Influence of Planting Date and Cultivar on Soybean Sudden Death Syndrome in Kentucky

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ABSTRACT

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In a 3-yr study in western Kentucky, soybean (*Glycine max*) cultivars differed in susceptibility to soybean sudden death syndrome (SDS), and their reactions, while not always consistent, were affected by planting date. In 1987 and 1988, May plantings resulted in higher SDS levels for most cultivars than did plantings in mid-June through early July. The reverse occurred for some cultivars in 1986, and others were unaffected by planting date. While the relative SDS reactions of most cultivars were generally consistent among years, all cultivars were affected, at least moderately, in one or more plantings. Overall, cultivars resistant to the soybean cyst nematode (*Heterodera glycines*) were less affected by SDS than were cultivars susceptible to *H. glycines*; however, yields were generally not correlated ($P > 0.05$) with either densities of viable cysts of *H. glycines* at soybean harvest or SDS progress (area under the disease progress curve). Similarly, area under the disease progress curve and densities of viable cysts were poorly correlated ($P > 0.5$) for most planting date and cultivar combinations. The number of pods per plant was reduced as SDS severity increased from moderate to severe levels; however, mild symptom expression did not affect pod numbers. Similarly, plant height was unaffected by SDS.

Additional keywords: *Fusarium solani*

Sudden death syndrome (SDS) of soybean (*Glycine max* (L.) Merr.), although discovered in Arkansas in 1971 (7), has only recently been recognized as a major disease of soybeans in parts of Arkansas, Illinois, Indiana, Kentucky, Missouri, Mississippi, and Tennessee (8,10,16,21). While SDS is not a serious problem every year, severe occurrences can reduce yields by 80% or more (10,18). These reductions are a result of reduced photosynthetic area, premature defoliation, flower and pod abortion, and reduced seed size (10,16,17).

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SDS was first observed in Kentucky in 1984 in four counties of the Green River area. Since then, its occurrence has been confirmed in 20 counties of western Kentucky, where 60% of the soybeans in the state are produced. The most severe episodes of the disease have been observed in conventionally tilled, river bottom fields of Melvin silt loam or Karnak silty clay soils that are infested with the soybean cyst nematode (*Heterodera glycines* Ichinohe) but have a high yield potential.

SDS is a disease of soybean roots, lower stems, and leaves and is reportedly the result of root infections by a slow-growing, blue-pigmented, macroconidium-forming strain of *Fusarium solani* (Mart.) Sacc. (*F. solani* strain A [11-14,17-19]). *F. solani* strain A has been isolated from soybeans with symptoms of SDS in Kentucky (18). The soybean cyst nematode has been implicated as being associated with SDS development (11,13,14,16-18,21). In greenhouse studies (11,13,14), high cyst density of *H. glycines* was not necessary for SDS to occur but was shown to exacerbate foliar symptoms of SDS and resulted in earlier and more severe symptom expression. However, the relationship between SDS severity and *H. glycines* under field conditions has been inconsistent, with Rupe (17) reporting good correlations for some cultivars and Hirrel (10) reporting poor correlations.

The development of effective SDS control recommendations has been impeded by the lack of data and the inconsistency of data on the effects of cultural practices and cultivars on SDS development. While numerous studies (2,3,5,9,10,16,17,20,21) have evaluated the SDS reactions of many soybean cultivars, many of the data have been variable and have depended on the location and the year. This has led to difficulties in the development of reliable lists of cultivars resistant to SDS. Similarly, there are few reports on the effects of planting date on SDS. Preliminary work (2,4,6; A. Y. Chambers, *unpublished*) has indicated that planting date has a major role and should be considered in the development of SDS control strategies.

The relationship between SDS and soybean yield loss under field conditions has received little attention. In cultivar tests (2,3,5,10,16,20), yield relationships with SDS have been inconsistent. Scott reported (21) that yields per plant were most adversely affected by SDS when symptoms began early in pod development. von Qualen et al reported (23) a relationship between yield reductions in plants and premature dying (i.e., SDS); however, neither Scott (21) nor von Qualen et al (23) evaluated yield loss as a function of relative disease severity. Conversely, Hirrel (10) developed yield loss equations for specific situations in Arkansas and southern Illinois; however, the applicability of these equations to other production areas is unknown.

