Incidence and Severity of Stewart's Bacterial Wilt on Sequential Plantings of Resistant and Susceptible Sweet Corn Hybrids

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ABSTRACT

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Naturally occurring Stewart's wilt, caused by *Erwinia stewartii*, was monitored in nine trials in Delaware, Illinois, and Missouri on sequential plantings of resistant, intermediate, and susceptible sweet corn (*Zea mays*) hybrids. Disease incidence and severity differed among trials, among early and late plantings, and among hybrids differing in resistance. Resistant hybrids were easily differentiated from susceptible hybrids by incidence or severity, but reactions of intermediate hybrids were not always distinguishable from those of resistant and susceptible hybrids. Development of Stewart's wilt differed among plantings within and between years. Incidence of Stewart's wilt on the early planting of the susceptible hybrids did not reliably indicate subsequent levels of disease. Nevertheless, it seems prudent to implement control measures for late plantings if Stewart's wilt is abundant at seedling stages of early plantings.

Stewart's bacterial wilt, caused by *Erwinia stewartii*, has been an important disease of sweet corn (*Zea mays* L.) in certain areas of North America in the past 10 years. Epidemics have occurred in areas where the disease usually is an infrequent problem, such as the Lake Ontario region of New York, southwestern Michigan, central and northeastern Illinois, and Ontario, Canada (1,4). Stewart's wilt has been extremely severe on susceptible sweet corn hybrids in areas where it usually is endemic (i.e., the Delmarva Peninsula, southern Pennsylvania, the Ohio River Valley, and southern Illinois and Missouri). These unusual and severe occurrences probably are associated with one or more of the following: (i) mild winters favoring the survival of the corn flea beetle, *Chaetocnema pulicaria* Melsh, the primary vector of *E. stewartii;* (ii) large numbers of infective individuals among overwintering populations of vectors due to high incidence of Stewart's wilt late in the previous growing season; and (iii) susceptibility of many early-maturing sweet corn hybrids planted at the beginning of the growing season.

In most areas where Stewart's wilt has been a problem recently, sweet corn is planted over an extended period of time. At any time after the beginning of the growing season, sequentially planted crops of sweet corn are at various stages of growth from seedlings to fresh-market harvest. Damage from Stewart's wilt depends partly on the growth stage at which plants are infected. Yield reduction can be extreme when seedlings of susceptible and moderately susceptible hybrids are infected by *E. stewartii*, but the leaf blight phase of Stewart's wilt has a relatively minor effect on sweet corn yield (7,10,11).

Seasonal development of Stewart's wilt was monitored previously to determine which plantings of sweet corn were most vulnerable to damage. Elliott and Poos (5) reported abundant early-season Stewart's wilt was followed by severe infection (>50% incidence) on late plantings of a susceptible, open-pollinated variety, Golden Bantam, in Virginia in 1934, 1935, and 1937. In contrast, in 1936 Stewart's wilt was severe by early August, but little disease occurred on early corn plantings because below-normal winter temperatures contributed to the scarcity of flea beetle vectors early in the season (5). In Connecticut, two cycles of Stewart's wilt were observed in 1975 on 14 successive plantings of a susceptible sweet corn hybrid, Jubilee (6). Heichel et al. (6) suggested that the cycles were associated with different generations of insect vectors, and that the disease might be avoided by altering time of planting so that seedlings emerged when populations of the vector were low, although they noted the impracticality of adjusting planting dates.

One alternative to adjusted planting dates is selection of resistant hybrids for mid- or late-season plantings when incidence or severity of wilt on early-planted crops predicts disease development on subsequent crops.

Table 1. Dates of four sequential plantings of six sweet corn hybrids differing in reactions to Stewart's bacterial wilt[a]

Location and year	Sequential plantings of sweet corn: First	Second	Third	Fourth
Newark, DE				
1989	28 April	26 May	12 June	28 June
1990	26 April	25 May	11 June	26 June
1991	3 May	20 May	5 June	17 June
1992	4 May	14 May	4 June	16 June
Urbana, IL				
1989	18 May	30 May	9 June	19 June
1990	2 May	31 May	12 June	28 June
1991	25 May	5 June	18 June	2 July
1992	6 May	21 May	2 June	15 June
Troy, MO				
1989	14 June	22 June	29 June	7 July

[a] Sweet corn hybrids: Crisp N Sweet 725 and Miracle (resistant), Extender and Hypak (intermediate), and Jubilee and Supersweet Jubilee (susceptible).

