Associations Between Stewart's Wilt Ratings and Maturity of Sweet Corn Hybrids

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ABSTRACT

Pataky, J. K., Suparyono, Hawk, J. A., Gardiner, M. L., and Pauly, M. H. 1990. Associations between Stewart's wilt ratings and maturity of sweet corn hybrids. Plant Dis. 74:792-796.

The time at which sweet corn hybrids were evaluated for reactions to *Erwinia stewartii* and the method of evaluation affected the degree to which Stewart's wilt ratings and relative maturity of hybrids were associated. Maturity and severity of Stewart's wilt symptoms were related when inoculated plants were evaluated as seedlings and when inoculated or naturally infected plants were evaluated near anthesis. Correlations ranged from −0.25 to −0.41 for maturity and ratings of inoculated seedlings and from −0.34 to −0.71 for maturity and ratings made near anthesis. Maturity was not correlated with incidence of naturally infected seedlings. When inoculated plants were evaluated for severity of symptoms from seedling stages until the fresh-market harvest stage, correlations between ratings and maturity increased from −0.24 to −0.65 with each of five weekly evaluations. Conversely, there was no correlation between ratings and maturity when all hybrids were evaluated at the midsilk growth stage. Thus, early-maturing hybrids were rated more susceptible to *E. stewartii* at the later evaluations than at seedling stages, and late-maturing hybrids were rated more resistant at the later evaluations than at seedling stages. As a group, early-maturing hybrids were more susceptible to *E. stewartii* than mid- or late-maturing hybrids, although resistant and susceptible hybrids were identified in all three classes of maturity.

Two phases of Stewart's bacterial wilt, caused by *Erwinia stewartii* (Smith) Dye, occur on corn (*Zea mays* L.). The seedling blight phase is characterized by stunted plants and water-soaked lesions on leaves and can damage susceptible sweet corn hybrids (14). The leaf blight phase occurs after anthesis and can reduce yields of susceptible dent corn hybrids but usually is of little consequence to sweet corn (14) because sweet corn is harvested about 3 wk after anthesis.

The importance of Stewart's wilt in the production of sweet corn depends on the growth stage at which plants become infected, the resistance or susceptiblity of the hybrid, and the abundance of inocula. Yields of susceptible or moderately susceptible sweet corn hybrids were reduced substantially when seedlings were inoculated or infected naturally at the three- to seven-leaf stages (1,5,12,14), whereas yields were not reduced as much when these hybrids were inoculated at the seven- to nine-leaf stages (14). Yields of resistant or moderately resistant hybrids were affected less adversely than were susceptible and moderately susceptible hybrids, regardless of the growth stage at the hybrids were infected (5,12,14).

Resistance is the most efficient control for Stewart's wilt. Several sweet corn hybrids are resistant or moderately resistant to *E. stewartii* (9,10–12), but susceptible or moderately susceptible hybrids often are grown because of superior horticultural and agronomic qualities. Hence, further development of sweet corn hybrids with superior quality and resistance seems prudent.

Sweet corn genotypes that differ in maturity are compared frequently when breeding for resistance to *E. stewartii*. In previous evaluations of reactions of varieties, early-maturing varieties were more susceptible than late-maturing varieties (4,6–8,13,15), although resistant early-maturing varieties and susceptible late-maturing varieties were identified (15). Herein we report on a relationship between the time at which plants were evaluated for Stewart's wilt and the degree to which maturity of sweet corn hybrids and Stewart's wilt ratings were associated.

MATERIALS AND METHODS

Sweet corn hybrid disease nurseries. In disease nurseries in Urbana, Illinois, 382 commercial sweet corn hybrids were evaluated for reactions to *E. stewartii* in one or more of five seasons. Seventy-five hybrids were evaluated in 1984, 115 in 1985, 100 in 1986, 150 in 1988, and 150 in 1989. A wide range of genotypes from 18 commercial seed companies and food processors were represented. In 1984, 1985, and 1986, many of the hybrids were mid- to late-season in maturity (75 days or more). In 1988 and 1989, a greater number of early-maturing hybrids were evaluated. Eight hybrids with known reactions to *E. stewartii* were included as standards in all five trials (12).