This paper reports the effects of planting date and cultivar on the development of soybean sudden death syndrome in Kentucky. The relationships between SDS and density of cysts of *H. glycines* and between SDS and yield under field conditions were also studied.

Table 1. Soybean cultivars used in soybean sudden death syndrome/planting date studies, 1986–1988

Cultivar	Maturity group	SCN race resistance[a]	SDS reaction[b]
Harper	III	...	MS
Fayette	III	3,4	S
Williams 82	III	...	S
Pershing	IV	...	R
Mitchell	IV	...	S
Franklin	IV	1,3	NR
Essex	V	...	S
Coker 355	V	3,4	R

[a] Reported resistance to races of soybean cyst nematode (SCN).
[b] Preliminary reports of soybean sudden death syndrome (SDS) reactions of cultivars at the SDS symposium in Little Rock, Arkansas, in December 1985; R = resistant, MS = moderately susceptible, S = susceptible, NR = not reported.

MATERIALS AND METHODS

Effect of cultivar and planting date on SDS. The cultivars (Table 1) were selected for their reported SDS reactions, resistance to *H. glycines*, and maturity grouping. The preliminary SDS reactions of the cultivars were based on reports by soybean researchers from various states at an SDS symposium in Little Rock, Arkansas, in December 1985.

During 1986–1988, the cultivars were planted in conventionally tilled bottomland soils. In 1986, the site was a field of Melvin silt loam, pH 6.3, near Rumsey, McLean County, Kentucky, that was planted to corn in 1984 and soybeans in 1985. In 1987 and 1988, the site was a field of Karnak silty clay, pH 6.8, near Sacramento, McLean County, Kentucky, that was planted to soybeans in 1985 and corn in 1986. Fields at both locations were infested with race 3 of *H. glycines* and had a history of severe SDS occurrence. The design was a split-plot, randomized complete block design, with four replications in 1986 and five in 1987 and 1988. Planting dates were the main plots and cultivars were the subplots. Plots consisted of four rows spaced 75 cm apart. Plots were 6.1 m long in 1986 and 1988 and 12.1 m long in 1987. The seeding rate was 26 seeds per meter.

The number of cysts of *H. glycines* that contained eggs or juveniles was determined in 473-cc soil samples. Six cores (15-cm deep × 2.5-cm diam., approximately 500 cc of soil) were taken just before soybean harvest in 1986–1988, in the center two rows of each plot. Cores were collected at random from within the root zones of plants and thoroughly mixed in a bucket. Samples were stored at 4 C for 1–2 wk before being processed. Cysts were extracted with a sucrose-centrifugation, flotation technique. A soil

Table 2. Significance of *F* value from analysis of variance for soybean sudden death syndrome (SDS) based on incidence, severity, and area under the disease progress curve and soybean yield for eight cultivars in planting date studies, 1986–1988

Independent variable	SDS incidence[a]			SDS severity[b]			AUDPC[c]			Yield		
	1986	1987	1988	1986	1987	1988	1986	1987	1988	1986	1987	1988
Planting date (PD)[d]	NS[f]	0.003	0.0001	NS	0.03	0.0001	NS	0.0001	0.0001	0.04	0.01	0.0001
Cultivar (cv)[e]	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0001	0.0001	0.0001	0.002	0.002	0.0001
PD × CV[e]	0.001	0.0001	0.0001	0.0001	0.009	0.005	NS	0.0001	0.0001	0.01	0.002	0.0001

[a] Based on percent of plants with symptoms at full pod stage (R_6).
[b] Based on average percent of foliar cholorosis and necrosis and general level of defoliation in plots at full pod (R_6).
[c] Area under disease progress curve (R_{3-6}).
[d] Rep × planting date was used as an error term in the *F* test.
[e] Cultivar × rep and planting date × cultivar × rep were pooled to give the error term in the *F* test.
[f] Not significant, $P > 0.1$.

