Classification of Sweet Corn Hybrid Reactions to Common Rust, Northern Leaf Blight, Stewart's Wilt, and Goss' Wilt and Associated Yield Reductions

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ABSTRACT

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Seventy-five, 120, and 100 commercial sweet corn hybrids were evaluated in 1984, 1985, and 1986, respectively, for reactions to inoculations with *Puccinia sorghi, Exserohilum turcicum, Erwinia stewartii*, and *Clavibacter michiganense* subsp. *nebraskense*. For each pathogen in each year, hybrids were classified as resistant, moderately resistant, moderately susceptible, or susceptible, according to a categorization procedure based on mean separation tests (Waller-Duncan Bayesian least significant difference) for disease severity. A hierarchical cluster analysis which considered reactions to all diseases in all years grouped 66 hybrids that were included in all three trials into seven major groups, 11 subgroups, and 17 sub-subgroups. Major groups were defined primarily by reactions to northern leaf blight, Stewart's wilt, and Goss' wilt and reflected the correlations among hybrid reactions to those diseases. Sub-subgroups were defined primarily by reactions to common rust, which reflected the lack of correlation among hybrid reactions to rust and the other diseases. Yield reductions associated with resistance categories were evaluated by regression analyses. For hybrids classified as resistant or moderately resistant, yield reductions were less than 12%, except for rust and Goss' wilt in 1986. Seven hybrids that were representative of each resistance category for each disease were selected as standards by which to compare these and other evaluations.

Additional key words: resistance, *Zea mays*.

When populations of virulent pathogens are present in environments favorable for disease, the amount of disease that develops in the absence of control practices is determined primarily by the resistance or susceptibility of the host genotype. Consequently, genotype selection is a major disease management decision, because it determines the potential for diseases to reach various levels of severity under favorable conditions. Resistance and susceptibility to plant pathogens are the two extremes of a continuum that is measured by the ability of a host to reduce the growth, reproduction, and/or disease-producing abilities of a pathogen. In some instances, host genotypes have major gene resistances that are easily identified and result in little or no disease. However, in many situations, the reactions of host genotypes are intermediate to the most resistant and most susceptible reactions. Often, a limited amount of growth or reproduction of the pathogen occurs on the host, whether resistance is the result of major genes or polygenes.

Ultimately, the economic value of any type of disease resistance can be determined from increased yields and/or quality that result from a reduced amount of disease on resistant genotypes. Thus, levels of resistance and susceptibility among genotypes can be compared by quantitative measurements of disease severity that are related to yield reductions, regardless of the method by which resistance is inherited. If accurate rating categories can be established and related to yield reductions, it is useful to categorize genotypes into broad classes, such as resistant, moderately resistant, moderately susceptible, or susceptible to a particular disease (6).

Common rust, caused by *Puccinia sorghi* Schwein., northern leaf blight (NLB), caused by *Exserohilum turcicum* (Pass.) Leonard and Suggs, and Stewart's wilt, caused by *Erwinia stewartii* (E. F. Smith) Dye, are prevalent diseases of sweet corn (*Zea mays* L.) in Illinois. Goss' bacterial wilt, caused by *Clavibacter michiganense* subsp. *nebraskense* (= *Corynebacterium michiganense* subsp. *nebraskense*), also has been of concern recently because it is a relatively new disease of corn and was observed in Illinois (16). Sweet corn disease management decisions can be considered when selecting genotypes if the reaction of sweet corn hybrids to these diseases and the relationships between disease reactions and yield reductions are known.

The objectives of this research were to evaluate commercial sweet corn hybrids for reactions to *P. sorghi, E. turcicum, E. stewartii*, and *C. m.* subsp. *nebraskense*; to group hybrids into resistance categories based on these reactions; and to associate resistance categories with yield reductions.

MATERIALS AND METHODS

One hundred forty-eight commercial sweet corn hybrids were evaluated in three years at the Agronomy/Plant Pathology South Farm in Urbana, IL. The experiments included 75, 120, and 100 hybrids in 1984, 1985, and 1986, respectively. Sixty-six of the hybrids were evaluated in all of the three years, and 16 were included in two of the three years. The hybrids represented a wide range of materials from 15 commercial seed companies and included four types of sweet corn: three high-sugar types (*sh*2, *sush*2, and *suse*) and standard sugary sweet corn (*su*1). Most of the hybrids were mid- to late-season in maturity (75 days or more).

Hybrids were inoculated and evaluated each year for reactions to *P. sorghi, E. turcicum, E. stewartii*, and *C. m.* subsp. *nebraskense*. A noninoculated control treatment also was included each year. For each of the pathogen and control experiments, three replications of hybrids were randomized in a field in each year. Within pathogen and control treatments, hybrids were arranged in a split-plot of a randomized complete block design, with sugary types as main plots and hybrids as subplots. Subplots were single rows about 3.5 m long, with approximately 16 plants per row. Pathogens and the control treatments were separated by 3.5-m rows of moderately resistant dent corn. Planting dates were 2 June 1984, 21 May 1985, and 9 May 1986.

