent such losses. Therefore, steps were taken to adapt yield-loss information into the concept of disease management.

MATERIALS AND METHODS

Planting.—Field plots were located at the Southeastern Field Experiment Station near Landisville, Pennsylvania. Plots were planted on 20 May 1975 and 11 May 1976. The plots were arranged in a randomized complete-block design. Experimental units consisted of Asgrow ATC-75 T-cms hybrid corn 10 rows wide (0.91 m spacing) and 15.24 m long replicated three times. Each plot was surrounded by at least 15 m of the same hybrid with normal cytoplasm. Each 10-row plot was divided into two subplots of two rows each which were adjusted to 41,183 plants per hectare in 1975 and 46,946 plants per hectare in 1976. Disease assessment and yield data were determined on a subplot basis. A different field was used in 1976 to avoid overwintering inoculum.

Inoculation.—Seven- to 10-day-old cultures of an isolate of *H. maydis* race T grown on potato-dextrose agar were ground in a Waring Blendor with distilled water. This isolate was collected in 1970 and maintained on dried leaf material. Inoculum of the proper concentration was mixed with 1 ml of Tween-20 surfactant and applied to subplots with a pressurized sprayer. Treatments consisted of inoculating plots on 7 July 1975 with three levels of inoculum in an attempt to generate epidemics differing in intensity at various times during the growth of the crop. Inoculum concentrations were 28×10^6, 16×10^6, and 8×10^6 conidia per subplot for high, medium, and low levels of inoculum, respectively, in 1975. A fourth treatment was inoculated with 28×10^6 conidia per subplot on 4 August 1975 and again 1 wk

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later. The control treatment consisted of noninoculated plot in which a weekly application of fungicide [a coordination product of zinc ion and manganous ethylenebis (dithiocarbamate), Manzate 200, 80 WP] was applied at the rate of 1.68 kg of active ingredient per hectare. This fungicide has no influence on yield other than to control disease (J. E. Ayers and L. V. Gregory, *unpublished*).

Inoculum levels used in 1975 resulted in high levels of disease early in the season; therefore, inoculum concentrations in 1976 were reduced to 20×10^6, 1.64×10^6, and 6.8×10^5 conidia per subplot for high, medium, and low levels of inoculum, respectively. These treatments were inoculated on 5 July. The fourth treatment was inoculated with 20×10^6 conidia per subplot on 4 and 11 August. A noninoculated control plot was sprayed with the zinc ion-maneb complex fungicide as in 1975.

Assessment of disease.—Eight plants within each subplot were used for disease assessment. The percent diseased tissue on each leaf of each plant was recorded at weekly intervals for 8 wk beginning 21 July in both years. The data were converted to percent diseased leaf area per plant by measuring the total leaf area of 15 plants after anthesis and determining the average area for each leaf. The values were averaged to determine the percent disease for each subplot.

Harvest.—Subplots were harvested by hand and shelled mechanically on 20 October 1975 and 19 October 1976. Yield was calculated as metric tons of shelled corn per hectare at 15.5% moisture. Yield loss in each year was determined by using the average yield observed in the control plots for that year, 7.78 metric tonnes per hectare in 1975 and 7.87 metric tonnes per hectare in 1976.

The influence of time of disease onset on yield was determined by analysis of variance and Duncan's modified (Bayesian) least significant difference test (3, 15). The influence of disease on yield at various growth stages of the crop was analyzed by regression.

RESULTS

Epidemics resulting from different levels of inoculum did not differ appreciably in 1975 (Table 1). Epidemics generated in 1976 resulted in a broader range of disease severities at each period of assessment (Table 2). Disease in the delayed-inoculation treatment progressed at a more rapid rate in both years than disease in the previous treatments owing to the presence of senescent tissue and more favorable environmental conditions late in the season.

There were no significant differences among yields associated with high-, medium-, and low-inoculum treatments in 1975 (Table 3). Yield of the delayed-inoculation treatment was significantly higher ($P = 0.05$) than yields observed in these treatments. Differences in yields between the delayed-inoculation treatment and the fungicide-sprayed control were not significant.

In 1976, yields of the medium- and low-inoculum treatments were not significantly different whereas the high-inoculum treatment yielded significantly less ($P = 0.05$) than all treatments (Table 3). A significant difference ($P = 0.05$) was observed between the delayed-inoculation treatment and the fungicide-sprayed controls.

Differences of comparisons made between years with particular reference to the delayed-inoculation treatment may be attributable to two factors. First, less variation was observed in the experiment in 1976 (coefficient of variation = 11.5% in 1975 and 9.1% in 1976). Second, disease was present earlier in the growth of the crop in 1976 with 7.9% disease at the late milk stage and 20.0% disease at the dough stage in the delayed-inoculation treatment.

