Relationships Between Common Rust Incidence and Severity on a Susceptible and a Partially Resistant Sweet Corn Hybrid

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ABSTRACT

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Incidence and severity relationships for common rust on a susceptible (Florida Staysweet) and a partially resistant (Sugar Loaf) sweet corn hybrid were examined for data where incidence was measured as the percentage of leaves per plant with at least one erupted uredinium and severity was assessed as the percentage of the total leaf area infected per plant using the Petersen scale. Relationships were similar for the two hybrids and were explained by a cubic regression of untransformed data with nonuniform variances with an intercept that was not significantly different from zero: $\hat{Y} = 0.072(X) - 0.00177(X)^2 + 0.0000145(X)^3$ where $\hat{Y}$= predicted rust severity (%) and X = rust incidence (%). Severity was relatively constant at 1% from 20 to 60% incidence but increased from 60 to 100% incidence. Variances also increased above 60% incidence. Severities of 1, 2, 3, and 4% were predicted from the regression of untransformed data at approximately 52, 82, 93, and 95% incidence, respectively. For square-root-transformed severity with variances that were more homogeneous, the relationship was: $\hat{Y} = 0.218 + 0.0516(X) - 0.00104(X)^2 + 0.000007(X)^3$ where $\hat{Y}$= predicted percent severity$^{1/2}$ and X= percent incidence. Severities of 1, 2, 3, and 4% (severity$^{1/2}$ of 1, 1.414, 1.732, and 2, respectively) were predicted at 28, 86, 95, and 100% incidence, respectively, for the regressions of severity$^{1/2}$. Slope coefficients of severity$^{1/2}$ regressed on incidence for each hybrid at different times (rating dates) were different probably because of the ranges of incidence over which severity$^{1/2}$ was regressed. At an 80% incidence action threshold for fungicidal control, predicted rust incidence and severity at 7 days (one latent period) after initiation of control were 99–100% and 3.5–7%, respectively, for Florida Staysweet and 85–95% and 3–4%, respectively, for Sugar Loaf. Considering the rapid development of rust on Florida Staysweet and the proximity of the 80% incidence action threshold to damaging disease levels, a lower threshold may be warranted for susceptible and moderately susceptible hybrids grown in rust-conducive environments.

Additional keywords: maize, *Puccinia sorghi*, *Zea mays*.

Common rust (*Puccinia sorghi* Schwein.) can be economically damaging on sweet corn (*Zea mays* L.) when environments are favorable for disease development (1,4,8,11). Relationships between sweet corn yield and rust severity assessed at 1 wk before harvest were linear with slope coefficients from 0.6 to 0.7. Thus, yield reductions due to rust were estimated to be approximately 6 to 7% for each 10% rust severity at approximately 1 wk before harvest (8).

Common rust can be controlled on sweet corn by host resistance or fungicides. Sweet corn hybrids that possess *Rp* resistance or partial resistance are available. However, many of the most popular hybrids are susceptible or moderately susceptible to common rust, especially many hybrids with the shrunken-2 (*sh2*) endosperm mutation for high-kernel sugars and several sugary (*su1*) hybrids that are grown for processing (3,9,10). Rust severity at about 1 wk before harvest ranged from 40 to 63%, 30 to 52%, and 35 to 50% on susceptible hybrids evaluated in disease nurseries in 1984, 1985, and 1986, respectively (9,10). Corresponding yield reductions of approximately 19–41% would be predicted for these hybrids based on rust yield loss models (8). Consequently, fungicide applications are necessary to prevent significant yield reductions on susceptible hybrids in environments favorable to rust.