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Assessments of resistance to Stewart's wilt may be affected by seasonal development of the disease when evaluations are based on responses to natural infection. Previous studies have shown wilt incidence or severity, assessed during the middle of the growing season, correlated with hybrid maturity because early- and late-maturing hybrids are at reproductive and vegetative growth stages, respectively (8).

The objectives of this study were to describe the development of Stewart's wilt on sequential plantings of partially resistant, intermediate, and susceptible sweet corn hybrids and to compare the incidence and severity of Stewart's wilt among early and late plantings of hybrids differing in resistance in order to determine if varietal recommendations could be made for late plantings based on early-season observations of the disease.

MATERIALS AND METHODS

Six sweet corn hybrids were planted on four successive dates in nine field trials at Newark, DE, and Urbana, IL, from 1989 to 1992, and at Troy, MO, in 1989. Stewart's wilt is endemic at these locations. Hybrids were selected for relatively similar maturities and different reactions to Stewart's wilt: resistant, Crisp N Sweet 725 and Miracle (Crookham Company, Caldwell, ID); intermediate, Extender and Hypak (Rogers Seed, Nampa, ID); and susceptible, Jubilee and Supersweet Jubilee (Rogers Seed).

Each trial was arranged in a split-plot design of a randomized complete block with four replicates. Main plots were planting dates (Table 1) and subplots contained hybrids. Each experimental unit consisted of two rows 3.6 m long, spaced 76 cm apart with 15 to 18 plants per row.

Natural infection occurred at all locations. Incidence of Stewart's wilt was based on the percentage of plants symptomatic in each experimental unit. Incidence was rated five to eight times through the season in trials at Urbana, prior to mid-silk in trials at Newark, and after mid-silk in the trial at Troy. Host growth stage was recorded with incidence. Severity was rated on a 1 to 9 (10) scale when the hybrids were at mid-silk and fresh-market-harvest growth stages.

Disease assessments made at similar host growth stages were compared by analysis of variance. Planting dates and hybrids were compared by Waller-Duncan BLSD minimum significant difference values (k = 100). Disease assessments made on similar dates also were analyzed but those analyses are not presented. Plots depicting seasonal development of Stewart's wilt were interpreted in conjunction with analyses of variance and means separation tests. Incidence of Stewart's wilt on the first planting of each trial was evaluated as a predictor of the amount of disease on subsequent plantings.

RESULTS

Incidence and severity of Stewart's wilt differed among trials. In Urbana, Stewart's wilt was least prevalent in 1990, when severity ranged from about 1 to 5 and incidence was less than 20% throughout the season for all plantings of all hybrids except Supersweet Jubilee and Jubilee. Stewart's wilt was most prevalent in Urbana in 1991, when severity ranged from about 3.5 to 8 and incidence reached 90% in all plantings of all hybrids. In Delaware, Stewart's wilt was least prevalent in 1990, when incidence in seedlings was less than 30% for all plantings of all hybrids except the first two plantings of Jubilee and Supersweet Jubilee. Severity was relatively low in Delaware in 1992.

Table 2. Probability at which planting date, hybrid, and planting date × hybrid interaction terms were significant in analyses of variance of Stewart's wilt incidence and severity in trials at Urbana, IL, and Troy, MO

	Incidence at host growth stage[a]								
Year, location, and source of variation	**Five-leaf**	**Seven-leaf**	**Nine-leaf**	**T**	**MS**	**MS1**	**MS2**	**HM**	**Severity[b]**
1989, Urbana, IL									
Planting date	**[c]	**	**	0.05	**	**	**	**	**
Hybrid	**	**	**	**	**	**	**	**	**
Planting date × hybrid	NS[d]	**	**	NS	**	**	NS	NS	NS
1990, Urbana, IL									
Planting date	**	NS	**	**	0.07	**	**	**	**
Hybrid	**	**	**	**	**	**	**	**	**
Planting date × hybrid	**	NS	**	**	NS	0.01	**	**	NS
1991, Urbana, IL									
Planting date	**	**	...	**	...	**	...	NS	**
Hybrid	**	**	...	**	...	**	...	0.03	**
Planting date × hybrid	**	**	...	**	...	**	...	NS	NS
1992, Urbana, IL									
Planting date	NS	0.01	**	**	0.04	**	**	**	**
Hybrid	NS	**	**	**	**	**	**	**	**
Planting date × hybrid	NS	**	**	**	NS	NS	0.01	**	NS
1989, Troy, MO									
Planting date	...	...	...	...	NS	...	...	0.03	**
Hybrid	...	...	...	...	**	...	...	**	**
Planting date × hybrid	...	...	...	...	0.07	...	...	0.10	**