Planting dates were 2 June 1984, 21 May 1985, 9 May 1986, 17 May 1988, and 16 May 1989. Each nursery included three replications of hybrids arranged in a split-plot, randomized complete block design. Endosperm types (shrunken-2, sugary extender, and sugary-1) were main plots and single rows of hybrids were subplots. Rows were about 3.5 m long and contained about 16 plants each.

Plants were inoculated with *E. stewartii* initially on 20 June 1984, 21 June 1985, 4 June 1986, 13 June 1988, and 16 June 1989 using the pinprick method (2,3). If symptoms of water-soaking were not apparent on the susceptible standard, Jubilee, by 5 days after inoculation, plants were inoculated a second time. Inoculum was produced as described previously (12,14), although strains of *E. stewartii* from Iowa and Ohio (courtesy of E. J. Braun, Iowa State University) also were used in 1988 and 1989. Each year, 10 plants per row were evaluated for severity of Stewart's wilt symptoms, 2–3 and 5–7 wk after the initial inoculation. The plants ranged from the six- to nine-leaf stage at the first evaluation (seedling ratings). At the second evaluation (anthesis ratings), most of the hybrids had tasseled, although growth stages ranged from very early tassel formation to about 10 days after midsilk. A scale of 1–9, illustrated and described previously (14), was used except in 1984, when a 1–5 scale was used; for both scales, 1 was the most resistant reaction. The date at which plants reached the midsilk growth stage (50% of plants with silks) also was recorded.

Data were analyzed by ANOVA and hybrids were compared using Waller-Duncan Bayesian least significant difference (BLSD) values. Sample means and standard deviations also were calculated in each year. Standardized z-scores were

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Research supported by the Illinois Agricultural Experiment Station, University of Illinois, Urbana, as part of project 68-0323; by the Delaware Agricultural Experiment Station, Department of Plant Science, College of Agricultural Sciences, University of Delaware, Newark; and by Rogers Brothers Seed Company.

Accepted for publication 15 March 1990 (submitted for electronic processing).

calculated for each rating of each hybrid as: $z_{i.} = (x_{i.} - x_{..})/sd$, where $z_{i.}$ = the z-score of the ith hybrid, $x_{i.}$ = the mean rating of the ith hybrid over replications, $x_{..}$ = grand mean rating of the sample, and sd = the standard deviation of the sample.

In each year, hybrids were classified as resistant (R), moderately resistant (MR), moderately susceptible (MS), or susceptible (S) according to a categorization procedure using BLSD separations, as described previously (12). In general, hybrids classified as R, MR, MS, and S had z-scores (standard deviations from the sample mean) below −0.8, from −0.8 to 0, from 0 to 0.8, and above 0.8, respectively. Hybrids also were classified as early-, mid- or late-maturing on the basis of the number of days from planting to the midsilk growth stage. Early-maturing hybrids reached the midsilk stage within 56 days, whereas the earliest late-maturing hybrid reached midsilk 6–7 days later than the latest early-maturing hybrid.

Correlations between maturity (days until midsilk) and ratings at the seedling or anthesis stages were calculated each year. Means of z-scores were calculated for all hybrids in each maturity class. Contingency tables were created from distributions of R, MR, MS, and S hybrids for each maturity class and each rating. Contingency tables were compared by chi-square tests for independence.