The number and timing of fungicide applications required to manage rust in the most economical manner are not known, but several aspects of rust development and spread provide information for efficient fungicidal control. Headrick and Pataky observed that sweet corn hybrids exhibited an adult plant rust reaction in which plants became more resistant as they matured (6). Hybrids were most susceptible to rust when inoculated as five- to six-leaved seedlings (6). Thus, fungicide applications after anthesis may not be warranted except for the most susceptible hybrids that are grown in environments that are particularly disease conducive and under severe inoculum pressure. Also, results from disease gradient studies with common rust suggested that, after initial alloinfection associated with the primary gradient, the increase of rust on individual plants of a susceptible hybrid was primarily due to autoinfection (7). Thus, fungicide treatments may be most effective at reducing rust development if initial applications are made at early growth stages to protect plants at their most susceptible stages and to prevent some cycles of autoinfection.

Early fungicide applications may be unnecessary if environmental conditions are not rust conducive or if rust inoculum levels are not sufficiently high. Because rust develops adequately over a wide range of cool temperatures (approximately 12–28 C) with a minimum moisture period of approximately 6 hr (5), environmental conditions usually are conducive for rust on sweet corn grown in the northern United States and on late-season crops grown in the Midwest. Therefore, a weather-based forecast to predict when to initiate fungicide applications is probably unrealistic. Inoculum levels required to initiate rust epidemics have not been investigated primarily because of difficulties in monitoring *P. sorghi* urediniospore movement through the North American *Puccinia* pathway (15), predicting the arrival of initial inoculum, and quantifying *P. sorghi* populations at low levels.

Even though monitoring *P. sorghi* populations may be impractical, disease assessments made at the early stages of rust epidemics may be useful in determining the need for fungicide treatments. Because disease incidence is usually easier to assess than disease severity at the very early stages of an epidemic (13), the quantitative relationships between rust incidence and severity may provide a basis for determining when to initiate fungicidal control. Dillard and Seem evaluated rust incidence and severity relationships for the sweet corn hybrid Jubilee and proposed a 6-uredinia-per-leaf action threshold for the initiation of fungicide sprays (2).

This paper reports an evaluation of relationships between common rust incidence and severity on a susceptible and a partially resistant sweet corn hybrid.

MATERIALS AND METHODS

Common rust incidence and severity data on a susceptible sweet corn hybrid, Florida Staysweet (Illinois Foundations Seeds, Inc., Tolono, IL), and a partially resistant hybrid, Sugar Loaf (Sunseeds, Inc., Farmington, MN), were collected from experiments designed to compare the spatial and temporal development of rust (7). The experiments were planted on 2 and 14 June 1984 and 9 May and 3 June 1985 at the University of Illinois Pomology Research Farm, Urbana, in fields that were isolated from other corn by at least 1 km in all directions. The design for each experiment was a split-plot with two replicates of a two-by-two factorial treatment design. Main plots were irrigation treatments and subplots were hybrids; however, because irrigation treatments had no significant effect on rust (7), the treatment and experimental designs were essentially four replications of hybrids in a randomized complete block. Each experimental unit consisted of a 134 m^2 plot with 16 rows that were spaced 0.76 m apart, were 11 m long, and were oriented east to west. Plots were separated by at least 8 m of a rust-resistant dent corn in order to reduce interplot interference. Plant populations were 54,000 plants/hectare.

A pattern to study disease gradients was established within each plot. A focus of infection was established on a single plant approximately 0.76 m from the southwest (windward) corner of each plot. Plants were tagged for evaluation at 0.8, 2.3, 4.6, 6.9, and 9.2 m from the focus in the compass directions: 0°, 23°, 45°, 68°, and 90°. A total of 22 plants and the focus were sampled in each plot (five plants for each distance except 0.8 m for which there were two plants).

The foci plants were inoculated at the six- to eight-leaf growth stage by injecting 5 ml of a urediniospore suspension (16 mg of *P. sorghi* urediniospores, 100 ml of water, and 0.5 ml of Tween 80) into the base of plant whorls. An additional 5 ml of inoculum was poured into the whorls. Plants were inoculated on 4 and 19 July 1984 and 15 June and 12 July 1985 at dusk to prevent rapid evaporation of inoculum and to aid in urediniospore germination.