[a] Incidence (%) rated at various host growth stages: T = tassel, MS = mid-silk, MS1 = mid-silk + 1 week, MS2 = mid-silk + 2 weeks, HM = harvest maturity.
[b] Severity rated at harvest maturity. Ratings made only for first two planting dates at Urbana, IL, in 1990 due to severe northern leaf blight, *Exserohilum turcicum*.
[c] Asterisks (**) indicate level of probability below 0.01.
[d] Nonsignificant F test (P = 0.10).

Table 3. Probability at which planting date, hybrid, and planting date × hybrid interaction terms were significant in analyses of variance of Stewart's wilt incidence and severity in trials at Newark, DE

	Incidence and host growth stage[a]			
Year and source of variation	**Five-leaf**	**Seven-leaf**	**Nine-leaf**	**Severity[b]**
1989				
Planting date	**[c]	**	**	0.07
Hybrid	**	**	**	**
Planting date × hybrid	**	**	**	0.03
1990[d]				
Planting date	**	...	...	...
Hybrid	**	...	...	...
Planting date × hybrid	**	...	...	...
1991[d]				
Planting date	**	...	...	...
Hybrid	**	...	...	...
Planting date × hybrid	**	...	...	...
1992				
Planting date	0.02	**	**	**
Hybrid	**	**	**	**
Planting date × hybrid	**	**	NS[e]	...

[a] Incidence (%) rated at various seedling stages.
[b] Severity rated at mid-silk.
[c] Asterisks (**) indicate level of probability below 0.01.
[d] Incidence at seven- and nine-leaf stages and severity were not rated in 1990 and 1991.
[e] Nonsignificant F test (P = 0.10).

Incidence and severity of Stewart's wilt differed among hybrids and plantings. The main effect of hybrids was significant in the 7 analyses of severity and in 38 of 39 analyses of incidence assessed at various growth stages and trials (Tables 2,3). The main effect of plantings was significant in 6 of 7 analyses of severity and in 34 of 39 analyses of incidence. For severity, the hybrid by planting interaction was significant for trials at Newark and Troy, but not for trials at Urbana. For incidence, hybrid by planting interaction was significant in 26 of 39 analyses.

Comparisons of hybrids. Severity of Stewart's wilt was compared among hybrids within plantings in 24 comparisons, i.e., severity rated in four plantings in six trials. Jubilee, Supersweet Jubilee, and Hypak were not different from the hybrid with the highest severity in 24, 13, and 1 multiple comparisons, respectively. Miracle, Crisp N Sweet 725, Extender, and Hypak were not different from the hybrid with the lowest severity in 23, 21, 8, and 4 multiple comparisons, respectively. General inferences from comparisons of hybrids within plantings are similar to those from hybrid main effect means (Table 4). Severity of Stewart's wilt was greatest on Jubilee in all seven trials. Supersweet Jubilee was not different from Jubilee when Stewart's wilt was severe (mean ratings above 7) in the trial at Urbana in 1991. Severity of Stewart's wilt was least on Miracle and Crisp N Sweet 725. Extender and Hypak did not differ from Miracle and Crisp N Sweet 725 when Stewart's wilt severity was relatively low (mean ratings below 1.5) in the trial at Urbana in 1990.

Table 4. Main effect means for planting date and hybrid on severity of Stewart's wilt in trials at Urbana, IL, Newark, DE, and Troy, MO

	Severity of Stewart's wilt						
	Urbana				Newark		Troy
Main effects	1989	1990	1991	1992	1989	1992	1989
Planting date							
First	3.5[a]	2.9	4.9	3.2	4.4	2.2	4.0
Second	4.3	1.5	5.0	4.1	4.4	2.1	3.0
Third	5.0	...	5.5	4.6	4.5	2.2	2.8
Fourth	3.7	...	6.5	4.7	3.8	2.4	2.2
BLSD (k = 100)[b]	0.34	0.71	0.40	0.33	0.37[c]	0.17[c]	0.67[c]
Hybrid							
Jubilee	6.6	4.8	7.6	7.4	6.8	3.5	5.7
Supersweet Jubilee	5.6	4.4	7.2	6.8	5.8	3.5	4.7
Hypak	3.9	1.3	5.7	3.7	3.4	2.0	2.8
Extender	3.7	1.3	4.7	3.1	3.8	1.9	2.1
Crisp n Sweet 725	2.6	1.0	3.9	2.1	3.1	1.4	1.5
Miracle	2.5	1.0	3.7	1.7	2.7	1.6	1.2
BLSD (k = 100)[b]	0.41	1.6	0.48	0.33	0.40[c]	0.20[c]	0.81[c]

[a] Severity rated from 1 to 9 (10) at harvest maturity in Urbana, IL, and Troy, MO, and at mid-silk in Newark, DE.