Multiple location trial. Groups of 38, 47, and 52 sweet corn hybrids were evaluated for reactions to *E. stewartii* in 1986, 1988, and 1989, respectively, in Newark, Delaware, and Urbana. In 1988 and 1989, the hybrids were also evaluated in Manheim, Pennsylvania. Most of the hybrids were different from those evaluated in the sweet corn hybrid disease nursery in Urbana. At all locations, hybrids were replicated three times. Hybrids were planted 29 April 1986, 7 June 1988, and 28 April 1989 in Newark; 9 May 1986, 18 May 1988, and 16 May 1989 in Urbana; and 26 May 1988 and 1 June 1989 in Manheim. In Illinois, plants were inoculated and rated as described previously. In Delaware and Pennsylvania, populations of corn flea beetles (*Chaetocnema pulicaria* Melsh., an overwintering host and vector of *E. stewartii*) were normal to above normal, and evaluations of Stewart's wilt were based on endemic levels of natural infection. In Delaware and Pennsylvania, the incidence of Stewart's wilt (percentage of symptomatic plants) was rated at the seedling stage; near anthesis (mature blight phase), symptom severity was estimated on a 1–9 scale, where 1 = no symptoms, 2 = trace amounts of symptoms, 3 = 1–10%, 4 = 11–20%, 5 = 21–30%, 6 = 31–40%, 7 = 41–50%, 8 = 51–75%, and 9 = over 75% of the leaf area symptomatic. Plants were rated 18 June and 22 July 1986, 27 June and 19 July 1988, and 6 and 26 July 1989 in Illinois; 10 and 30 June and 24 July 1986, early July and 17 August 1988, and 24 June and 28 July 1989 in Delaware; and 23 June and 16 August 1988 and 26 July and 15 August 1989 in Pennsylvania. Relative maturity was based on date of midsilk in Illinois in 1988 and 1989 and on data from previous yield trials for the 1986 trial.

Data from each trial were analyzed by ANOVA and hybrids were classified for reactions to *E. stewartii*. Correlations between ratings and relative maturity were calculated within and among trials.

Multiple rating trial. In 1988, 79 hybrids from nine different commercial seed companies were evaluated weekly at Urbana for reactions to *E. stewartii*. Most of these hybrids were different from those evaluated in the disease nursery and multiple location trials. Twenty-seven hybrids (three from each company) that reached the midsilk growth stage before 55 days were considered early-maturing, 27 at midsilk beyond 61 days were considered late-maturing, and 25 at midsilk between 55 and 61 days were considered mid-maturing.

The experimental design was a split-plot, randomized complete block with three replications. Maturity classes were main plots and single rows of hybrids were subplots. Rows were about 3.5 m long and contained about 16 plants each. Seed were planted on 17 May and plants were inoculated on 13 June as described previously. Ten plants per row were evaluated on the 1–9 scale (14) on 24 and 30 June, on 8, 14, and 21 July, and on the day plants were at the midsilk growth stage. Growth stage was recorded for each hybrid at each evaluation.

Data were analyzed by ANOVA and hybrids were compared by mean separation tests. Standardized z-scores were calculated as previously described. Correlations between maturity and weekly or midsilk ratings of Stewart's wilt were calculated.

RESULTS

Sweet corn hybrid disease nurseries. On the basis of multiple comparison tests and z-scores, hybrids rated below 3.5 (7% severity) usually were classified as resistant and hybrids rated above 5 (20% severity) usually were classified as susceptible, although classifications differed slightly among evaluations and years (9–12). The correlation coefficients between seedling and anthesis ratings were 0.86, 0.73, 0.66, 0.85, and 0.84 in 1984, 1985, 1986, 1988, and 1989, respectively.

Hybrid maturity and Stewart's wilt ratings were correlated negatively. However, the correlations were higher for maturity and ratings made near anthesis than for those made at seedling stages. Correlation coefficients between

Table 1. Means of z-scores for Stewart's wilt ratings made at a seedling stage and near anthesis for groups of early-, mid-, and late-maturing sweet corn hybrids[a]

	Early-maturing		Mid-maturing		Late-maturing	
Year	Seedling[b]	Anthesis[c]	Seedling	Anthesis	Seedling	Anthesis
1984	0.51	0.62	−0.24	−0.24	−0.24	−0.38
1985	0.24	0.37	−0.19	−0.14	−0.13	−0.05
1986	0.31	0.47	−0.19	−0.26	0.01	−0.08
1988	0.28	0.54	0.10	0.05	−0.55	−0.66
1989	0.62	1.01	−0.05	−0.13	−0.36	−0.50

[a] Z-scores calculated as described in text; wilt ratings based on a 1–9 scale (14).
[b] Plants with six to nine leaves.
[c] Plants ranging from very early tassel stages to about 10 days after midsilk, depending on maturity.