Plants in each experiment were inoculated with the appropriate pathogen at about the fifth-leaf stage. Plants were inoculated with *P. sorghi* on 5 and 12 July 1984, 27 June 1985, and 11 June 1986. Urediniospore suspensions (about 3 g of urediniospores in 36 L of water and 5 ml of Tween 80) were sprayed into plant whorls. Urediniospores had been collected from infected corn leaves at various locations in Illinois and increased in the field and greenhouse on dent and sweet corn. Urediniospores were stored in a desiccator at −20 C until used.

Corn leaf tissue infected with *E. turcicum* was collected the previous fall and ground in a Wiley mill. Approximately 2 g of ground leaf tissue was placed into corn whorls on 2 July 1984, 24 June 1985, and 10 June 1986. Conidial and mycelial suspensions of *E. turcicum* were sprayed into whorls on 3 July 1984, 27 June 1985, and 18 June 1986. Conidial and mycelial inocula were produced by culturing *E. turcicum* on lactose-casein hydrolyslate agar at room temperature for 2–3 wk. Cultures were flooded with tap water, ground in a blender, and filtered through several layers of cheesecloth. In 1984, race 1 and race 2 of *E. turcicum* were treated as separate experiments. In 1985 and 1986, the NLB evaluations were done using a 1:1 mixture of race 1 and race 2 inoculum.

Plants were inoculated with both bacterial pathogens using the pinprick technique (1,2). Inoculations with *E. stewartii* were done on 20 June and 5 July 1984, 21 June 1985, and 4 and 18 June 1986. Plants were inoculated with *C. m.* subsp. *nebraskense* on 20 June and 5 July 1984, 20 June 1985, and 5 June 1986. Both bacterial pathogens were isolated from infected corn leaves collected in Illinois. Cultures were preserved at −80 C as described by Sleesman and Leben (14). Stock cultures were used to produce inoculum by growing bacteria in nutrient broth shake cultures for 2 days at room temperature. Loops of inoculum from shake cultures were streaked onto nutrient broth/yeast extract agar plates and incubated at 25 C for 3–4 days. Bacterial inoculum was adjusted with a 0.1 M NaCl solution to about 10^7 colony-forming units per milliliter before inoculation.

Diseases were assessed at least twice every year for each disease. Rust severity was assessed on a plot basis as the relative percentage of the total leaf area covered by uredinia using a Peterson scale (12). Rust was rated on 18 July and 1, 10, and 24 August 1984, 12 and 24 July and 6 August 1985, and 27 June and 17 July 1986. For NLB, the percentage of the total leaf area diseased was estimated on a plot basis using the standard diagram of Elliot and Jenkins (3) which was modified to include additional classes. The NLB ratings were done on 28 July and 15 August 1984, 18 July and 7 August 1985, and 5 and 22 July 1986. For both bacterial diseases, each plant was categorized into one of five classes in 1984 (7) or one of nine classes in 1985 and 1986 where: 1 = 1%, 2 = 1–3%, 3 = 3–5%, 4 = 5–15%, 5 = 15–25%, 6 = 25–50%, 7 = 50–75%, 8 = 75–90%, and 9 = <90% severity. Severity of Stewart's and Goss' wilt was calculated as mean severity of all plants per plot.

Disease severity at each rating date and mean disease severity for all ratings within a year were analyzed by ANOVA for each disease. Waller-Duncan Bayesian least significant difference (BLSD) values with $k = 100$ were used to compare hybrids. Then, hybrids were classified in each year as resistant, moderately resistant, moderately susceptible, or susceptible to each pathogen according to the following categorization procedure. Starting with the most resistant hybrid, categories were established as: resistant—disease severity not significantly different from the most resistant hybrid; moderately resistant—disease severity significantly greater than the most resistant hybrid but not significantly different from the least severely diseased moderately resistant hybrid; moderately susceptible—disease severity significantly greater than the least severely diseased moderately resistant hybrid but not significantly different from the least severely diseased moderately susceptible hybrid; and susceptible—disease severity significantly greater than the least severely diseased moderately susceptible hybrid. The procedure was then repeated, beginning with the most susceptible hybrid and progressing to the most resistant. The categorization procedure was done for each disease rating and for mean disease severity in each year. In each year, hybrids were assigned to the category in which they were most frequently classified by this procedure. The range of disease severity associated with each category was determined by the most susceptible and the most resistant hybrid in each category.

The 66 hybrids in the experiment all three years were grouped for reaction to all diseases by hierarchical cluster analysis using Ward's method (13). Mean severity of each of the four diseases in each of the three years were the 12 dependent variables over which hybrids were grouped by cluster analysis. The SAS procedure TREE was used to create a dendogram that depicted clusters and their associations. Interpretation of clusters was based on previous assignment of resistance categories according to the classification procedure based on BLSD separations.

Disease ratings and hybrid rankings for each disease rating were correlated within and among years. Early- and late-season ratings and hybrid rankings based on each disease rating were correlated within years to determine whether hybrid reactions were consistent throughout the growing season. Among years, mean severity of each disease in each year and hybrid rankings based on mean severity were correlated.