[b] According to the Waller-Duncan BLSD test.

[c] The planting date × hybrid interaction is significant in the analyses of variance of severity for Newark, DE, and Troy, MO (Tables 2,3). Main effects should be interpreted cautiously (see text).

Table 5. Main effect means for planting date and hybrid on incidence of Stewart's wilt in trials at Urbana, IL, Newark, DE, and Troy, MO

	Incidence of Stewart's wilt[a]								
	Urbana				Newark				Troy
Main effects	1989	1990	1991	1992	1989	1990	1991	1992	1989
Planting date									
First	34	14	24	35	44	21	33	28	19
Second	47	4	56	31	23	12	15	27	9
Third	76	2	45	39	21	9	15	19	23
Fourth	74	8	73	48	15	3	15	17	11
BLSD (k = 100)[b]	4.7	3.6	5.9	6.1	4.1	4.7	4.8	5.4	4.3
Hybrid									
Jubilee	96	27	88	85	57	29	54	73	35
Supersweet Jubilee	95	10	85	78	55	22	37	60	31
Hypak	62	1	38	20	8	4	12	10	9
Extender	54	4	48	24	13	8	19	5	8
Crisp n Sweet 725	23	1	27	15	13	6	2	4	4
Miracle	22	1	14	8	8	5	6	4	2
BLSD (k = 100)[b]	5.6	4.3	7.2	7.1	5.1	6.2	6.3	6.6	5.1

[a] Incidence (%) rating at the host growth stage at which hybrids were best separated. Urbana, IL, 1989, mid-silk + 1 week; 1990, nine-leaf; 1991, seven-leaf; 1992, harvest maturity. Newark, DE, 1989, nine-leaf; 1990, five-leaf; 1991, five-leaf; 1992, nine-leaf. Troy, MO, 1989, harvest maturity.

[b] According to the Waller-Duncan BLSD test. The planting date × hybrid interaction was significant in all analyses of variance except Troy, MO, and Newark, DE, 1992 (Tables 2,3). Main effects should be interpreted cautiously (see text).

Incidence of Stewart's wilt was compared in each trial at the host growth stage at which hybrids differed the most, i.e., five-leaf stage for Newark in 1990 and 1991; seven-leaf stage for Urbana in 1991; nine-leaf stage for Urbana in 1990 and Newark in 1989 and 1992; 1-week past mid-silk for Urbana in 1989; and harvest maturity for Urbana in 1992 and Troy in 1989. When hybrids were compared within plantings, Jubilee and Supersweet Jubilee were not different from the hybrid with the highest incidence in 34 and 24 of 36 comparisons (i.e., four plantings in nine trials), respectively. Hypak, Extender, Crisp N Sweet 725, and Miracle did not differ from the hybrid with the highest incidence for 4, 3, 2, and 2 comparisons, respectively. Miracle, Crisp N Sweet 725, Extender, Hypak, and Supersweet Jubilee did not differ from the hybrid with the lowest incidence in 33, 32, 23, 21 and 2 comparisons, respectively. General inferences from comparisons of hybrids within plantings are similar to those from hybrid main effect means (Table 5). In all trials, incidence of Stewart's wilt was highest for Jubilee, ranging from 27% at the nine-leaf stage in the trial at Urbana in 1990 to 96% at 1-week past mid-silk in the trial at Urbana in 1989. Incidence on Supersweet Jubilee was not different from Jubilee in four of nine trials. Incidence was lowest for Miracle and Crisp N Sweet 725. Extender and Hypak did not differ significantly from Miracle and Crisp N Sweet 725 when incidence was below 15%.

Comparison of plantings. Severity and incidence were compared among plantings within hybrids. As with the comparison of hybrids, generalizations from an analysis of interactions were similar to the inferences from main effect means. Incidence was highest for the first planting and lowest for the fourth planting in all trials at Newark (Table 5). At Urbana, incidence was highest for the fourth planting and lowest for the first planting except in 1990 when incidence was highest for the first planting. At Troy, the first and third plantings had the highest incidence. Severity varied among plantings. At Urbana, the first planting usually had lower severity than later plantings.