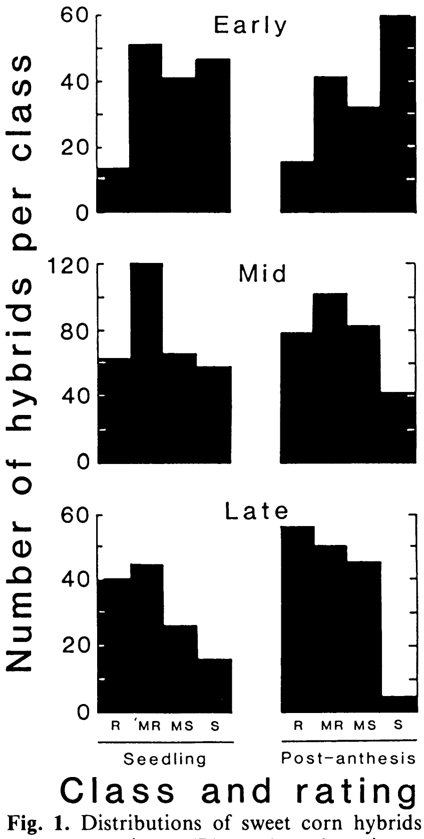

Fig. 1. Distributions of sweet corn hybrids classed as resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S) to *Erwinia stewartii* based on ratings made at seedling stages and after anthesis. Hybrids were grouped according to early, late, and midseason maturity as determined by the number of days after planting at which plants reached the midsilk growth stage. Chi-square values for comparing distributions are presented in Table 2.

maturity and ratings made near anthesis were −0.51, −0.28, −0.37, −0.35, and −0.52 in 1984, 1985, 1986, 1988, and 1989, respectively, whereas those between maturity and ratings made at the seedling stages were −0.37, −0.23, −0.20, −0.21, and −0.32, respectively. Moreover, means of z-scores for early- and late-maturing hybrids were further from zero for the evaluations near anthesis than were those of seedlings (Table 1). Thus, early- and late-maturing hybrids were more divergent from the overall sample mean when evaluated near anthesis than when evaluated at the seedling stages. Nevertheless, distributions of R, MR, MS, and S hybrids (Fig. 1) were not different among seedling and anthesis when compared by chi-square tests of independence within early-, mid-, and late-maturity groups (Table 2).

The group of early-maturing hybrids was more susceptible and the group of late-maturing hybrids was more resistant than the mean of all 382 hybrids. Means of z-scores for early-maturing hybrids ranged from 0.24 to 1.01, whereas means of z-scores for late-maturing hybrids ranged from 0.01 to −0.66 (Table 1). Thus, the means for early-maturing hybrids were 0.24–1.01 standard deviations above the means of all hybrids, and the means for late-maturing hybrids usually were below the overall means. Similarly, at both evaluations, a greater number of early-maturing hybrids were classified S and MS and a greater number of late-maturing hybrids were classified R and MR (Fig. 1, Table 2).

Multiple location trial. Reactions of hybrids to *E. stewartii* were relatively similar among locations except for evaluations at the seedling stage in Pennsylvania in 1988. Correlation coefficients between ratings of hybrids in Illinois and Delaware in 1986, 1988, and 1989 were 0.72, 0.58, and 0.59, respectively, for evaluations at seedling stages and 0.92, 0.63, and 0.83, respectively, for evaluations near anthesis. Correlation coefficients between ratings near anthesis in Pennsylvania and Illinois were 0.66 and 0.82 in 1988 and 1989, respectively, and those for Pennsylvania and Delaware were 0.75 and 0.87, respectively.

Ratings based on incidence of symptomatic plants (seedling ratings in Pennsylvania and Delaware) were not highly correlated with ratings based on symptom severity. Correlations between ratings made at the seedling stage and near anthesis were not as high in Delaware and Pennsylvania (r = nonsignificant to 0.52) as in Illinois ($r = 0.51$–0.92). In addition, the seedling ratings in Illinois (which were based on severity of symptoms) were relatively well correlated with the anthesis ratings in Delaware and Pennsylvania ($r = 0.51$–0.70).

Maturity and Stewart's wilt ratings near anthesis were correlated negatively at all locations (Table 3). Correlation coefficients ranged from −0.34 in Pennsylvania in 1988 to −0.80 in Delaware in 1986. Also, maturity was correlated negatively ($r = -0.41$ and -0.25) with ratings made at the seedling stage in Illinois in 1988 and 1989 when inoculated seedlings were rated for severity of symptoms. Correlations between maturity and seedling stage ratings were not significant in Delaware and Pennsylvania, where seedlings were rated for incidence of natural infection.