Table 3. Effect of planting date and cultivar on soybean sudden death syndrome (SDS) and soybean yields, 1986

Cultivar[y]	Maturity group	SDS incidence[u]			SDS severity[v]			AUDPC[w]		
		21 May	16 June	30 June	21 May	16 June	30 June	21 May	16 June	30 June
Harper (S)	III	2.0 aA[z]	1.8 aA	2.8 bB	1.8 aA	2.3 bAB	2.8 bB	42.9 aA	48.0 bA	62.0 bcB
Fayette (R)	III	2.5 abB	1.5 aA	1.0 aA	2.8 bB	1.5 aA	1.0 aA	55.3 aB	41.0 bB	0.0 aA
Williams 82 (S)	III	3.8 cB	3.3 bcAB	2.5 abA	3.0 bB	3.3 cB	2.0 abA	109.9 a–cAB	142.6 bcB	79.6 cA
Pershing (S)	IV	3.0 bA	3.8 cAB	4.0 cB	2.5 abA	3.5 cB	3.8 cB	132.9 b–dA	214.9 cdAB	264.9 deB
Mitchell (S)	IV	3.3 bcA	3.8 cA	4.0 cA	3.0 bA	3.8 cA	3.8 cA	176.6 cdA	238.1 dA	181.5 dA
Franklin (R)	IV	1.8 aA	1.0 aA	1.3 aA	2.0 aA	1.0 aA	1.3 aA	77.0 abB	0.0 aA	38.4 aAB
Essex (S)	V	3.3 bA	3.8 cAB	4.3 cB	2.8 bA	3.5 cB	3.5 cB	204.5 dA	263.1 dB	291.0 eB
Coker 355 (R)	V	1.8 aA	3.0 bB	1.8 aA	3.3 bB	1.5 aA	1.5 aA	128.8 b–dA	97.3 bcA	92.3 cA
Cultivar Mean		2.7 A	2.8 A	2.7 A	2.7 A	2.6 A	2.5 A	116.0 A	130.6 A	126.2 A

[u] 1 = no symptoms, 2 = 1–10% of plants with symptoms, 3 = 11–30%, 4 = 31–70%, 5 = > 70%; ratings are for cultivars in the full pod (R_6) stage.
[v] 1 = no symptoms; 2 = < 10% chlorotic spotting, no necrosis; 3 = 11–30% chlorosis, ≤ 10% necrosis; 4 = 11–30% necrosis with no to light defoliation; 5 = 31–70% necrosis with light to moderate defoliation; 6 = > 70% necrosis with severe defoliation; ratings are for cultivars in the full pod (R_6) stage.
[w] Area under the disease progress curve (R_{3-6}) based on a disease index calculated at the product of the scores from disease incidence and disease severity.
[x] Yield at 11.7% moisture.
[y] S = susceptible to *Heterodera glycines*; R = resistant to *H. glycines*, race 3.
[z] All values are averages of four replications. Means in a column followed by a common letter are not significantly different, Duncan's multiple range test, $P = 0.05$; uppercase letters compare means among planting dates within each dependent variable.

subsample of approximately 250 cc from each plot was suspended in water, allowed to stand for 30 sec, and decanted through 20- and 60-mesh sieves. The residue collected on the 60-mesh screen was resuspended in water and centrifuged for 4 min at 3,000 rpm. The pellet was suspended in a sucrose solution (480 g/l of water) and centrifuged for 1 min at 3,000 rpm. Cysts in the supernatant were collected on a 100-mesh sieve and washed into a gridded petri dish for counting. Only cysts that contained eggs and/or juveniles were counted.