Primary ears from 10 plants per row were harvested each year and weighed unhusked to estimate yield. In 1986, primary ears harvested from 10 plants also were counted as a measure of yield. Ears were harvested within 3–4 days of fresh market maturity for 75, 55, and 65 hybrids in 1984, 1985, and 1986, respectively. Harvest dates were 8, 11, 17, and 21 August 1984; 1, 6, 12, and 18 August 1985; and 16, 21, and 30 July and 1 August 1986. For each hybrid harvested, the mean yield of the three replications for each disease was converted to the percentage of the mean yield from the control treatment. Yield as a percentage of the control was regressed on disease severity assessed at the rating date closest to harvest. Yield reductions associated with each resistance category for each disease were determined by solving the appropriate regression equation for the values of disease severity which defined the range of each resistance category, and then by subtracting those solutions from the intercept coefficient of the appropriate regression.

RESULTS

Disease development was adequate in all years to evaluate hybrid reactions. Rust severity at harvest was 5–63%, 0–52%, and 0–50% in 1984, 1985, and 1986, respectively. At harvest, NLB severity was 3–40%, 7–57%, and 1–26% in 1984, 1985, and 1986,

TABLE 1. Correlations between years and diseases for disease severities (above diagonal) and hybrid rankings (below diagonal) for hybrids evaluated in 1984, 1985, and 1986 for reactions to common rust, northern leaf blight (NLB), Stewart's wilt, and Goss' wilt[a]

Disease and year	Rust			NLB			Stewart's wilt			Goss' wilt		
	1984	1985	1986	1984	1985	1986	1984	1985	1986	1984	1985	1986
Rust												
1984	···	0.79	0.72	NS	NS	NS	NS	NS	NS	NS	NS	NS
1985	0.75	···	0.88	NS	NS	NS	NS	NS	NS	NS	NS	NS
1986	0.77	0.83	···	NS	NS	NS	NS	NS	NS	NS	NS	NS
NLB												
1984	NS	NS	NS	···	0.83	0.85	0.47	0.63	0.58	0.57	0.54	0.47
1985	NS	NS	NS	0.86	···	0.79	0.64	0.74	0.65	0.56	0.70	0.48
1986	NS	NS	NS	0.89	0.81	···	0.47	0.63	0.41	0.57	0.53	0.49
Stewart's wilt												
1984	NS	NS	NS	0.46	0.61	0.50	···	0.79	0.65	0.74	0.74	0.58
1985	NS	NS	NS	0.68	0.74	0.68	0.74	···	0.76	0.73	0.88	0.68
1986	NS	NS	NS	0.51	0.52	0.52	0.68	0.75	···	0.61	0.68	0.59
Goss' wilt												
1984	NS	0.23	NS	0.53	0.56	0.46	0.72	0.62	0.64	···	0.66	0.83
1985	NS	NS	NS	0.57	0.60	0.56	0.63	0.77	0.76	0.65	···	0.70
1986	NS	NS	NS	0.41	0.44	0.31	0.48	0.51	0.59	0.75	0.68	···

[a] NS = not significant.

TABLE 2. Ranges of disease severity for sweet corn hybrids classified as resistant, moderately resistant, moderately susceptible, or susceptible to common rust, northern leaf blight (NLB), Stewart's wilt, and Goss' wilt in 1984, 1985, and 1986

Disease and year	Resistant (%)	Moderately resistant (%)	Moderately susceptible (%)	Susceptible (%)
Rust				
1984	<15[a]	15–25	25–40	>40
1985	<20	20–25	25–30	>30
1986	<20	20–30	30–35	>35
NLB				
1984	<10	10–20	20–30	>30
1985	<15	15–20	20–25	>25
1986	< 5	5–10	10–15	>15
Stewart's wilt				
1984	<4	4–15	15–25	>25
1985	<4	4–7	7–15	>15
1986	<4	4–8	8–10	>10
Goss' wilt				
1984	<9	9–18	18–30	>30
1985	<4	4–7	7–14	>14
1986	<6	6–11	11–20	>20

[a] Percentage disease severity based on evaluations made closest to harvest (as described in text).

respectively. Stewart's wilt severity at harvest was 1–41%, 2–44%, and 2–47% in 1984, 1985, and 1986, respectively. Goss' wilt severity at harvest was 3–53%, 2–37%, and 2–68% in 1984, 1985, and 1986, respectively. In control plots, relatively low levels of rust (less than 15% severity on susceptible hybrids) were observed on all hybrids, and Stewart's wilt and NLB were observed on susceptible hybrids.

Hybrid reactions to diseases were generally consistent between early- and late-season ratings (r ranging from 0.51 to 0.91) and among years. Correlations for mean disease severity among years ranged from 0.72 to 0.88 for rust, 0.79 to 0.85 for NLB, 0.65 to 0.79 for Stewart's wilt, and 0.66 to 0.83 for Goss' wilt (Table 1). Hybrid rank correlations were similar to correlations of disease severity (Table 1). Correlations also were observed for hybrid reactions to NLB and Stewart's wilt (ranging from 0.41 to 0.74), NLB and Goss' wilt (ranging from 0.31 to 0.70), and Stewart's wilt and Goss' wilt (ranging from 0.48 to 0.88).