Multiple rating trial. Severity of Stewart's wilt symptoms increased each week for the 79 hybrids of different maturity evaluated in 1988. Stewart's wilt averaged 3.5, 3.9, 4.3, 4.9, and 5.0 and ranged from 2.4 to 6.3, 2.6 to 6.3, 2.6 to 7.4, 3.3 to 8, and 3.5 to 8 for ratings on 24 and 30 June and on 8, 14, and 21 July, respectively. Stewart's wilt rated at the midsilk growth stage averaged 4.3 and ranged from 2.8 to 7.2.

Maturity and weekly ratings of Stewart's wilt were correlated negatively, but maturity was not correlated with ratings at the midsilk growth stage (Fig. 2). The strength of the correlations increased each week from −0.24 on 24 June to −0.65 on 21 July. Stewart's wilt ratings for early-maturing hybrids increased each week relative to the mean of all 79 hybrids, as indicated by increasingly positive z-scores (Fig. 2, Table 4). Likewise, Stewart's wilt ratings for late-maturing hybrids decreased each week relative to the mean of all 79 hybrids, as indicated by increasingly negative z-scores. Means of z-scores for ratings done at midsilk were near zero (Table 4), and z-scores for individual hybrids rated at midsilk were randomly distributed around zero for all three classes of maturity (Fig. 2).

Stewart's wilt was slightly more severe on early-maturing hybrids than on mid- and late-maturing hybrids in June and considerably more severe on early-maturing hybrids in July. On 24 and 30 June and on 8, 14, and 21 July, means of Stewart's wilt ratings were, respectively, 3.7, 4.1, 4.8, 5.5, and 6 for early-maturing hybrids; 3.5, 4, 4.3, 4.8, and 4.8 for mid-maturing hybrids; and 3.2, 3.6, 3.8, 4.3, and 4.2 for late-maturing hybrids. Means of ratings done at midsilk were 4.1, 4.3, and 4.3 for early-, mid-, and late-maturing hybrids, respectively.

DISCUSSION

The time at which sweet corn hybrids were evaluated for reactions to *E. stewartii* affected the strength of correlations between Stewart's wilt ratings and relative maturity of hybrids. Correlations between maturity and Stewart's wilt ratings were higher for evaluations of symptom severity near anthesis than for evaluations at seedling stages. This is probably due, in part, to greater variation in growth stages when plants were evaluated later in the season than when seedlings were evaluated. When seedlings were inoculated and rated for severity of symptoms in Illinois, there was a significant correlation between maturity and Stewart's wilt

Table 2. Chi-square values for comparisons of distributions of groups of early-, mid-, and late-maturing sweet corn hybrids classified as resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S) to *Erwinia stewartii* based on ratings made at seedling stages and after anthesis

Comparison	Chi-square value[a]
Seedling vs. postanthesis ratings	
Early hybrids	4.36 (ns)
Midseason hybrids	7.55 (ns)
Late hybrids	7.53 (ns)
Early vs. midseason hybrids	
Seedling rating	18.74**
Postanthesis rating	43.76**
Early vs. late hybrids	
Seedling rating	30.41**
Postanthesis rating	62.19**
Midseason vs. late hybrids	
Seedling rating	7.95*
Postanthesis rating	13.49**

[a] * = Significant at the 0.05 and ** = significant at the 0.01 level of probability (3 df) and indicating that distributions of hybrids in R, MR, MS, and S classes are not the same.