The influence of disease on yield loss was determined by regression analysis with disease severities used as independent variables (Tables 4, 5). All regression coefficients were significant ($P = 0.01$) in both years. The relationship of severity of disease and yield loss was best

TABLE 1. The severity[a] of southern corn leaf blight on T-cms corn at different times and approximate growth stages of the crop resulting from inoculation with three concentrations of *Helminthosporium maydis* race T conidia and a delayed inoculation in 1975

	Inoculum concentrations[a]:					
Date (1975)	High (%)	Medium (%)	Low (%)	High (delayed) (%)	Control[b] (%)	Growth stage
7/21	7.1[c]	6.3	4.0	0	0	
7/28	14.5	13.3	11.7	0	0	Tasselling
8/04	22.6	21.7	17.6	I[d]	0	
8/11	34.3	34.0	29.6	I	0	Blister
8/18	46.0	48.3	41.5	14.4	Trace	Dough
8/25	60.0	61.8	55.3	30.4	Trace	Dent
9/02	75.2	81.5	76.3	53.4	31.4	
9/11	100	100	100	91.6	51.5	

[a]Inocula: high = 28×10^6 conidia/subplot; medium = 16×10^6 conidia/subplot; low = 8×10^6 conidia/subplot (all applied 7 July); and high (delayed) = 28×10^6 conidia/subplot applied 4 and 11 August.

[b]Sprayed with 1.68 kg/hectare of zinc ion-maneb complex (Manzate 200, 80 wp) at 1-wk intervals.

[c]Percent diseased tissue presented as an average of three replications.

[d]The symbol I indicates the plants were inoculated on the indicated date.

TABLE 2. The severity[a] of southern corn leaf blight on T-cms corn at different times and approximate growth stages of the crop resulting from inoculation with three concentrations of *Helminthosporium maydis* race T and a delayed inoculation in 1976

Date (1976)	Inoculum concentrations[a]					Growth stage
	High (%)	Medium (%)	Low (%)	High (delayed) (%)	Control (%)	
7/21	2.6[c]	0.5	0.3	0	0	
7/28	7.7	2.2	2.2	0	0	Tasselling
8/04	15.5	7.6	7.3	I[d]	0	
8/11	23.7	13.9	13.7	I	0	Blister
8/18	35.0	24.1	22.1	7.9	0	Late Milk
8/25	50.4	41.1	37.8	20.0	Trace	Early Dough
9/02	72.0	65.0	60.8	49.3	14.7	Dent
9/11	100	100	100	87.0	30.7	

[a]Inocula: high = 20×10^6 conidia/subplot; medium = 1.64×10^6 conidia/subplot; low = 6.8×10^5 conidia/subplot (all applied 5 July); and high (delayed) = 20×10^6 conidia/subplot applied on 4 and 11 August.
[b]Sprayed with zinc ion-maneb complex at weekly intervals.
[c]Percent diseased tissue presented as an average of three replications.
[d]The symbol I indicates the plants were inoculated on the indicated date.

TABLE 3. Yield in metric tonnes per hectare and percent loss of T-cms corn inoculated with three concentrations of *Helminthosporium maydis* race T and a delayed inoculation in 1975 and 1976 at Landisville, Pennsylvania

Treatment[a]	1975		1976	
	Metric tonnes/hectare		Metric tonnes/hectare	
	Yield[c]	% Loss	Yield[c]	% Loss
High	5.37 A	31.0	5.31 A	32.5
Medium	5.11 A	34.3	6.04 B	23.2
Low	5.82 A	25.2	6.01 B	23.7
High (delayed)[b]	7.02 B	9.7	6.95 C	11.7
Control	7.77 B	0	7.87 D	0
Coefficient of variation	11.5		9.1	

[a]In 1975, high = 28×10^6 conidia/subplot; medium = 16×10^6 conidia/subplot; and low = 8×10^6 conidia/subplot. In 1976, high = 20×10^6 conidia/subplot; medium = 1.64×10^6 conidia/subplot; and low = 6.8×10^5 conidia/subplot.
[b]Inoculated with high spore concentration on 4 and 11 August in both 1975 and 1976.
[c]Yield values are an average of three replications. Values followed by the same letter are not significantly different ($P = 0.05$) by Duncan's modified (Bayesian) least significant difference test.