Stewart's wilt development. In Newark, incidence of Stewart's wilt increased very little during the vegetative growth stages. Conversely, incidence increased substantially when ratings were extended through harvest in trials at Urbana. Differences between hybrids, plantings, and their interactions were apparent when Stewart's wilt development in the Urbana trials was compared at similar host growth stages

(Figs. 1–4). Incidence tended to be higher for the fourth planting and lower for the first planting in 1989, 1991, and 1992 although that varied with growth stage, hybrid, and year.

Incidence of Stewart's wilt on the first planting of Jubilee was not particularly indicative of subsequent levels of disease. In 1990, when Stewart's wilt was less prevalent than in other years, incidence of 50% at the five-leaf stage of the first planting of Jubilee was five times higher than in any other year. In 1991, when Stewart's wilt was greater than in any other year, incidence on the first planting of Jubilee was only 10% at the five-leaf stage but increased to about 65% by the seven-leaf stage and 100% by the nine-leaf stage. In 1989, incidence on the first planting of Jubilee was less than 20% between the five- and nine-leaf stages, but development of Stewart's wilt on subsequent plantings of all hybrids was similar to that in 1992 when incidence on the first planting of Jubilee increased from about 5 to 50% between the five- and nine-leaf stages.

DISCUSSION

Resistant sweet corn hybrids were differentiated easily from susceptible hybrids in all trials based on incidence or severity of Stewart's wilt resulting from natural infection. Separation of intermediate hybrids from resistant or susceptible hybrids varied among trials. Reactions of hybrids should be interpreted cautiously if evaluations are done when levels of natural Stewart's wilt are relatively low or high. When incidence and severity were relatively low, below 15% and 1.5, respectively, the intermediate hybrids often were not significantly different from the resistant hybrids. When incidence approached 100%, intermediate hybrids could not be differentiated from susceptible hybrids based on incidence although these hybrids could be separated by severity. Previously, we observed relatively good correlations among incidence from natural infection in Delaware and severity from inoculation in Illinois, i.e., r values ranging from 0.58 to