Plots were observed at 2-wk intervals until SDS symptoms were found. Once symptoms were detected for a plot, ratings were made at 7- to 10-day intervals through the R_6 stage (1) of plant development. Plots were rated for incidence and severity of SDS by observing the center two rows of each plot. SDS incidence was rated with the aid of a transformed scale of 1–5 in 1986 and 1–8 in 1987 and 1988, which represented a visual estimate of the percent of plants in each plot with any SDS symptoms. During 1986–1988, SDS severity was rated with a transformed scale of 1–6 representing visual estimates of the average percent of foliar chlorosis/necrosis and general defoliation levels in each plot. The rating scales were refined over the course of this work, and the criteria used are given in each table. The area under disease progress curve (AUDPC) was calculated (22). Disease progress was based on changes in a disease index (DI) over time. DI was calculated for each plot at each rating date by multiplying the incidence rating by the severity rating.

Soybean yields (1986–1988) were obtained by hand harvesting and threshing (Swanson Thresher, Swanson Machine Co., Champaign, IL) a 4.8-m length of the center two rows in each plot. Seed were cleaned and yields were calculated on a basis of 11.7% moisture content.

Pod number and plant height relationships with SDS severity. The studies relating severity of SDS to soybean pod number and plant height were conducted at a location near Rumsey in a conventionally tilled bottomland tract of Melvin silt loam, pH 6.6. The site was planted to soybeans in 1985 and 1986 and corn in 1984 and had a history of infestation of *H. glycines* race 3 and SDS occurrence. In 1987 and 1988, conventional methods were used to plant the field in 75 cm-rows with Douglas soybeans. Douglas is an indeterminant, maturity group IV cultivar that has shown a severe SDS reaction (D. E. Hershman, *unpublished*) and is susceptible to all races of *H. glycines*. In 1987 and 1988, 60 and 200 plants in the R_6 stage with varying severities of SDS, respectively, were collected from within each of four randomly selected 54-m-long rows in the field. Collected plants were then segregated according to severity of SDS symptoms following the rating scale described for planting date studies. For each plant in each severity category, both plant height and the number of green pods were determined. Plant height was measured (cm) from the soil level of plants to the uppermost growing point. Pod counts in 1987 included all pods, both developing and fully expanded. In 1988, however, only fully expanded pods were counted.

Yield (kg/ha)[x]		
21 May	16 June	30 June
2,409 NS A	2,492 NS A	1,561 aB
2,868 A	2,919 A	2,320 bB
2,683 A	2,537 A	1,747 abB
2,530 A	2,518 A	1,561 aB
2,594 A	2,369 AB	1,925 abB
2,651 A	2,862 A	2,219 cB
2,907 A	2,460 AB	2,033 bB
2,900 A	2,931 A	2,218 bB
2,693 A	2,636 A	1,948 B

RESULTS

Cultivar response to SDS and the influence of planting date. In all years and plantings where SDS occurred, foliar symptoms first occurred in plants during the R_{3-5} stages and generally increased in severity through R_6. SDS symptoms were not observed in plants before the R_3 stage. Overall, SDS incidence was moderate throughout this study (Tables 2–5).

From the analysis of variance on data for 1986–1988, we concluded that incidence and severity of SDS at soybean stage R_6 and AUDPC differed significantly ($P \leq 0.04$) among the planting dates in 1987 and 1988, but not in 1986 (Table 2). In 1987 and 1988 (Tables 4 and 5), the early plantings had significantly higher SDS ratings among cultivars than late plantings. In 1986, however, SDS occurred in plantings made on all three dates at about equal levels (Table 3).