Rust incidence and severity were assessed on a per plant basis. Incidence was measured as the percentage of leaves per plant with at least one erupted uredinium. Severity was assessed as the percentage of the total leaf area infected using the Peterson scale (12). Ratings began 7 days (one latent period) after sporulating uredinia were observed on foci plants. Plants were rated twice weekly until harvest maturity (approximately 20 days after mid-silk). There were 8, 6, 11, and 7 ratings for the 2 and 14 June 1984 plantings and the 9 May and 3 June 1985 plantings, respectively.

Mean rust incidence and severity were calculated in each experiment from the five subsamples (compass directions) and four replications for each hybrid-distance-time combination. Severity was plotted on incidence by experiments, hybrids, time (that is, rating dates as days after inoculation of foci), and distance from the foci of inoculum. Data for which incidence was 100% were deleted. Severity then was regressed on incidence by ordinary least squares, and linear quadratic and cubic models were evaluated. Polynomial terms were included based on significant *F*-values ($P \leqslant 0.05$). Nonuniform variances above 60% incidence were unaccounted for in preliminary regresssions in order to present the actual data and the variation associated with that data. Severity also was square root transformed and regressed on incidence so that relationships could be evaluated with variances that were more homogeneous. To compare regressions of severity$^{1/2}$ on incidence by hybrid among distances from foci and rating dates (time), distances and time were qualitative independent variables and incidence was the quantitative independent variable. Coincident, concurrent, and parallel regressions were compared to general regressions by *F*-tests as follows:

$$F_l = \frac{(\mathrm{RSS}_l - \mathrm{RSS}_g)/(\mathrm{df}_l - \mathrm{df}_g)}{(\mathrm{RSS}_g/\mathrm{df}_g)} \tag{1}$$

where F_l = the *F*-test for comparison of model$_l$, RSS$_l$ = the residual sum of squares for model$_l$, RSS$_g$ = the residual sum of squares for the general model, df$_l$ = the degrees of freedom for model$_l$, and df$_g$ = the degrees of freedom for the general model$_g$ (14). Coefficients from regressions were then determined by hybrid for each distance and rating date when general models were appropriate.

RESULTS

Rust incidence ranged from 0 to 100% in all four experiments. Incidence was 100% on Florida Staysweet for 84 of 160 ratings and for all ratings made 33 days after inoculation of the foci. On Sugar Loaf, incidence was 100% for 13 of 160 ratings. At 100% incidence, severity ranged from 1 to 55% on Florida Staysweet (Fig. 1A) and from 2 to 8.5% on Sugar Loaf (Fig. 1B). Below 100% incidence, severity ranged from 0 to 15% on Florida Staysweet and from 0 to 7% on Sugar Loaf (Fig. 1C and D). When incidence was below 60%, severity was below 1% on both hybrids except for one data point for Sugar Loaf.

When severity was regressed on incidence, cubic models with intercepts that were not significantly different from zero fit the data for both hybrids although variances were nonuniform and increased above 60% incidence particularly for Florida Staysweet (Fig. 1C). Models were not significantly different between hybrids based on *F*-tests. When data for both hybrids were combined, the relationship between severity and incidence was explained by the following equation:

$$\hat{Y} = 0.072(X) - 0.00177(X)^2 + 0.0000145(X)^3 \tag{2}$$

where $\hat{Y}$ = predicted rust severity (%) and X = rust incidence (%). Predicted severities of 1, 2, 3, and 4% occurred at approximately 52, 82, 93, and 95% incidence, respectively. Severity was about 1% and relatively constant from 20 to 60% incidence but increased from 1 to 4% as incidence increased from 60 to 100% (Fig. 1C and D).