Ranges of disease severity at harvest varied slightly among years for the various resistance categories (Table 2). In general, ranges were broader when disease severity was higher. For example, in 1984 when NLB severity was 3–40%, resistant, moderately resistant, moderately susceptible, and susceptible categories were defined by <10%, 10–20%, 20–30%, and >30%, respectively, whereas, in 1986 when NLB severity was 1–26%, these categories were defined by <5%, 5–10%, 10–15%, and >15%, respectively. Among years, hybrids that ranked at the extremes of categories often changed categories (e.g., the most severely diseased resistant hybrid in 1985 was the least severely diseased moderately resistant hybrid in 1984 and 1986, etc.). When these changes occurred between moderately resistant and moderately susceptible categories, hybrids were classified as moderate. Rarely did hybrid rankings change more than one category.

Hierarchical cluster analysis classified hybrids into seven major groups, 11 subgroups, and 17 sub-subgroups (Fig. 1, Table 3). Major groups occurred at dissimilarity levels greater than 0.6 and were defined primarily by reactions to NLB, Stewart's wilt, and Goss' wilt, with the exception of group IV. Sub-subgroups occurred at dissimilarity levels below 0.5 and were defined primarily by reactions to rust, with the exceptions of sub-subgroups h to l.

Group I consisted of subgroup 1 and sub-subgroup a. Group I-1-a included six hybrids that were resistant to rust, Stewart's wilt, and Goss' wilt and resistant or moderately resistant to NLB (Fig. 1, Table 3).

Group II included two subgroups, 2 and 3, and five sub-subgroups, b to f (Fig. 1, Table 3). The 21 hybrids in group II were resistant or moderately resistant to Stewart's wilt and Goss' wilt. The nine hybrids in subgroup 2 were resistant or moderately resistant to NLB; 13 hybrids in subgroup 3 were moderately resistant to moderate to NLB. Within subgroup 2, sub-subgroups b and c were differentiated by moderate and moderately susceptible reactions to rust, respectively. Within subgroup 3, sub-subgroups d, e, and f were differentiated by moderate, moderately susceptible, and susceptible reactions to rust, respectively.

Hybrids in group III were susceptible to rust, resistant to NLB, moderately resistant to Stewart's wilt, and moderately susceptible to Goss' wilt (Table 3).

Group IV was formed of hybrids resistant or moderately resistant to rust and moderately resistant or moderate to NLB (Table 3). Subgroups 5 and 6 were differentiated by moderate to susceptible reactions to Stewart's wilt and resistant to susceptible reactions to Goss' wilt.

Hybrids in group V were moderately susceptible or susceptible to NLB and moderate or moderately susceptible to Stewart's wilt (Table 3). Subgroups 7 and 8 were differentiated by resistant to susceptible reactions to rust.

In group VI, hybrids were susceptible to Goss' wilt and susceptible or moderately susceptible to Stewart's wilt (Table 3). Subgroup 9 included hybrids moderate in reaction to NLB and rust. Hybrids in subgroup 10 were susceptible or moderately susceptible to NLB. Sub-subgroups o and p were differentiated by moderately resistant to moderately susceptible reactions to rust.

Group VII was a single subgroup and sub-subgroup of hybrids that were susceptible or moderately susceptible to all four diseases (Table 3).

Mean disease severity of all hybrids in groups, subgroups, and sub-subgroups were within the ranges of the resistance categories established from the mean separation tests. Thus, classification of hybrids based on the mean separation tests was used to categorize the 16 hybrids that were included in the experiments for only two of the three years. These hybrids were assigned to six of the seven major groups and 10 of the 17 sub-subgroups (Table 4).

Regressions of percent yield (weight) on disease severity were significant for all diseases in all years although coefficients of determination ranged from 0.08 to 0.79 (Fig. 2). Regressions were linear in each year for rust and NLB, with slope coefficients from −0.37 to −0.78 and −0.30 to −0.53, respectively (Fig. 2A–F). For Stewart's wilt and Goss' wilt, regressions were quadratic in 1984 and 1985 and linear in 1986 (Fig. 2G–L). Intercept coefficients varied from 100, partly because of random error associated with the data and partly due to the location of each pathogen in relation to the control treatment. For example, in 1986, the control treatment was located betwen the NLB and Goss' wilt treatments, and intercept coefficients for those two diseases were 101 and 99, respectively (Fig. 2F and L). The rust and Stewart's wilt treatments were located at a more fertile end of the field in 1986 compared with the control treatment, and the intercept coefficient for both of those diseases was 107 (Fig. 2C and I).

Yield reductions estimated from the regression equations for hybrids in each of the resistance categories varied among years