The reactions of cultivars to SDS among planting dates were highly significantly different ($P \leq 0.005$) in 1986–1988 (Table 2); however, a significant ($P \leq 0.01$) cultivar × planting date interaction for the 3 yr precluded interpretation of the main effect of reaction of cultivars to SDS (Tables 2–5). As a general interpretation covering all planting dates for the full 3 yr, the cultivars least affected by SDS were Coker 355, Franklin, and Fayette (Tables 3–5). Essex and Mitchell were the most affected, followed by Harper, Williams 82, and Pershing. However, rankings of cultivars were not consistent and depended on the year and planting date. For example, in the 15 May 1987 planting (Table 4), Franklin had the lowest SDS ratings except for Coker 355; however, in the 22 June 1987 planting, the SDS ratings for Franklin were either equal to or greater than ratings for all cultivars except Mitchell. Similarly, although overall the least affected cultivar was Coker 355 followed by Franklin, the reverse was true in the 16 June 1986 planting (Table 3), where Coker 355 had significantly higher SDS ratings than Franklin, which was unaffected. Also, Essex, Harper, and Pershing, which were most severely affected in the early plantings in 1987 and 1988 (Tables 4 and 5), had significantly higher SDS ratings in the late (30 June) planting in 1986 than in the early (21 May) planting (Table 3). The reverse was true for Fayette in 1986, while Franklin, Mitchell, and Williams 82 were unaffected by planting date (Table 3). Fayette was the only cultivar to consistently have higher SDS ratings for early plantings than for late plantings among the 3 yr of this study (Tables 3–5).

Soybean yield relationships with planting date and SDS. In planting date studies, soybean yields differed significantly among the eight cultivars, among planting dates, and for cultivar by planting date interactions (Table 2). Among planting dates and within years, cultivar yields were variable except for Fayette and Pershing, which had consistently high and low yields, respectively, relative to the other cultivars (Tables 3–5). Among planting dates, within years, late planting resulted in consistently lower yields for all cultivars as compared with early planting (Tables 3–5). Within planting dates, cultivar yield differences were mostly not significantly different ($P >$ 0.05) from one another.

Correlation coefficients for planting dates, within years, for the individual cultivars were typically nonsignificant ($P > 0.05$) for AUDPC-yield relationships. Exceptions were for Pershing, Mitchell, and Essex in the 16 June 1986 planting; Essex in the 30 June 1986 planting; and Fayette in the 15 May 1987 planting.

Differences in severity of SDS did not affect plant height in either 1987 or 1988 (Fig. 1A). However, the number of green pods per plant (Fig. 1B) decreased as the level of SDS severity increased from moderate to severe; mild symptom expression, however, had no effect on pod numbers.

Relationship between SDS and cyst densities of *H. glycines*. Correlations between AUDPC and cyst densities of *H. glycines* at soybean harvest were nonsignificant ($P > 0.5$) for almost every cultivar/planting date combination. Exceptions were Pershing and Coker 355 in the 30 June 1986 planting and Harper in the 17 May 1988 planting. Similarly in 1986–1988, soybean yield was correlated ($P < 0.05$) with cyst densities of *H. glycines* at soybean harvest only for Pershing (two of seven planting dates) and for Williams 82 and Essex (one of seven planting dates).

DISCUSSION

Among years and planting dates, soybean cultivars differed in their reaction to SDS (Tables 3–5). Overall, cultivars resistant to soybean cyst nematode were less affected by SDS than cultivars susceptible to the nematode; this is in general agreement with other reports (8,10, 16,17). However, in this study, all cultivars were at least moderately affected in one or more planting and some cultivars had wide-ranging SDS reactions, depending on the year and the planting.

Many reports (2,3,5,9,10,16,20,21) have indicated specific levels of SDS susceptibility for many different soybean cultivars. Close scrutiny of the data, however, reveals conflicting results for many cultivars, similar to our findings, and the results depend on the year and/or location. Thus, great care must be taken when classifying the reactions of soybean cultivars to SDS.

Part of the variability associated with cultivar response to SDS may be related to planting date effects. In Tennessee, significantly reduced levels of SDS were observed with the cultivars Deltapine 417 and 105 when planting was delayed, especially from late May or early June to late June or early July (A. Y. Chambers, *unpublished*). This is reinforced by our observations that double-cropped soybeans, which are typically planted in Kentucky in late June through early July, rarely have SDS (D. E. Hershman, *unpublished*). Our tests in 1987 and 1988 (Tables 4 and 5) were in general agreement with this. However, in 1986 (Table 3), SDS was more severe in some cultivars in the late (30 June) planting than in the early (21 May) planting, whereas other cultivars were unaffected by planting date.