When severity was square root transformed, variances were somewhat more uniform, although variance of Florida Staysweet severity$^{1/2}$ increased above 60% incidence (Fig. 2). Regressions of severity$^{1/2}$ on incidence were cubic with slope coefficients that were not significantly different between Florida Staysweet (FSS) and Sugar Loaf (SL):

$$\hat{Y} = 0.11 + 0.0537(X) - 0.00105(X)^2 + 0.000007(X)^3 \text{ (FSS)} \qquad (3)$$

$$\hat{Y} = 0.25 + 0.0502(X) - 0.00103(X)^2 + 0.000007(X)^3 \text{ (SL)} \qquad (4)$$

where $\hat{Y}$ = predicted percent severity$^{1/2}$ and X = percent incidence. Severities of 1, 2, 3, and 4% (severity$^{1/2}$ of 1, 1.414, 1.732, and 2, respectively) were predicted at 28, 86, 95, and 100% incidence, respectively, for the combined model (Fig. 2).

When severity$^{1/2}$ was regressed on incidence by distance from the foci, F-tests were significant, which indicated that relationships varied among distances. Data from the 9 May 1985 experiment were representative (Fig. 3A and B, Table 1). Severity at a particular incidence was greater for both hybrids at 0.8 m from the infection focus than at distances further than 0.8 m (Fig. 3A and B). For Sugar Loaf, slope coefficients of severity$^{1/2}$ on incidence were similar among distances except for 0.8 m (Table 1). For Florida Staysweet, regressions by distance usually were linear, and slopes decreased with increased distance from the focus (Table 1).

When severity$^{1/2}$ was regressed on incidence by time, F-tests were significant, which indicated that relationships were different at time. Data from the 9 May 1985 experiment were representative (Fig. 3C and D). Slope coefficents increased with time for both hybrids (Table 2).

DISCUSSION

Relationships between common rust incidence and severity were similar for a susceptible (Florida Staysweet) and a partially resistant (Sugar Loaf) sweet corn hybrid when incidence was below 100%. From 20 to 60% incidence, severity was approximately 1%. Severity increased from approximately 1% at 60% incidence to about 3–4% at 93–100% incidence. These relationships were similar to those reported for the sweet corn hybrid Jubilee (2).

Based on rust incidence and severity relationships, Dillard and Seem proposed a 6-uredinia-per-leaf action threshold that corresponded to 1% severity and 80% incidence on Jubilee (2).