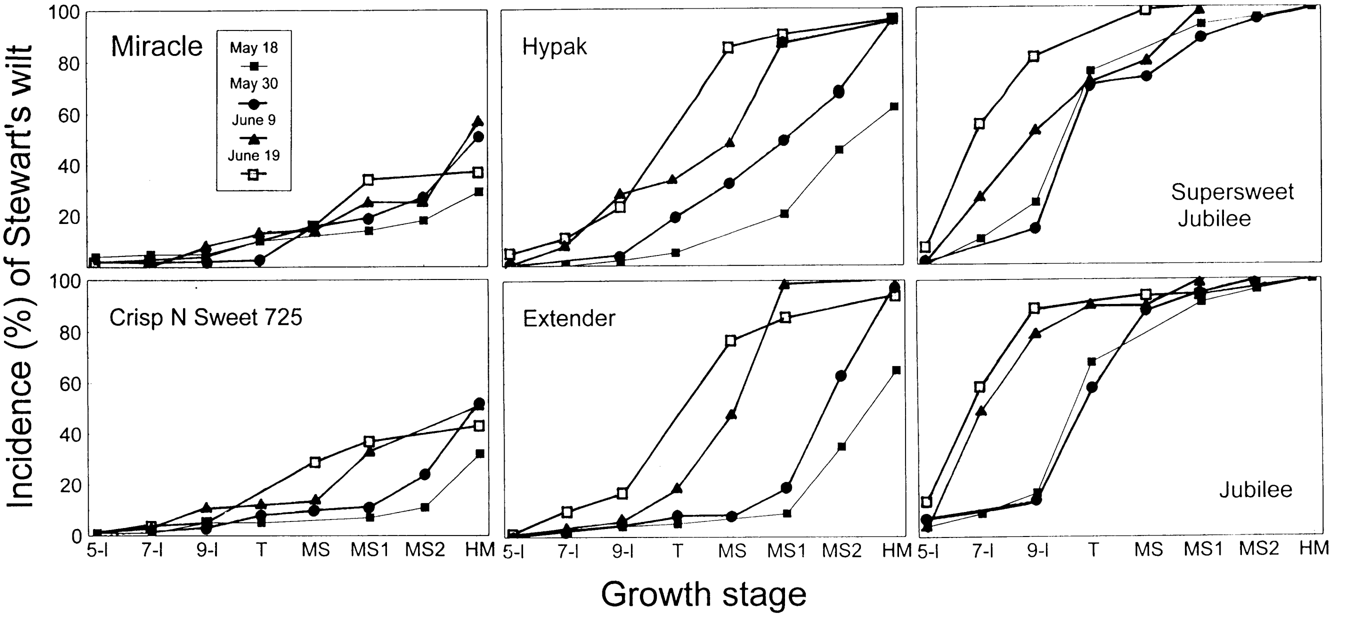

Fig 1. Incidence (%) of Stewart's wilt on six sweet corn hybrids planted on four dates in Urbana, IL, in 1989. Comparisons at eight growth stages: 5-l, 7-l, and 9-l = five-, seven-, and nine-leaf stages; T = tassel; MS, MS1, and MS2 = mid-silk, mid-silk + 1 week, and mid-silk + 2 weeks; and HM = harvest maturity.

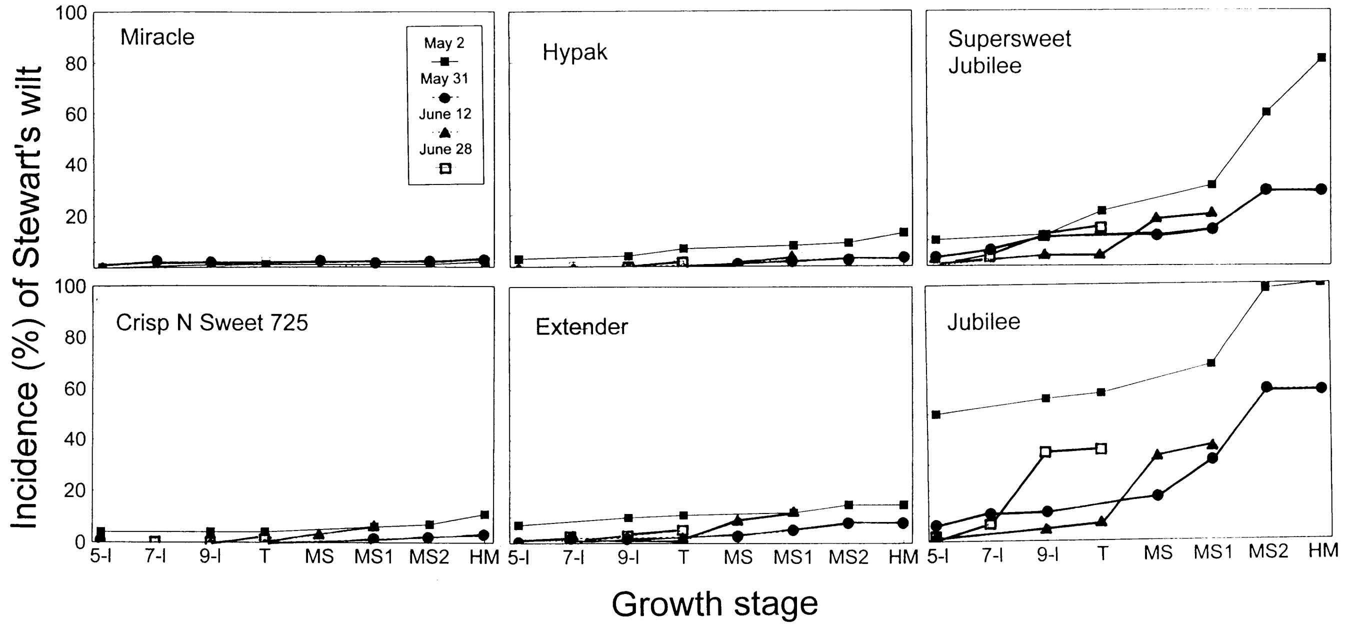

Fig 2. Incidence (%) of Stewart's wilt on six sweet corn hybrids planted on four dates in Urbana, IL, in 1990. Comparisons at eight growth stages: 5-l, 7-l, and 9-l = five-, seven-, and nine-leaf stages; T = tassel; MS, MS1, and MS2 = mid-silk, mid-silk + 1 week, and mid-silk + 2 weeks; and HM = harvest maturity.

0.72 for hybrids rated at seedling stages and from 0.63 to 0.92 for hybrids rated near anthesis (8).