Table 3. Correlations between maturity of sweet corn hybrids and Stewart's wilt ratings made at seedling stages or near anthesis in Illinois, Delaware, and Pennsylvania in 1986, 1988, and 1989[a]

Year	Illinois		Delaware		Pennsylvania	
	Seedling[b]	Anthesis[c]	Seedling	Anthesis	Seedling	Anthesis
Maturity, 1986	ns	−0.71	ns	−0.80[d]	···	···
Maturity, 1988	−0.41	−0.66	ns	−0.70	ns	−0.34
Maturity, 1989	−0.31	−0.56	ns	−0.67	−0.30	−0.60

[a] Wilt ratings based on a 1–9 scale (14) for seedling and anthesis evaluations in Illinois; in Delaware and Pennsylvania, ratings based on incidence of symptomatic plants for seedling evaluations and on a different 1–9 scale for anthesis evaluations.
[b] Plants with six to nine leaves.
[c] Plants ranging from very early tassel stages to about 10 days after midsilk, depending on maturity.
[d] Based on rating made on 24 July; correlation coefficient was −0.55 for maturity and postanthesis rating made on 30 June.

ratings, although the correlation was higher when hybrids were rated later in the season. When hybrids were inoculated and evaluated weekly from seedling stages until the fresh-market harvest stage, correlations between Stewart's wilt ratings and maturity increased with each weekly rating. Apparently, these correlations increased as the difference between growth stages of early- and late-maturing hybrids became more diverse later in the season. Conversely, there was no correlation between ratings and maturity when all hybrids were rated at the midsilk growth stage.

There was no correlation between maturity and Stewart's wilt ratings when seedlings were rated for incidence of natural infection in Delaware and Pennsylvania. However, maturity and ratings were correlated in Delaware and Pennsylvania when plants were evaluated for severity of symptoms near anthesis. Differences in the method of evaluation (incidence vs. severity) or time of evaluation (seedlings vs. mature plants) may have been responsible for the different relationships between ratings and maturity in Delaware and Pennsylvania. These differences may reflect different mechanisms of resistance in seedlings and mature plants. Alternatively, ratings based on incidence of naturally infected seedlings may have been been biased by escapes if early-season inoculum pressure was not uniform.

When reactions of hybrids were compared relative to the response of all hybrids being evaluated, Stewart's wilt ratings made later in the season (i.e., near or after anthesis) were higher for early-maturing hybrids and lower for late-maturing hybrids than those made at seedling stages. Thus, early-maturing hybrids were rated more susceptible to *E. stewartii* at the later evaluations than at seedling stages, and late-maturing hybrids were rated more resistant at the later evaluations than at seedling stages. Consequently, selection for resistance to *E. stewartii* based on late-season evaluations also may select for later maturity than would selection for resistance based on early evaluations.

A variety of procedures could be used to reduce the confounding effect of maturity when selecting for resistance to *E. stewartii*. Seedlings could be inoculated and evaluated for reactions to *E. stewartii*, which would allow breeders to make selections before maturity affected ratings and before pollinations. However, evaluation of inoculated seedlings would require additional resources to maintain virulent cultures of *E. stewartii*, increase inoculum, and inoculate plants. In areas such as Delaware where Stewart's wilt is endemic, naturally infected plants could be evaluated at a common growth stage, such as midsilk; however, this would require multiple evaluations at a time when most breeders are busy with pollinations. In Delaware and Pennsylvania, naturally infected seedlings showed no association with maturity. Thus, resistance could be evaluated at the seedling stage without the confounding effect of maturity as long as escapes do not bias these evaluations. Alternatively, a stratified selection procedure could be used in which plants are grouped according to maturity and selections for resistance are made within each maturity group. Stratified selection could be applied to seedling or late-season evaluations of inoculated or naturally infected plants, although evaluations of seedlings seems most logical, since yield reductions due to Stewart's wilt were greatest when plants were inoculated at seedling stages (14). Various other procedures could be used, depending on the resources available to a breeding program. Regardless of the procedures, however, there appears to be a greater need for improving resistance to *E. stewartii* among early-maturing hybrids than among mid- or late-maturing hybrids.

As a group, early-maturing hybrids were more susceptible to *E. stewartii* than mid- or late-maturing hybrids, although resistant and susceptible hybrids were identified in all three classes of maturity. Thus, the reactions of currently grown hybrids were similar to those of cultivars grown 30–50 yr ago (4,6–8,13,15). Considering the reactions of the most popular early- and late-maturing cultivars from previous generations (4,6–8,13,15), it is likely that the current pattern of susceptibility among early-maturing hybrids and resistance among late-maturing hybrids resulted primarily from the genotypes used to develop these hybrids. On the basis of the observations