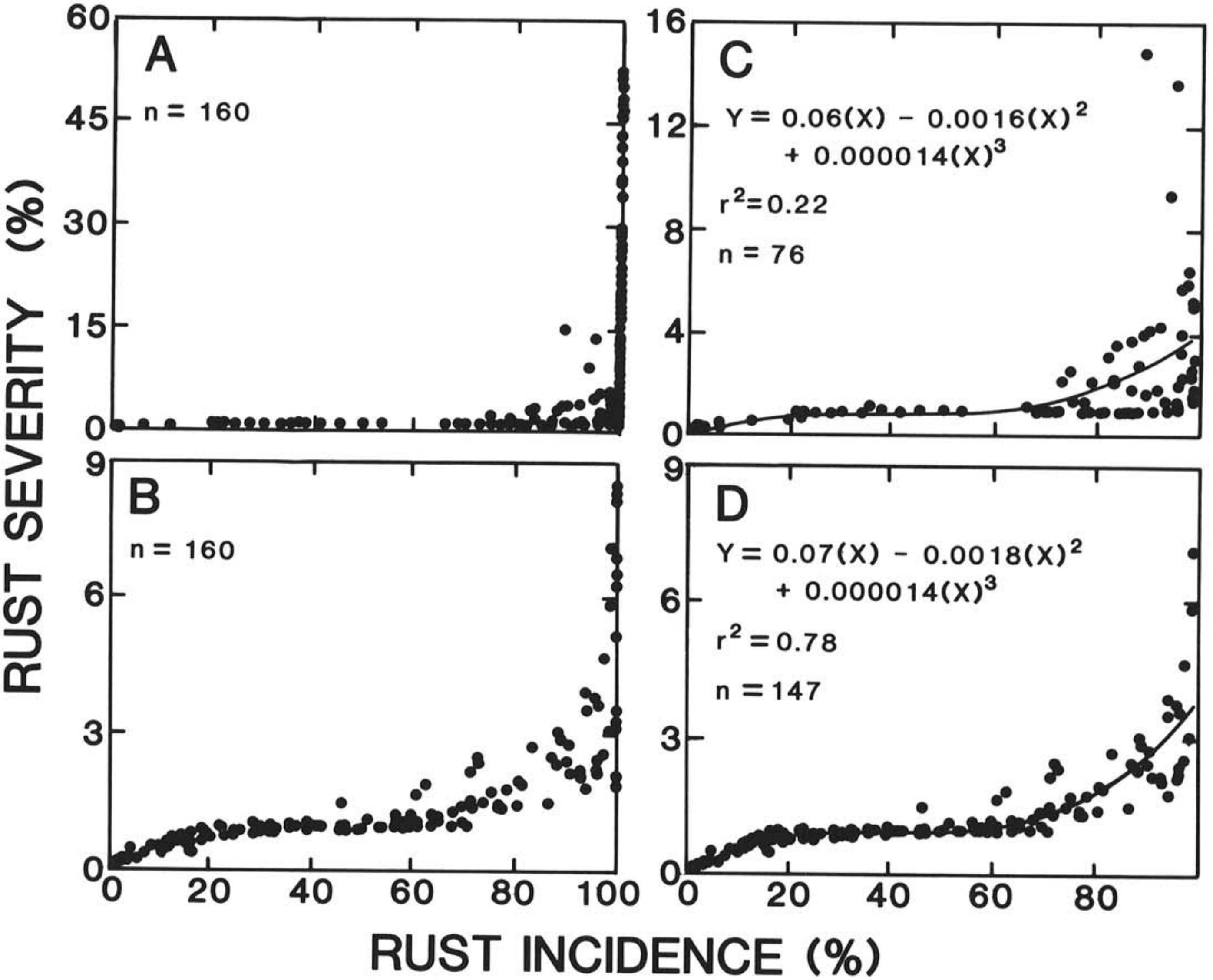

Fig. 1. Rust severity (%) plotted on rust incidence (%) for a susceptible (Florida Staysweet) and a resistant (Sugar Loaf) sweet corn hybrid grown in four experiments designed to study rust development from a focus of inoculum: **A,** Florida Staysweet with 100% incidence included, **B,** Sugar Loaf with 100% incidence included, **C,** Florida Staysweet with 100% incidence excluded, and **D,** Sugar Loaf with 100% incidence excluded.

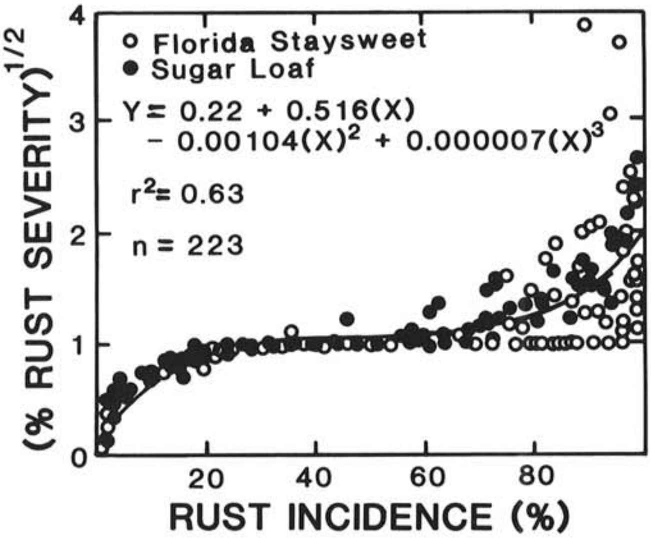

Fig. 2. Square-root-transformed rust severity (%) plotted on rust incidence for a susceptible (Florida Staysweet) and a resistant (Sugar Loaf) sweet corn hybrid grown in four experiments designed to study rust development from a focus of inoculum.