TABLE 4. The relationship of disease and loss in yield due to southern corn leaf blight in 1975 determined by simple linear regression

Date of disease assessment 1975	Simple linear regression[a]			Growth stage
	α[b]	β[c]	R^2[d] (%)	
7/21	6.85	3.80	67.1	
7/28	5.27	1.87	73.0	Tasselling
8/04	4.83	1.22	76.6	
8/11	4.43	0.80	79.6	Blister
8/18	− 0.66	0.69	86.3	Dough
8/25	− 2.53	0.54	80.3	Dent
9/02	−24.20	0.69	79.9	
9/11	−32.67	0.60	61.7	

[a]The number of observations in each analysis was 30.
[b]The symbol α stands for the y-intercept of regression equation.
[c]The symbol β stands for the regression coefficient.
[d]Coefficient of determination.

described as simple and linear. From the inspection of residual plots it appeared that curvilinear relationships may be more appropriate for early and late assessments of disease. Transformations were applied to the data but they did not increase precision. Multiple regression techniques failed to account for a significant portion of variation over the simple model when tested by either partial F-tests or coefficients of determination adjusted for degrees of freedom. The best relationship between disease and yield loss was derived using disease severities recorded on 18 August 1975 and 25 August 1977 as independent variables. Regression coefficients for these equations were 0.69 and 0.70 with coefficients of determination of 86.3 and 87.0% for 1975 and 1976, respectively. These dates correspond approximately to the dough stage in the growth of the crop for each year. Values for the y-intercept for these regression equations were not significantly different from zero ($P = 0.01$). Therefore, in this experiment, yield loss in corn due to SCLB can be computed by the equation: $\hat{y} = 0.69x_d$, where $\hat{y}$ equals the percent loss in yield and x_d equals the percent disease assessed at the dough stage.

DISCUSSION

Yield losses in the delayed-inoculation treatment averaged 9.7 and 11.7% in 1975 and 1976, respectively. Disease in this treatment did not reach measurable levels until approximately the dough stage when 14.4% disease was observed in 1975 and 20.0% disease in 1976. Apparently this was not a sufficient amount of disease to have a major influence on yield. Since much of the carbohydrate has been accumulated by the dough stage, disease would have little influence on either the rate of accumulation or the amount of photosynthate translocated to the grain (5). These data suggest that disease resulting from infection occurring late in the season does not affect yield greatly. These findings are similar to those reported by Bolton (2) and Ayers et al. (1). The dough stage appears to be the most favorable time for describing the relationship between disease and loss in yield. Data on the influence of time of disease onset indicate that disease appearing just prior to or at the dough stage has little influence on yield loss. In future research, greater reliability may be achieved in deriving a yield-loss equation for corn and SCLB by concentrating on or around the dough stage.

The dough stage as a point of yield loss prediction offers insight into the nature of the interaction of the pathogen and suscept. The dough stage may approximate the critical point as described by James (7). However, significant yield losses that were observed from infection initiated late in the season in 1976 raised questions whether it was valid to equate the dough stage to the critical point. Furthermore, the effect of disease occurring very late in the season, after the dough stage, has not been investigated. Further research is necessary for an adequately based critical-point model.

From an epidemiological approach, the critical-point model has notable limitations. The model ignores what occurs after the critical point and does not take into account the conditions under which disease progressed to the critical point. According to Van der Plank (14), the progress of disease is characterized by an initial amount of inoculum and the apparent infection rate over some period of time. Neither of these two sources of variation are distinguishable in a critical-point model. The same amount of disease could be observed at the dough stage from two different epidemics by altering the amount of initial inoculum and apparent infection rate. The yield-loss equation would fail to distinguish between the two epidemics in terms of resulting yield losses. Such variables may not be of major consequence since the same basic equation for yield loss was derived in two separate years of research when apparent infection rates and inoculum concentrations were different in each year. Also, it may be possible for disease to appear after the dough stage and increase at a fast rate. Yield losses in such cases would not be detected by the model. Knowledge of the interaction of the pathogen and host and its influence in yield would indicate the importance of these variables in a critical-point model. Such information would be essential in

TABLE 5. The relationship of disease and loss in yield due to southern corn leaf blight in 1976 determined by simple linear regression

Date of disease assessment 1976	Simple linear regression[a]			Growth stage
	α[b]	β[c]	R^2[d] (%)	
7/21	12.46	8.10	39.2	
7/28	9.57	3.40	54.2	Tasselling
8/04	6.55	1.83	65.6	
8/11	5.36	1.20	68.9	Blister
8/18	0.15	0.97	81.9	Late milk
8/25	− 3.59	0.70	87.0	Early dough
9/02	−12.54	0.58	82.1	Dent
9/11	−17.28	0.42	73.3	

[a]The number of observations used in each analysis was 29.
[b]The symbol α stands for the y-intercept of the regression equation.
[c]The symbol β stands for the regression coefficient.
[d]Coefficient of determination.

evaluating and determining the limitations of the critical-point model.