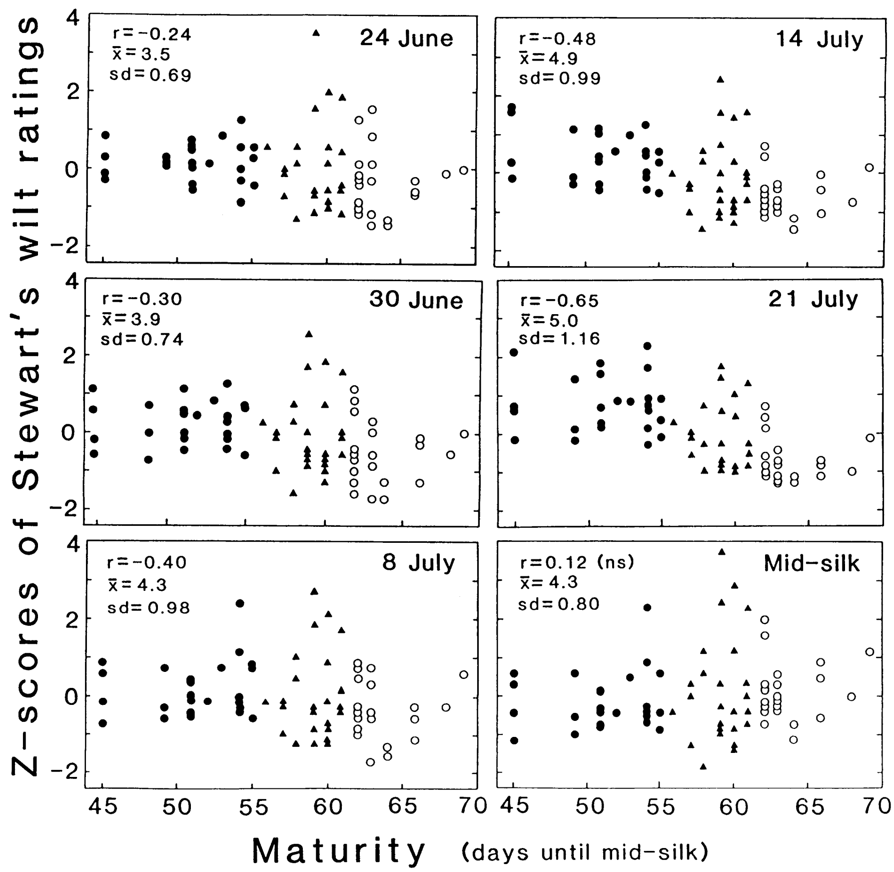

Fig. 2. Plots of standardized *z*-scores of Stewart's wilt ratings made at weekly intervals and at the midsilk growth stage for 79 sweet corn hybrids that were early- (●), mid- (▲), or late- (○) maturing as determined by the number of days after planting at which plants reached the midsilk growth stage. Means ($\bar{x}$) and standard deviations (sd) for each rating were used to calculate *z*-scores for each hybrid as described in the text. Evaluations on 24 and 30 June and on 8, 14, and 21 July were made 38, 44, 52, 58, and 65 days after planting, respectively.

Table 4. Means of *z*-scores for Stewart's wilt rating made at five dates and a rating made at the midsilk growth stage for 79 early-, mid-, or late-maturing sweet corn hybrids[a]

Time of rating	Early-maturing	Mid-maturing	Late-maturing
24 June	0.18	−0.05	−0.40
30 June	0.17	−0.03	−0.42
8 July	0.35	−0.10	−0.54
14 July	0.47	−0.14	−0.58
21 July	0.76	−0.22	−0.74
Midsilk	−0.15	0.06	0.06

[a] *Z*-scores calculated as described in text; wilt ratings based on a 1–9 scale (14). Midsilk reached within 55 days with early-maturing, between 55 and 61 days with mid-maturing, and after 61 days with late-maturing hybrids.

reported herein, however, it is probable that the current reactions of early- and late-maturing hybrids also were due, in part, to the procedures used to evaluate and select for Stewart's wilt resistance.

ACKNOWLEDGMENTS

We thank Julie Klapproth, John Gantz, and Crystal Huff for assistance with trials in Delaware, Illinois, and Pennsylvania, respectively.

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