Jubilee has been classified as moderately rust resistant when evaluated with Florida Staysweet and Sugar Loaf which were susceptible and resistant, respectively (9,10). Even though rust incidence and severity relationships were similar for Jubilee,

TABLE 1. Coefficients from regressions of percent rust severity$^{1/2}$ on percent rust incidence at various distances from an infection focus in plots of a susceptible (Florida Staysweet) and a partially resistant (Sugar Loaf) sweet corn hybrid planted 9 May 1985

Hybrid and distance (m)	b_0	b_1	b_2	b_3	r^2
Sugar Loaf					
0.8	0.497	0.0142	NS[a]	NS	0.87
2.3	0.412	0.0329	−0.00063	0.000005	0.95
4.6	0.351	0.0476	−0.00107	0.000008	0.97
6.9	0.350	0.0532	−0.00128	0.000010	0.97
9.2	0.425	0.0439	−0.00104	0.000008	0.93
Florida Staysweet					
0.8	−0.323	0.0414	NS	NS	0.58
2.3	0.315	0.0189	NS	NS	0.80
4.6	1.310	−0.0239	0.00036	NS	0.99
6.9	0.578	0.0119	NS	NS	0.68
9.2	0.511	0.0107	NS	NS	0.79

[a] NS = not significant.

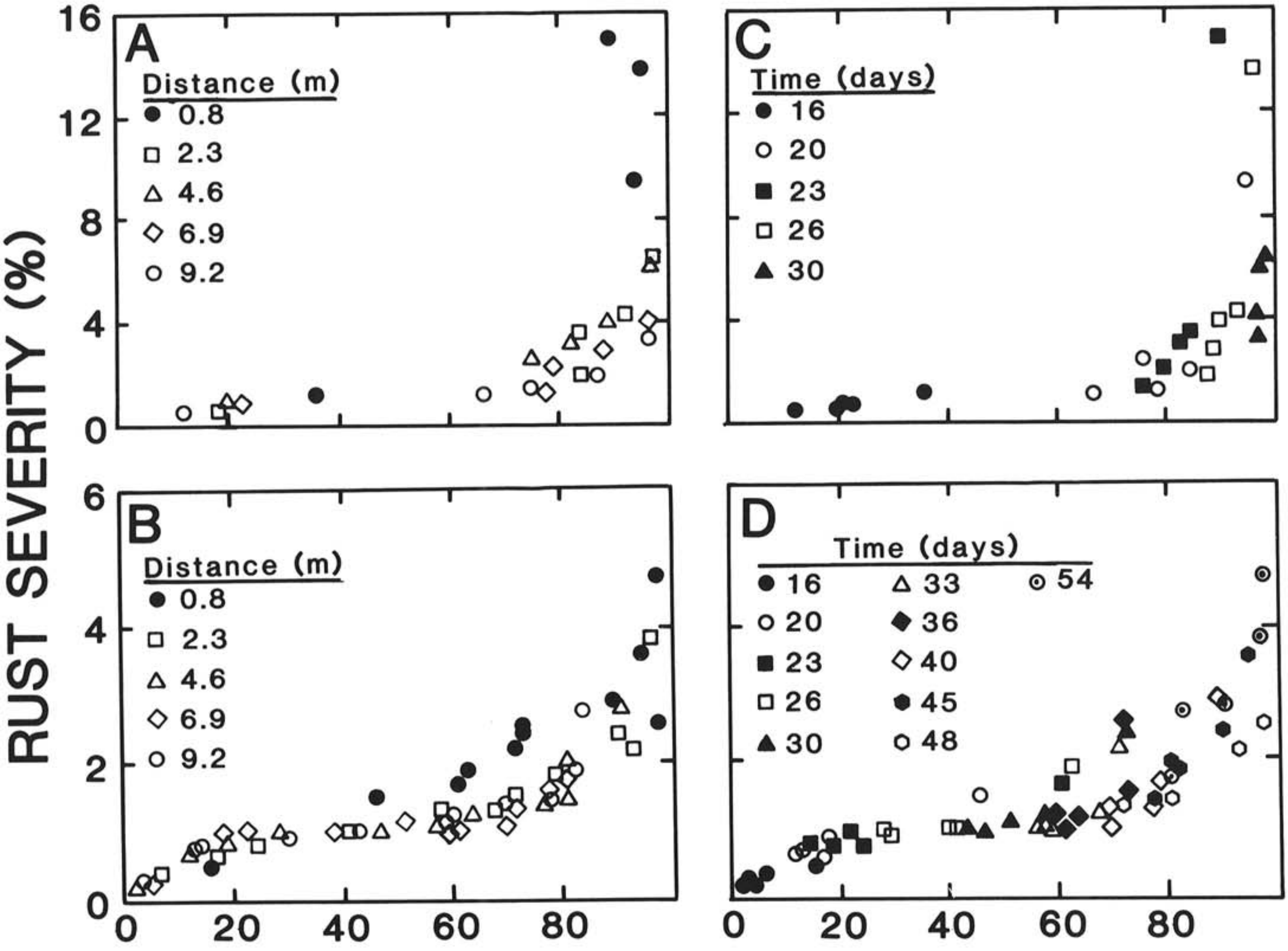

Fig. 3. Rust severity (%) plotted on rust incidence (%) by distance from an infection focus and by time (days) after inoculation of the focus for a susceptible (Florida Staysweet) and a resistant (Sugar Loaf) sweet corn hybrid planted 9 May 1985: **A**, Florida Staysweet evaluated by distance, **B**, Sugar Loaf evaluated by distance, **C**, Florida Staysweet evaluated by time, and **D**, Sugar Loaf evaluated by time.

TABLE 2. Coefficients from regressions of percent rust severity$^{1/2}$ on percent rust incidence at various times (rating dates) after inoculation of an infection focus in plots of a susceptible (Florida Staysweet) and a partially resistant (Sugar Loaf) sweet corn hybrid planted 9 May 1985