The difficulty in pinpointing consistent relationships between SDS, cultivar, and planting date may be attributable to the involvement of other factors capable of influencing SDS development, such as processes leading to root colonization by *F. solani* strain A and SDS symptom expression. Environmental factors preceding symptom expression have received the most attention (8–10,14,15, 18,21). Generally, the appearance of

Table 4. Effect of planting date and cultivar on soybean sudden death syndrome (SDS) and soybean yields, 1987

Cultivar[y]	Maturity group	SDS incidence[u]		SDS severity[v]		AUDPC[w]		Yield (kg/ha)[x]	
		15 May	22 June	15 May	22 June	15 May	22 June	15 May	22 June
Harper (S)	III	3.6 cB[z]	1.6 aA	2.8 bcB	1.6 abA	181.7 bB	59.1 bA	2,779 aA	2,027 aB
Fayette (R)	III	3.6 cB	1.6 aA	2.5 bA	2.0 bcA	135.9 bB	49.5 abA	2,731 abA	2,097 aB
Williams 82 (S)	III	4.3 cB	2.4 bA	3.6 cdB	2.4 bcA	250.5 cB	88.8 cA	2,499 abA	2,098 aB
Pershing (S)	IV	4.2 cB	1.6 aA	3.0 bcB	1.8 abA	302.0 cB	53.1 abA	2,435 bA	1,919 abB
Mitchell (S)	IV	7.8 aB	4.4 dA	4.0 dB	3.0 cA	465.2 dB	187.3 dA	2,499 abA	1,989 aB
Franklin (R)	IV	2.6 bA	3.4 cA	2.4 bA	2.8 cA	65.2 aA	96.6 cA	2,473 abA	1,868 abB
Essex (S)	V	6.6 dB	3.2 cA	3.4 cdB	2.0 bcA	477.5 dB	75.0 bcA	2,511 abA	1,995 abB
Coker 355 (R)	V	1.0 aA	1.0 aA	1.0 aA	1.0 aA	0.0 aA	0.0 aA	2,696 abA	1,714 bB
Cultivar average		4.2 B	2.4 A	2.8 B	2.0 A	234.8 B	76.2 A	2,577A	1,963 B

[u] 1 = no symptoms, 2 = < 1% of plants with symptoms, 3 = 1–5%, 4 = 6–15%, 5 = 16–30%, 6 = 31–50%, 7 = 51–70%, 8 = > 70%; ratings are for cultivars in the full pod (R_6) stage.
[v] 1 = no symptoms; 2 = ≤ 10% chlorotic spotting, no necrosis; 3 = 11–30% chlorosis, ≤ 10% necrosis; 4 = 11–30% necrosis, no defoliation; 5 = 30%–70% necrosis, slight defoliation; 6 = > 70% necrosis, moderate to severe defoliation; ratings are for cultivars in the full pod (R_6) stage.
[w] Area under the disease progress curve (R_{3-6}) based on a disease index calculated as the product of the scores from disease incidence and disease severity.
[x] Yield at 11.7% moisture.
[y] S = susceptible to *Heterodera glycines*; R = resistant to *H. glycines*, race 3.
[z] All values are averages of five replications. Means in a column followed by a common letter are not significantly different, Duncan's multiple range test, $P = 0.05$; uppercase letters compare means between planting dates.

Table 5. Effect of planting date and cultivar on soybean sudden death syndrome (SDS) and soybean yields, 1988