Incidence and severity of Stewart's wilt on early plantings do not appear to be extremely accurate predictors of the amount of Stewart's wilt on subsequent plantings. This may be partially due to the influence of weather on symptom development and/or populations of flea beetle vectors. In 1990, incidence of Stewart's wilt in Urbana was very high initially but decreased in subsequent plantings. Possibly, rainfall (20.5 cm in June 1991, recorded in a rain gauge near the field), inhibited the development of flea beetle populations, although we did not attempt to measure vector populations. Conversely, when rainfall was only 2.2, 7.3, and 5.5 cm in June, July, and August of 1991, Stewart's wilt symptom development was rapid. Heichel et al. (6) observed two cycles of severe Stewart's wilt in 14 consecutive plantings of Jubilee in Connecticut in 1975. Incidence was above 40% for four plantings prior to June and for four of six plantings after June 25. Incidence was lower for three plantings between June 1 and 16. They hypothesized that two broods of corn flea beetles may have been responsible. Conversely, Elliott and Poos (5) observed both increases and decreases in the amount of Stewart's wilt on successive plantings of sweet corn in the mid-1930s, although increased incidence on successive plantings was more common.

Decisions regarding control of Stewart's wilt are based partly on the predictability of this disease from winter temperatures (3,5,9) and are made prior to planting. In general, susceptible and moderately susceptible hybrids are not recommended when the average winter temperature is above freezing. Insecticides applied at planting, or experimental insecticides being tested as seed treatments, also provide some control when winter temperatures predict severe Stewart's wilt as a result of flea beetle overwintering (2,6). In some cases, severity of Stewart's wilt is greater than expected based on the winter tem-

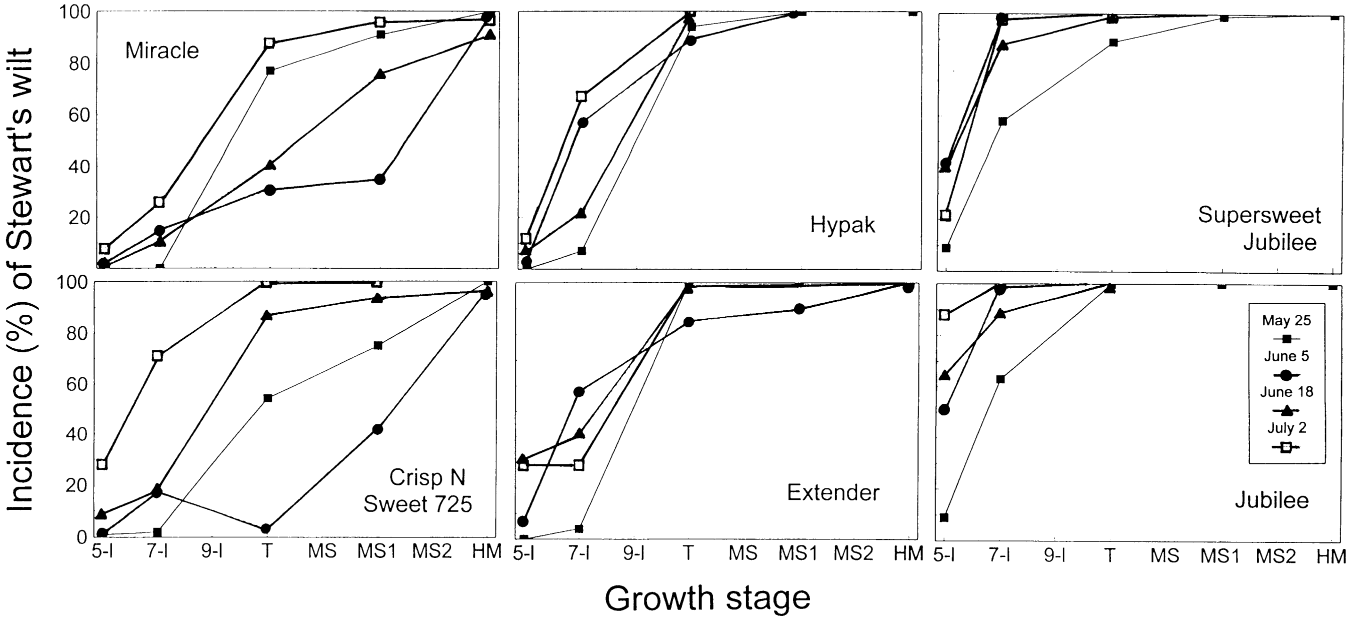

Fig 3. Incidence (%) of Stewart's wilt on six sweet corn hybrids planted on four dates in Urbana, IL, in 1991. Comparisons at eight growth stages: 5-l, 7-l, and 9-l = five-, seven-, and nine-leaf stages; T = tassel; MS, MS1, and MS2 = mid-silk, mid-silk + 1 week, and mid-silk + 2 weeks; and HM = harvest maturity.