Hybrid and time (days)	b_0	b_1	b_2	r^2
Florida Staysweet				
16	0.53	0.017	NS[a]	0.84
20	−3.64	0.067	NS	0.71
23	−12.96	0.183	NS	0.84
26	−19.74	0.242	NS	0.87
30[b]	−21.74	0.247	NS	0.25
Sugar Loaf				
16	0.47	0.016	NS	0.80
20	0.70	0.011	NS	0.89
23	0.75	0.009	NS	0.92
26	1.48	−0.031	0.00046	0.99
30	2.04	−0.049	0.00058	0.99
33	20.81	−0.647	0.00527	0.99
36	−0.88	0.032	NS	0.71
40	−0.97	0.029	NS	0.89
45	−1.35	0.034	NS	0.90
48	5.15	−0.109	0.00075	0.99
54	−1.72	0.039	NS	0.84

[a] NS = not significant.

[b] Incidence = 100% for all ratings of Florida Staysweet after 33 days.

Florida Staysweet, and Sugar Loaf, action thresholds may be affected by differing rates of rust development on susceptible and resistant hybrids grown in different environments. In previous research with common rust, the Gompertz model (gompit) was most appropriate for describing the increase of rust incidence and severity in time (7). Rates of incidence increase (*k*-values of gompit[incidence] regressed on time) were estimated to range from 0.35 to 0.41 for Florida Staysweet (7); thus, an increase from 40 to 90% incidence would be predicted to occur within 7 to 8 days, which is one latent period for *P. sorghi*. For Sugar Loaf, *k*-values were estimated to range from 0.05 to 0.18 depending upon the proximity to a focus of inoculum (7). Thus, an increase in incidence from 40 to 90% on Sugar Loaf would be predicted to occur within 15 to 55 days depending upon inoculum density. Weather conditions would affect these rates because rust development was more rapid in cool, moist environments (5).