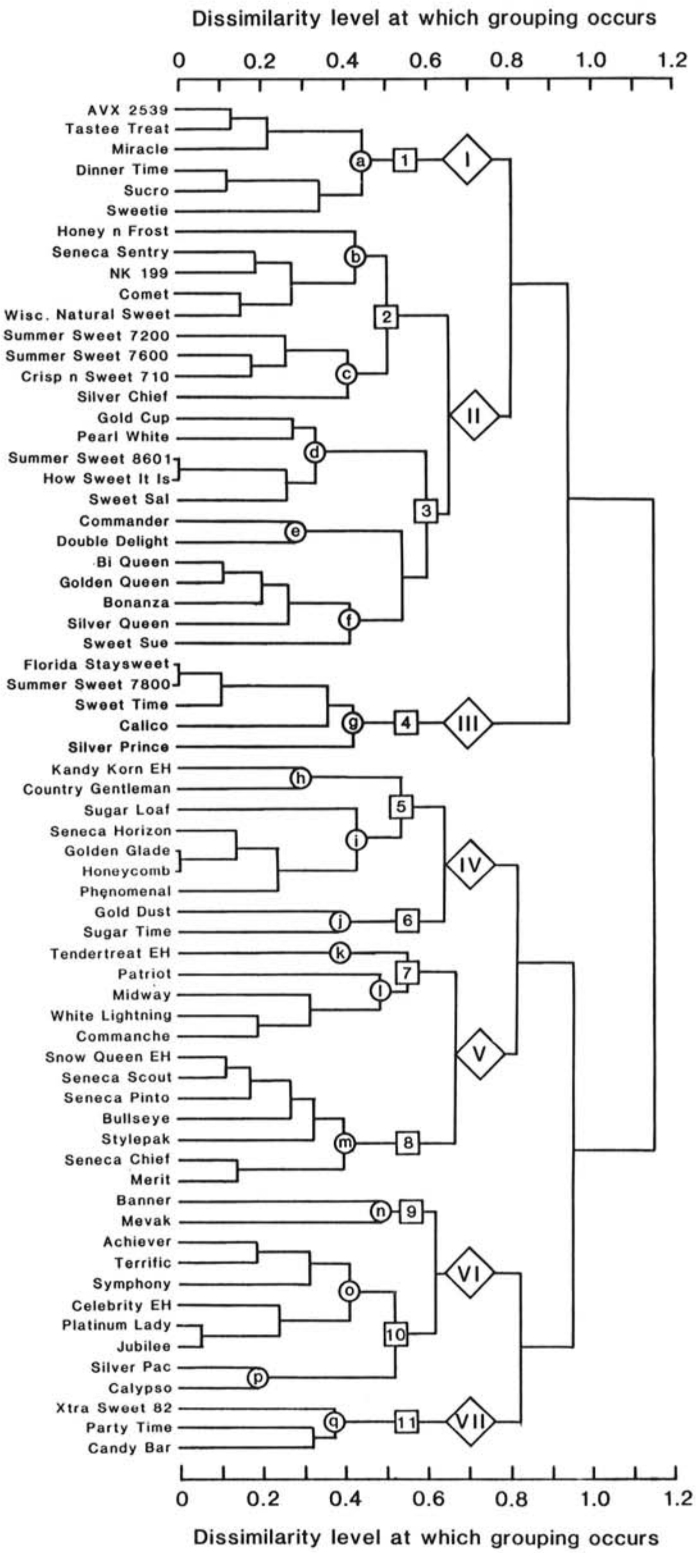

Fig. 1. Dendogram depicting groupings and associations among sweet corn hybrids evaluated by a hierarchical cluster analysis for reactions to common rust, northern leaf blight, Stewart's wilt, and Goss' wilt.

TABLE 3. Reactions of groups of sweet corn hybrids to common rust, northern leaf blight (NLB), Stewart's wilt, and Goss' wilt

Grouping[a]		Rust[b]	NLB	Stewart's wilt	Goss' wilt
I	1 a	R	R-MR	R	R
II	2 b	M	R-MR	R	R-MR
	c	MS	R-MR	R-MR	R
	3 d	M	MR-M	R-MR	MR
	e	MS	M	R-MR	R
	f	MS-S	MR	R-MR	MR
III	4 g	S	R	MR	MS
IV	5 h	MR	M	M	R-MR
	i	MR-R	MR	M-MS	M
	6 j	R	M	MS-S	MS
V	7 k	R	MS-S	M	R-MR
	l	R-MR	MS-S	M	M
	8 m	M-MS	MS-S	M-MS	M
VI	9 n	M	M	MS-S	S
	10 o	MR-M	S	S	S
	p	MS	MS-S	MS	S
VII	11 q	MS-S	MS-S	S	MS-S

[a] Groupings based on hierarchical cluster analysis with levels of dissimilarity at >0.6 (Roman numerals), 0.5–0.6 (Arabic numerals), and <0.5 (lowercase letters).

[b] Resistance classes based on Waller-Duncan Bayesian least significant difference mean separation of hybrids for disease severity for individual trials in 1984, 1985, and 1986.

TABLE 4. Assignment of resistance groups for sweet corn hybrids evaluated for 2 years

Group[a]		Hybrid
I	1 a	Prevailer
II	2 b	Gold Ring
	c	Crisp n Sweet 720
	3 d	AVX 2563
		HXP 3359S
		Paramount
		Remarkable
		83-F450
		84-F271
III	4 g	Ivory and Gold
IV	5 h	Excellency
	i	aRRestor
V	8 m	Cherokee
VI	10 o	Sunbeam
		XPH 2565
	p	Sweet Treat

[a] Groupings based on similar reactions to rust, northern leaf blight, Stewart's wilt, and Goss' wilt as hybrids grouped by hierarchical cluster analysis.