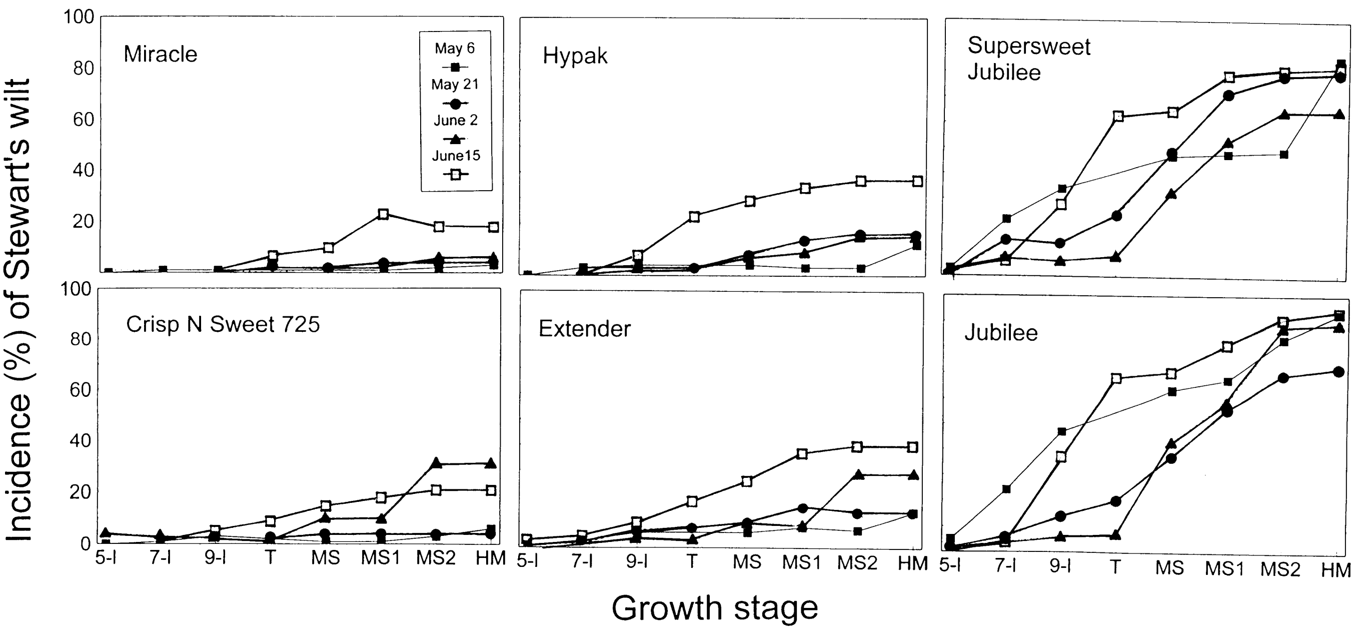

Fig 4. Incidence (%) of Stewart's wilt on six sweet corn hybrids planted on four dates in Urbana, IL, in 1992. Comparisons at eight growth stages: 5-l, 7-l, and 9-l = five-, seven-, and nine-leaf stages; T = tassel; MS, MS1, and MS2 = mid-silk, mid-silk + 1 week, and mid-silk + 2 weeks; and HM = harvest maturity.

perature index (1).

Although our results and those of others (5,6) indicate that incidence of Stewart's wilt on early plantings is not a reliable predictor of subsequent levels of disease, decisions regarding control of Stewart's wilt might be modified based on scouting early-planted crops for symptoms. It seems prudent to implement control measures for subsequent plantings if Stewart's wilt is abundant on early plantings in spite of average winter temperatures well below freezing. Conversely, a relatively low incidence of Stewart's wilt on early-planted crops is not indicative of a low amount of disease on later plantings based on our and others' observations. Assessments of Stewart's wilt incidence at early growth stages, e.g., three- to seven-leaf, also could be used to estimate the effect of the disease on yield as long as levels of resistance and susceptibility are considered (11). Estimates of yield reduction could be useful to food processors who frequently estimate yields near the tasseling stage in order to plan production schedules at processing plants.

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