If protectant fungicides were applied regularly to Florida Staysweet beginning at 80% rust incidence, and if fungicidal control prevented further infection but did not affect latent infections, rust incidence on Florida Staysweet would be predicted to increase to 99–100% due to latent infections (an estimated 7-day increase in disease). Severity on Florida Staysweet would be predicted to be approximately 3.5–7% based on the 7-day latent period, our estimate of 2% severity at 80% incidence, and estimated *k*-values from 0.020 to 0.056 for gompit(severity) regressed on time (7). Based on previously derived yield loss functions (8), yield reductions from 2 to 5% would result from 3.5 to 7% rust severity on Florida Staysweet. For Sugar Loaf, rust incidence would increase to 85–95%, severity would range from 3 to 4%, and yield reductions would be from 2 to 3% based on the same assumptions and *k*-values of 0.009–0.019 for gompit(severity) regressed on time (7). Thus, an 80% incidence action threshold, which corresponds to Dillard and Seem's 6-uredinia-per-leaf threshold (2), would prevent rust from reaching severities that would result in substantial yield reductions.

Nonetheless, considering the rapid development of rust on Florida Staysweet and the proximity of the 80% incidence action threshold to damaging disease levels, a slightly lower threshold may be warranted for susceptible and moderately susceptible hybrids grown in rust-conducive environments. Possibly, a 40–60% incidence threshold would be appropriate because severity was relatively constant from 20 to 60% incidence but increased more rapidly after 40% incidence, the inflection point of our untransformed regression model. For moderately resistant and resistant hybrids, fungicides usually are not necessary, but under severe rust pressure, an 80% incidence action threshold seems reasonable.

Measurement of uredinia per leaf was not done in our study but may be a superior method of determining action thresholds for common rust when rust development and sweet corn plant growth are considered. Young plants invariably have some uredinia-free leaves because new leaves emerge from plant whorls faster than the 7-day latent period necessary for uredinia to erupt. Thus, from the three- to nine-leaf stage when action thresholds will occur, incidence will be affected by new growth. The relationships between uredinia per leaf and incidence reported by Dillard and Seem (2) could be used to determine thresholds based on uredinia counts that correspond to 40, 60, or 80% incidence. Uredinia per leaf then would be an alternative method to determine thresholds and would be a more accurate measure of severity at low disease levels and at seedling stages.

Adult plant growth stages also must be considered when evaluating fungicidal control decisions for common rust on sweet corn. Headrick and Pataky observed an adult plant rust reaction in which susceptible and resistant hybrids became more resistant to *P. sorghi* as plants approached anthesis (6). Whether or not the adult plant reaction would directly affect action thresholds cannot be discerned from this research; however, because the rate of rust development decreased with plant age, it seems logical that action thresholds may be slightly higher on older plants.

The change in slope coefficients for regressions of severity$^{1/2}$ on incidence at different times probably was due to the ranges of incidence over which severity$^{1/2}$ was regressed. Slopes and incidence increased with time. Also, the susceptibility of Florida Staysweet probably resulted in the exceptionally steep slopes and the nonuniform variances above 60% incidence as compared to Sugar Loaf.

Higher slope coefficients for regressions of severity$^{1/2}$ on incidence at 0.8 m from the foci for Florida Staysweet and Sugar Loaf suggest that, under severe inoculum pressure, severity may be greater than predicted from our regression models. Severity was particularly high on Florida Staysweet plants that were close to the foci (Fig. 3A) but also was higher on Sugar Loaf plants close to the foci than on plants at distances further from the foci (Fig. 3B). Because infection foci are spatially much closer in commercial sweet corn fields than in our study, an effect of inoculum density on incidence-severity relationships could significantly alter action thresholds if the effects of inoculum density are large. Further evaluation of relationships between rust incidence and severity at various inoculum densities and under different environments may expose specific relationships for particular conditions. However, our data and that of Dillard and Seem (2) provide a method to generally define action thresholds until more specific data are available.

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