Cultivar[y]	Maturity group	SDS incidence[u]		SDS severity[v]		AUDPC[w]		Yield (kg/ha)[x]	
		17 May	11 July	17 May	11 July	17 May	11 July	17 May	11 July
Harper (S)	III	7.6 cB[z]	1.0 NS A	3.6 bB	1.0 NS A	557.3 cB	0.0 NS A	2,288 NS A	1,077 bB
Fayette (R)	III	6.2 bB	1.0 A	3.2 abB	1.0 A	395.5 bB	0.0 A	2,504 A	1,141 bB
Williams 82 (S)	III	5.8 bB	1.0 A	3.4 abB	1.0 A	194.4 aB	0.0 A	2,569 A	1,122 bB
Pershing (S)	IV	6.0 bB	1.0 A	3.6 bB	1.0 A	666.5 dB	0.0 A	2,620 A	739 abB
Mitchell (S)	IV	6.8 bcB	1.0 A	4.0 bB	1.0 A	597.9 cdB	0.0 A	2,518 A	1,262 bB
Franklin (R)	IV	3.2 aB	1.0 A	2.6 aB	1.0 A	130.1 aB	0.0 A	2,486 A	1,013 abB
Essex (S)	V	6.2 bB	1.0 A	3.8 bB	1.0 A	470.7 bcB	0.0 A	2,352 A	720 aB
Coker 355 (R)	V	3.2 aB	1.0 A	2.8 aB	1.0 A	252.7 aB	0.0 A	2,543 A	427 aB
Cultivar average		5.6 B	1.0 A	3.4 B	1.0 A	445.6 B	0.0 A	2,485 A	937 B

[u] 1 = no symptoms, 2 = < 1% of plants with symptoms, 3 = 1–5%, 4 = 6–15%, 5 = 16–30%, 6 = 31–50%, 7 = 51–70%, 8 = > 70%; ratings are for cultivars in the full pod (R_6) stage.
[v] 1 = no symptoms; 2 = ≤ 10% chlorotic spotting, no necrosis; 3 = 11–30% chlorosis, ≤ 10% necrosis; 4 = 11–30% necrosis, no defoliation; 5 = 30%–70% necrosis, slight defoliation; 6 = > 70% necrosis, moderate to severe defoliation; ratings are for cultivars in the full pod (R_6) stage.
[w] Area under the disease progress curve (R_{3-6}) based on a disease index calculated as the product of the scores from disease incidence and disease severity.
[x] Yield at 11.7 moisture.
[y] S = susceptible to *Heterodera glycines*; R = resistant to *H. glycines*, race 3.
[z] All values are averages of five replications. Means in a column followed by a common letter are not significantly different, Duncan's multiple range test, $P = 0.05$; uppercase letters compare means between planting dates.

foliar symptoms under field conditions has been associated with cool and/or wet weather (8–10,14,15,18). In the greenhouse, conditions of continuously high soil moisture (14), especially when initiated in the early vegetative growth stages (V_3), resulted in more severe SDS than did low soil moisture or alternate low and high soil moistures. Soybeans under field conditions also showed more SDS when irrigated continuously from the V_3 growth stage than from the V_5 growth stage (14). Our work generally supports the idea of increased SDS with higher soil moisture. Hot and dry conditions late in the season in 1987 and during most of the season in 1988 were associated with limited SDS development, especially in late plantings (Tables 4 and 5). In 1986, however, moisture late in the season was not limiting and significant SDS developed in both early and late plantings (Table 3).

In addition to environmental factors, organisms other than *F. solani* may influence expression of SDS symptoms and result in variable reactions of the same cultivar under different conditions (18,23). Of the many possible disease organisms that could influence SDS, the soybean cyst nematode has received the most attention. Others have reported

