Brown Spot Severity and Yield Reduction in Soybean

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ABSTRACT

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The effect of brown spot, which is caused by *Septoria glycines*, on yield and 300-seed weight of two soybean cultivars, Wells and Williams, and the relationship between brown spot severity and yield reduction were studied in 1977 and 1978. Different levels of brown spot epidemics were established by inoculating soybean plants at various growth stages. Disease severity and apparent infection rate in 1977 were not significantly different between the two cultivars when they were inoculated and evaluated at corresponding growth stages. Infection rates were higher in both cultivars when they were inoculated at late growth stages (R4–R5). Williams was more severely diseased than was Wells at corresponding stages in 1978, but there were no significant differences in apparent infection rates between cultivars or between plants inoculated at the different growth stages. Yield and 300-seed weight differed significantly between inoculated, control (protected with benomyl spray), and naturally infected plots. Yield reduction in both Wells and Williams ranged 12 – 34% during the 2 yr. The regression of yield reduction on the area under the brown spot progress curve (AUBC) gave a good fit with the data. Regression of yield reduction on disease severity rated at the R6 stage also satisfactorily explained the relationship between brown spot severity and yield.

Additional key words: Glycine max, AUBC model, critical-point model, epidemiology.

Brown spot of soybean (*Glycine max* L.), which is caused by *Septoria glycines* Hemmi, is a foliar disease widely distributed in all soybean-growing areas of the world (3,10). Brown spot develops on leaves throughout the growing season and often causes severe defoliation. It also may occur on stems and pods as plants approach maturity (10).

Infection, usually initiated by conidia from pycnidia that overwinter on diseased plant debris in the soil, is most prevalent in fields planted to soybeans in consecutive years. Warm, moist weather and poor drainage favor the spread of the disease. Recently, the importance of brown spot in Illinois has been realized (1,8). Resistant cultivars are not currently available (7) and crop rotation is suggested to minimize disease damage (1).

Although yield losses caused by *S. glycines* have been reported (11), little is known about the damage potential of this disease or the relationship between brown spot severity and yield reduction. Young and Ross (11) reported that the yield of Essex soybeans inoculated with *S. glycines* was 17% less than that of uninoculated plants. The experiments described herein were designed to assess the potential effect of brown spot epidemics on soybean yield and 300-seed weight, and to determine the relationships between disease severity and reductions in yield and 300-seed weight.

MATERIALS AND METHODS

Experiments were conducted in 1977 and 1978 on the Agronomy South Farm, Urbana, IL, on Drummer silty clay loam soil that had been planted to corn in previous years. The soybean cultivars planted were Wells, which is in maturity group II, and Williams, which is in maturity group III and matures about 2 wk later than Wells. Both cultivars are susceptible to *S. glycines* and are grown extensively in Illinois and other midwestern states.

The relationship between soybean growth stage (2) and severity of brown spot was studied. Inoculum was prepared from 2-to 3-wk-old cultures of *S. glycines* grown on potato-dextrose agar. Cultures were blended in tap water for 2–3 min and suspensions were filtered through several layers of cheesecloth. For field inoculations, soybean plants received a spore suspension containing about 2×10^5 spores per milliliter applied until run-off with a hand gun sprayer operated at 5.6 kg/cm^2 (80 psi). Williams was inoculated at growth stages V7, R2, R3, R4, and R5 and Wells at growth stages V8, R3, R4, R5, and R6. In 1977, these stages occurred on 24 June, 10 July, 22 July, 2 August, and 15 August, respectively. In 1978, these stages occurred on 29 June, 14 July, 28 July, 9 August, and 24 August, respectively. Control plots were protected both years with four applications of benomyl (Benlate® 50% WP formulation: methyl 1-[butylcarbamoyl]-2-benzimidazole carbamate) applied at 1.1 kg/ha in 280 L of water per hectare. Plants in plots to be inoculated were protected in 1977 with benomyl until 2 wk before inoculations; however, benomyl was not applied in 1978, because natural infection was not noticed until mid-August.

In 1977, four-row plots, 6.1 m in length, and 76 cm between the rows were planted on 18 May at a seeding rate of eight seeds per 30 cm of row. The experiment was replicated four times in a split-plot arrangement of a randomized complete block design in which the two soybean cultivars were whole plots and the five times of inoculation and control were subplots. In 1977, all four rows of a given plot were inoculated at a specified growth stage. In 1978, eight-row plots were planted on 27 May. The center four rows of the eight-row plots were inoculated and the two remaining rows on each side served as guard rows bordering the plots. The experimental design was the same as that in 1977 except for the addition of uninoculated subplots to provide an estimate of the incidence of natural infection.