Another disadvantage to this model is that the yield loss prediction is determined too late in the season for control measures to check disease and prevent losses. The value of the yield-loss equation would be enhanced by projecting the amount of disease at the dough stage from an assessment of disease made earlier in the season. A simple method for predicting the amount of disease at the dough stage can be derived using the formula for disease progress proposed by Van der Plank (14):

$$r = \frac{1}{\Delta t}\left(\log_e \frac{x_2}{1 - x_2} - \log_e \frac{x_1}{1 - x_1}\right)$$

where x_1 and x_2 are disease severities, expressed as proportions observed over some interval of time, t, in days; and r is the apparent infection rate of the epidemic. Latin and MacKenzie (10) rearranged this formula to solve for x_2, the amount of disease, (in this case, at the dough stage):

$$x_2 = \left(e^{rt + \log_e \frac{x_1}{1 - x_1}}\right) \div \left(1 + e^{rt + \log_e \frac{x_1}{1 - x_1}}\right)$$

By substituting this equation into the yield loss equation

$$\hat{y} = 0.69\, x_d$$

one can solve for the percent yield loss, $\hat{y}$,

$$\hat{y} = 0.69\left\{\left(e^{rt + \log_e \frac{x_1}{1 - x_1}}\right) \div \left(1 + e^{rt + \log_e \frac{x_1}{1 - x_1}}\right)\right\}$$

from any disease assessment made before the dough stage by knowing only three variables: (i) x_1, the amount of disease observed; (ii) t, the time in days to the dough stage from the period when disease was assessed; and (iii) r, the anticipated apparent infection rate of the epidemic. Consider the case in which 5% disease was observed after tasselling, approximately 25 days before the dough stage. An r-value of 0.11 units/day was chosen based on this and previous research (1) to exemplify a medium rate of disease increase. Using the above formula, predicted yield loss under these conditions would be estimated at 31.2%. If control measures could be undertaken to reduce r to 0.07 only 16.0% loss would be predicted. Predicting yield loss by this formula also affords the opportunity to compare in terms of yield loss, the effect of control measures such as fungicide application, race-specific resistance, and rate-limiting resistance.

Yield-loss research must be approached from the aspect of the host and yet maintain an epidemiological perspective. The scope of early research is necessarily limited in order to identify the fundamental variables present. The influence of such factors as host cultivar, management practices, and environmental parameters must be quantified in future research. Simple and accurate estimates of yield loss can be made that can provide additional and pertinent information for decision making in disease management.

LITERATURE CITED

1. AYERS, J. E., R. R. NELSON, L. L. CASTOR, and M. H. BLANCO. 1976. Yield losses in corn caused by Helminthosporium maydis race T. Plant Dis. Rep. 60:331-335.
2. BOLTON, A. T. 1974. Preliminary studies to determine effect of southern leaf blight on yield of corn in eastern Ontario. Can Plant Dis. Surv. 54:152-154.
3. DUNCAN, D. B. 1965. A Bayesian approach to multiple comparisons. Technometrics 7:171-222.
4. FISHER, D. E., A. L. HOOKER, S. M. LIM, and D. R. SMITH. 1976. Leaf infection and yield loss caused by four Helminthosporium leaf diseases of corn. Phytopathology 66:942-944.
5. HANWAY, J. J. 1966. How a corn plant develops. Special Report 48, Ames, Iowa; Iowa State University, 17 p.
6. HOOKER, A. L. 1972. Southern leaf blight of corn: present status and future prospects. J. Environ. Qual. 1:244-249.
7. JAMES, W. C. 1974. Assessment of plant diseases and losses. Annu. Rev. Phytopathol. 12:27-48.
8. JELLUM, M. D., and W. J. ETHRIDGE. 1971. Effect of race T of Helminthosporium maydis on corn grain yield. Agron. J. 63:647-648.
9. JOSEPHSON, L. M., C. R. GRAVES, H. C. KINCER, and S. C. HILTZ. 1971. Reductions in yield of corn from southern corn leaf blight. Plant Dis. Rep. 55:115-118.
10. LATIN, R. X., and D. R. MAC KENZIE. 1976. The application of multiple point methods for forecasting yield losses caused by potato late blight. Proc. Am. Phytopathol. Soc. 3:307.
11. LIM, S. M., A. L. HOOKER, J. G. KINGSEY, and D. R. SMITH. 1974. Comparative grain yields of corn hybrids in normal and Texas male sterile cytoplasm (cms-T) infected with Helminthosporium maydis race T and diseased components of cms-T corn hybrids. Crop Sci. 14:190-195.
12. SHARVELLE, E. G. 1970. Fungicides for southern corn leaf blight. Plant Dis. Rep. 54:112-113.
13. ULLSTRUP, A. J. 1972. The impacts of the southern corn leaf blight epidemics of 1970-1971. Annu. Rev. Phytopathol. 10:37-50.
14. VAN DER PLANK, J. E. 1963. Plant diseases: epidemics and control. Academic Press. New York. 349 p.
15. WALLER, R. A., and D. B. DUNCAN. 1969. A Bayes rule for the symmetric multiple comparisons problem. J. Am. Statist. Assoc. 64:1484-1503.