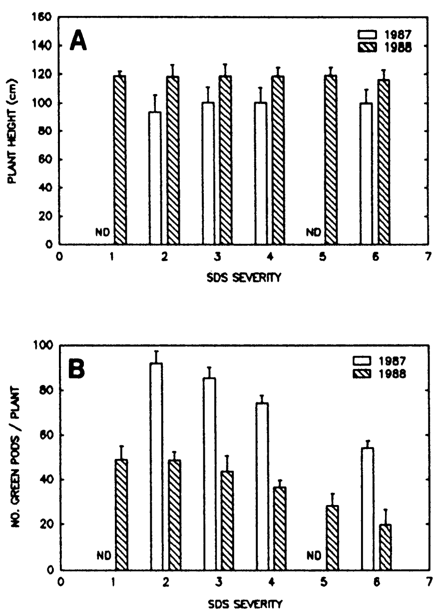

Fig. 1. Effect of soybean sudden death syndrome (SDS) severity on **(A)** plant height (cm) and **(B)** number of green pods per plant (developing and fully expanded pods in 1987 and only fully expanded pods in 1988) of Douglas soybeans at full pod (R_6), 1987–1988. SDS foliar severity ratings: 1 = no symptoms; 2 = ≤ 10% chlorotic spotting, no necrosis; 3 = 11–30% chlorosis, ≤ 10% necrosis; 4 = 11–30% necrosis, no defoliation; 5 = 31–70% necrosis, slight defoliation; 6 = > 70% necrosis, moderate to severe defoliation. Number of observations for SDS severity ratings in 1987: 1 = No data (ND), 2 = 50, 3 = 51, 4 = 59, 5 = ND, 6 = 70; in 1988, 1 = 44, 2 = 213, 3 = 182, 4 = 127, 5 = 103, 6 = 68. Values are means and the bar represents ± 1 standard deviation.

(11,12,14,17,21) that *H. glycines*, when present in significant populations, may be involved in SDS development. Our study supports this idea because cultivars resistant to *H. glycines* were less affected by SDS than were nematode-susceptible cultivars (Tables 3–5). However, cyst densities of *H. glycines* measured at soybean harvest were not correlated ($P >$ 0.05) with AUDPC in most instances. Similarly, lack of correlations ($P > 0.05$) between cyst densities of *H. glycines* and soybean yield indicate that *H. glycines* was not a major factor in this study. Perhaps greater correlation between *H. glycines* and SDS, as reported by Rupe (18), would occur with greater density of soybean cyst nematodes. Alternately, the inconsistent relationship between cyst densities of *H. glycines* and SDS may be attributable to a nonessential, but frequently significant, role of *H. glycines* in SDS development. A consistent relationship between the nematode and SDS would be expected only if *H. glycines* were obligately linked with SDS development. This apparently is not the case (11,13,14); high densities of *H. glycines* in greenhouse studies enhanced the earliness and severity of SDS, but severe SDS developed in the absence of the nematode.

In all years, plantings, and cultivars where SDS occurred in our study, symptom expression was tied to plant development rather than calendar age. Symptoms were not observed before plants reached the early- to mid-pod fill stages (R_{3-5}), regardless of planting age or cultivar. This is in general agreement with other reports (2,3,21); however, SDS has been observed under field conditions at earlier plant stages in Arkansas (10,18), Mississippi (20), and Kentucky (D. E. Hershman, *unpublished*). Similarly, soybean plants inoculated with *F. solani* in greenhouse studies (11,14,18) and in a field study using natural inoculum in Arkansas (J. Rupe, *unpublished*) expressed SDS symptoms without regard to the physiologic age of plants.

There was no relationship between the severity of SDS and plant height in either 1987 or 1988 (Fig. 1A). Scott (21) reported similar findings under field conditions. Others have associated reductions in plant height with SDS in both greenhouse studies (14,18) and in a field study (23). The inconsistent relationship between the onset of SDS symptoms and plant development indicate great variability in the events that precede SDS symptom expression. Additional work is needed to define the factors that control or modify the presymptomatic stages of SDS, particularly as they relate to soybean development.

Disease ratings for SDS are not always well correlated with yield (2,3,5,10, 16,20), and we also found this relationship to be generally poor. This inconsistent relationship may be related to the stage of soybean development when SDS ratings are made (10) or the earliness of SDS symptom expression (21). In this study, relatively late (mid-R_5 or later) symptom expression may have resulted in the minor yield effects observed (Tables 3–5). Also, the predominantly moderate symptom expression, as noted in this study, may have resulted in the poor yield associations. Specifically, our findings support those of Scott (21) and von Qualen et al (23) in which reduced numbers of pods were associated with SDS (Fig. 1B). Additionally, we determined that pod numbers are reduced with increasing SDS severity, but only when symptoms were moderate to severe. Thus, a planting with a large number of plants with mild to moderate SDS symptoms, although very conspicuous, may have little adverse effect on yields. This may account, at least in part, for some of the poor yield associations with SDS as reported by others (2,3,5,10,16,20).

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