(Table 5). For example, estimated yield reductions in 1984 ranged from 0 to 5.5% for rust-resistant hybrids and from 9.3 to 14.8% for moderately rust-susceptible hybrids, whereas estimated yield reductions in 1986 for rust-resistant hybrids ranged from 0 to 15.6%. Higher estimated yield reductions due to rust in 1986 resulted from higher rust severity on resistant hybrids (e.g., 0 to 20% for resistant hybrids in 1986 compared with 0 to 15% for resistant hybrids in 1984) and a higher estimated slope coefficient (−0.78 and −0.31 in 1986 and 1984, respectively). Estimated yield reductions for all diseases were less than 10% for resistant hybrids, except for the rust-resistant hybrids in 1986. Estimated yield reductions were less than 12% for most hybrids categorized as moderately resistant, except for hybrids moderately resistant to rust and moderately resistant to Goss' wilt in 1986. Moderately susceptible hybrids generally exceeded 10% estimated yield reductions, except for NLB in 1986 and Stewart's wilt and Goss'

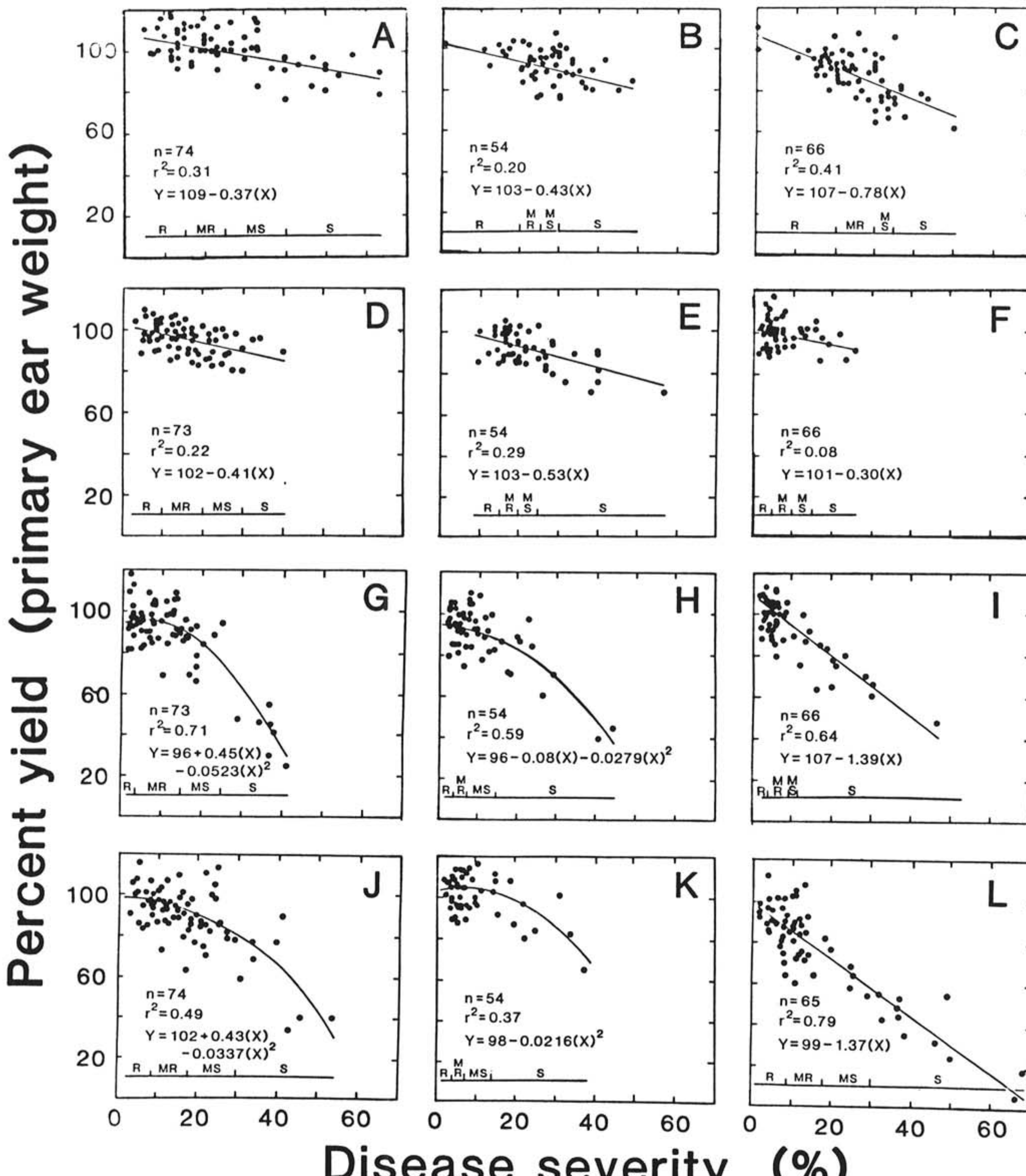

Fig. 2. Relationships between percent yield (measured as percentage of the primary ear weight of control plots) and disease severity assessed closest to harvest for: **A,** common rust—1984; **B,** common rust—1985; **C,** common rust—1986; **D,** northern leaf blight—1984; **E,** northern leaf blight—1985; **F,** northern leaf blight—1986; **G,** Stewart's wilt—1984; **H,** Stewart's wilt—1985; **I,** Stewart's wilt—1986; **J,** Goss' wilt—1984; **K,** Goss' wilt—1985; and **L,** Goss' wilt—1986. Resistance categories: R = resistant, MR = moderately resistant, MS = moderately susceptible, and S = susceptible (defined in text).

wilt in 1985. For the two bacterial wilts, yield reductions for the most susceptible hybrids were greater than 40%, except for Goss' wilt in 1985 (Fig. 2G–L).

When yield also was measured as the number of primary ears harvested from 10 plants in 1986, there was no effect of rust or NLB on yield (Fig. 3A and B). Severe Stewart's wilt and Goss' wilt greatly reduced the number of ears (Fig. 3C and D). For hybrids classified as resistant to the bacterial wilts, estimated yield as numbers of ears was reduced by less than 10%.

DISCUSSION

The categorization procedure based on the BLSD mean separation tests and hierarchical cluster analysis were complementary in grouping hybrids into resistance categories. The

TABLE 5. Ranges of estimated yield reductions for sweet corn hybrids classified as resistant, moderately resistant, moderately susceptible, or susceptible to common rust, northern leaf blight (NLB), Stewart's wilt, and Goss' wilt in 1984, 1985, and 1986

Disease and year	Resistant[a] (%)[a]	Moderately resistant (%)	Moderately susceptible (%)	Susceptible (%)
Rust				
1984	<5.5	5.5–9.3	9.3–14.8	>14.8
1985	<8.6	8.6–10.8	10.8–12.9	>12.9
1986	<15.6	15.6–23.4	23.4–27.3	>27.3
NLB				
1984	<4.1	4.1–8.2	8.2–12.3	>12.3
1985	<8.0	8.0–10.6	10.6–13.3	>13.3
1986	<1.5	1.5–3.0	3.0–4.5	>4.5
Stewart's wilt				
1984	<0.6	0.6–5.0	5.0–21.4	>21.4
1985	<0.8	0.8–1.9	1.9–7.8	>7.8
1986	<5.6	5.6–11.1	11.1–13.9	>13.9
Goss' wilt				
1984	<0	0–3.2	3.2–17.4	>17.4
1985	<0.3	0.3–1.1	1.1–4.2	>4.2
1986	<8.2	8.2–15.1	15.1–27.4	>27.4

[a] Percentage yield reduction determined from regression equations of percent yield on disease severity (as described in text).

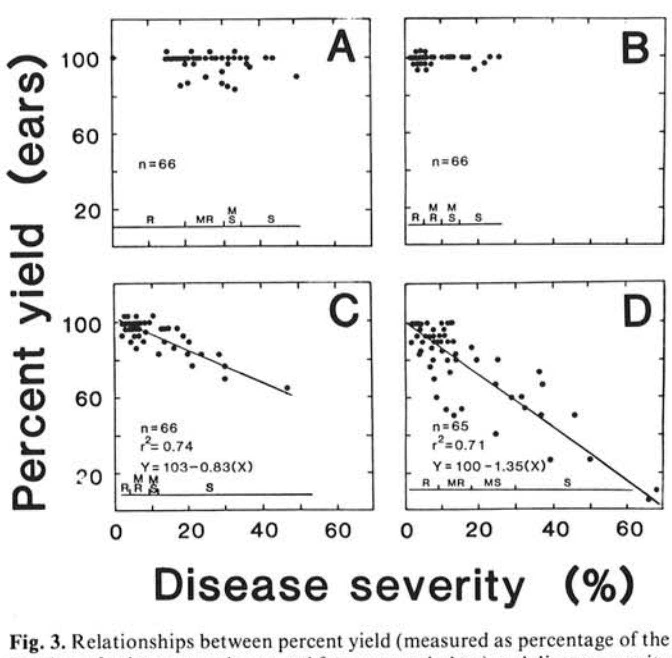

Fig. 3. Relationships between percent yield (measured as percentage of the number of primary ears harvested from control plots) and disease severity assessed closest to harvest for: **A,** common rust—1986; **B,** northern leaf blight—1986; **C,** Stewart's wilt—1986; and **D,** Goss' wilt—1986. Resistance categories: R = resistant, MR = moderately resistant, MS = moderately susceptible, and S = susceptible (defined in text).

categorization procedure based on BLSD separations considered hybrid reaction to one disease in one year. Although the establishment of these categories was based on BLSD separations, the categories should not be interpreted to indicate that all hybrids in one category were significantly different from all hybrids in another category. As with any trait for which a population displays continuous variation, distinct, nonoverlapping, homogeneous groups did not occur. Usually, hybrids at the extreme end of one category were not significantly different from hybrids at the extreme of the adjacent category. Nonetheless, the assignment of hybrids to resistance categories by the procedures used in this research provided an alternative method by which to classify and compare the relative response of genotypes to these pathogens. Because most hybrids consistently were classified into the same resistance category at all rating dates within a year and among years, the reaction of hybrids relative to other sweet corn could be defined and the classifications could be used for disease management decisions.

Hierarchical cluster analysis was a statistical procedure that grouped many independent variables (hybrids) for multiple dependent variables (disease ratings). It considered reaction to all four diseases in all three years and produced groups of hybrids with similar multiple disease reactions. The groups produced by cluster analysis could be interpreted by the resistance categories derived from the BLSD procedure. Main groups formed by cluster analysis were defined primarily by hybrid reaction to NLB, Stewart's wilt, and Goss' wilt, which reflected the correlations among hybrid reactions to these three diseases. Sub-subgroups usually were defined by reactions to rust, which reflected the lack of correlation among hybrid reactions to rust and the other three diseases. Correlations among hybrid reactions to these diseases have been observed previously (7).

Genetic relationships may have been responsible for the association of some hybrids in groups formed by cluster analysis. For example, sub-subgroup f consisted of hybrids that were resistant or moderately resistant to NLB, Stewart's wilt, and Goss' wilt and moderately susceptible to rust; however, three of the five hybrids in that sub-subgroup (Bi Queen, Golden Queen, and Silver Queen) are closely related. Likewise, three of the six hybrids in sub-subgroup a (AVX2539, Tastee Treat [= AVX 2540], and Miracle) are *se*-type hybrids and probably derive rust resistance from a source of the *se* gene, IL677a (10). Of the four pairs of hybrids that were joined at dissimilarity levels of less than 0.1, three pairs (Summer Sweet 8601-How Sweet It Is, Florida Staysweet-Summer Sweet 7800, and Platinum Lady-Jubilee) are probably closely related genetically. If traits other than reactions to these four diseases were measured and included in cluster analysis, this procedure might further discern potential genetic relationships among genotypes. Such relationships could be important in determining which materials to be included in the development of a population for improved multiple disease resistance.

Under normal field situations, the performance of resistant and moderately resistant hybrids may be superior to their performance in these experiments. Because all plants were inoculated and many hybrids were susceptible or moderately susceptible, a relatively large amount of secondary inoculum was produced. Consequently, the amount of secondary inoculum to which resistant and moderately resistant hybrids were exposed may have been greater than under normal field situations. For NLB and rust, sporulation and reproduction-related components of the disease cycle were affected by partial resistance (8,11). Also, when NLB and rust disease gradients were used to compare resistant and susceptible hybrids, differences in the spread and severity of these diseases in plots of resistant and susceptible hybrids were greater than the differences among disease severities in these experiments (5,11).

The regression equations from this trial relate yield reductions and resistance categories. For Stewart's and Goss' wilt, susceptible hybrids sustained substantial yield reductions under early-season moderate disease pressure. Yields of resistant and moderately resistant hybrids were not reduced considerably under similar situations. A preliminary report of previous research indicated that yield reductions from the two bacterial wilts were greater when

TABLE 6. Groupings and reactions of seven sweet corn hybrids selected as standards for future evaluations of sweet corn hybrids for reactions to common rust, northern leaf blight (NLB), Stewart's wilt, and Goss' wilt

Hybrid	Grouping		Rust	NLB	Stewart's wilt	Goss' wilt
Florida Staysweet	III	4 g	S	R	MR	MS
Honey n Frost	II	2 b	MR	R	R	MR
Jubilee	VI	10 o	MR	S	S	S
Miracle	I	1 a	R	R	R	R
Phenomenal	IV	5 i	MR	MR	MS	MS
Xtra Sweet 82	VII	11 q	MS	MS	S	MS
Summer Sweet 7200	II	2 c	MS	R	R	R

plants were infected at seedling stages (15). As plants neared the reproductive growth stages, the effect of the bacterial wilts on sweet corn yield decreased even for susceptible hybrids (15). For NLB, disease pressure was relatively low and yields of resistant, moderately resistant, and moderately susceptible hybrids were reduced little. Hybrids that were susceptible to NLB sustained less yield reduction than hybrids that were susceptible to the bacterial wilts. Ear size and weight were reduced by severe NLB and rust but the number of primary ears was not affected greatly. Plants severely infected by the bacterial wilts did not produce ears (7,15, and J. K. Pataky, *unpublished*). Rust-resistant hybrids minimized yield reductions except under the most severe rust pressure. Moderately susceptible and susceptible hybrids were damaged under conditions that were similar to late-season rust-conducive environments.

Yield reductions associated with each resistance category may have been slightly underestimated by the regressions of percent primary ear weight on severity because secondary ears were not considered. Slope coefficients of the regression equations for rust generally agreed with previous estimates of primary ear weight reductions due to rust (9); however, previous studies of the effects of rust on yield demonstrated that secondary ears were more adversely affected than primary ears (4,9). Similar reactions of primary and secondary ears might be expected for NLB. Likewise, predictions of yield reductions based on numbers of ears also may have been underestimated, because the marketability of primary ears was not evaluated in these trials and the number of marketable primary ears was affected by rust for some hybrids (4,9).

To compare future evaluations with these nurseries, seven hybrids were selected as standards based on their consistent performance and various responses to the four diseases (Table 6). The seven hybrids are representative of each resistance category for each disease. By including these seven standards in future trials, comparisons between evaluations can be made even though ranges of disease severity and/or disease rating methods differ. Such comparisons seem pertinent because sweet corn breeders are rapidly developing new high-sugar hybrids with improved disease resistance.

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