Disease severity in each plot was rated at 2-wk intervals from the first inoculation in both years by using a modified Horsfall and Barratt scale (5). The percent severity (as percentage of leaf area infected) was calculated by conversion of disease ratings with Elanco conversion tables (Elanco Products Co., Indianapolis, IN 46140). The soybean growth stage (2) was recorded on each disease rating date. The regression of disease progress over time in each plot was estimated with logit transformation of disease severity expressed as proportion of disease (9): $\hat{Y} = a + bt$ with $\hat{Y} = \text{logit } Y = \log_e Y(1-Y)^{-1}$ for predicted disease proportion (Y), b = regression coefficient of logit Y on t which is the same as Vanderplank's (9)

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TABLE 1. Area under brown spot progress curves (AUBC), yield, and seed weight of two soybean cultivars

	Wells						Williams					
			Yield		300-seed wt				Yield		300-seed wt	
Inoculation date	Growth stage	AUBC value	q/ha	loss (%)	g	loss (%)	Growth stage	AUBC value	q/ha	loss (%)	g	loss (%)
1977												
24 Jun	V8[a]	165.1	36.4	28.7	51.3	15.0	V7[a]	207.2	37.2	30.0	57.6	12.0
10 Jul	R3	168.8	33.9	33.7	48.9	19.0	R2	197.3	36.5	31.7	56.6	13.3
22 Jul	R4	83.8	38.0	25.3	51.4	15.0	R3	87.1	42.9	19.3	60.1	8.0
2 Aug	R5	40.5	40.4	20.3	51.9	14.0	R4	83.2	42.7	19.7	57.8	12.0
15 Aug	R6	16.1	44.8	12.0	62.0	0.0	R5	40.4	46.0	13.3	61.9	5.7
Control[b]		0.7	50.9	···	60.4	···		0.7	53.3	···	65.4	···
FLSD 0.05[c]		22.9	2.9	···	2.5	···		22.9	2.9	···	2.5	···
FLSD 0.01 = 24.8[d]												
1978												
29 Jun	V8[a]	51.1	26.2	22.7	46.5	8.2	V7[a]	117.5	31.0	17.2	55.6	11.2
14 Jul	R3	92.8	23.9	30.0	43.6	13.5	R2	173.9	28.8	22.0	56.1	10.5
28 Jul	R4	39.7	28.3	17.0	48.3	4.5	R3	98.7	30.6	18.0	54.9	12.0
9 Aug	R5	35.1	28.6	15.7	48.2	5.0	R4	112.4	29.0	22.0	55.0	12.2
24 Aug	R6	31.8	29.6	13.0	48.1	5.2	R5	100.8	31.3	16.5	57.0	9.0
Natural infections		29.3	31.1	8.7	49.2	3.0		92.8	34.4	8.0	58.1	7.2
Control[b]		3.7	34.0	···	50.7	···		13.1	37.3	···	62.6	···
FLSD 0.05[c]		12.9	2.3		2.5			12.9	2.3		2.5	
FLSD 0.01 = 25.9[d]												

[a] The growth stage (2) at the inoculation date.
[b] Benomyl applied at the rate of 1.1 kg/ha.
[c] Fisher's least significant difference, $P = 0.05$ and 0.01.
[d] Difference between two AUBC-values of cultivars at the same inoculation date.

average apparent infection rate (r), and t = time in days after the first inoculation date. The area under the brown spot progress curve (AUBC) was calculated for each plot to express the severity of brown spot for the entire season and to regress yield reduction on cumulative disease severity:

$$AUBC = \sum_{i=1}^{k} (Y_i + Y_{i-1})/2$$

in which Y_i = the severity of brown spot, i = the week of rating, and k = number of successive ratings.

The center two rows of all plots were trimmed to 4.6 m in length before harvest. Soybeans were harvested from these trimmed rows and dried at 37.8 C for 72 hr to 7% moisture. The 300-seed weights were based on 7% moisture, but yields were adjusted to the basis of 13% moisture. Percent yield reductions and 300-seed weight were calculated as follows: ([control treatment − inoculated treatment]/control treatment) × 100. The results of 1977 and 1978 were not compared statistically because different procedures were used to establish different severity levels of brown spot epidemics.

RESULTS

In 1977, the severity of brown spot, as expressed by the AUBC values, was significantly different among plots inoculated at different growth stages except for Wells inoculated at stages V8 and R3, Williams inoculated at stages V7 and R2, and Williams inoculated at stages R3 and R4 (Table 1). Highest AUBC values were obtained from plots inoculated at early stages. Control plots of both Williams and Wells had an AUBC value of 0.7 which was not significantly different from the value of 16.1 obtained from Wells inoculated at stage R6. In 1978, AUBC values from Wells inoculated at stage R3 and Williams inoculated at stage R2 were significantly higher than AUBC values from any other plot for each cultivar. For both years, there were significant differences in AUBC values between the two cultivars inoculated at different growth stages except values obtained from Wells at stage R4 and Williams at stage R3 in 1977. In the control plots, brown spot lesions did not appear until physiological maturity (stage R7), when a few lesions usually were visible on the leaves.

Apparent infection rates, as expressed by regression coefficients (b) and correlation coefficients (r) of logit Y for disease proportion on time, are given in Table 2. The r values for all inoculated plots were highly significant ($0.85 \leqslant r \leqslant 0.99$; $P \leqslant 0.01$). In 1977, apparent infection rates were high in all plots that were inoculated at late growth stages except for Wells inoculated at stage R6. The highest rate in each cultivar was observed in plots inoculated at stage R5 (b = 0.43 for Wells and 0.39 for Williams). Also, the scaling factors, a values (constants that partly fix the position of the regression lines), were considerably lower (more negative) for plots inoculated at late growth stages. In 1978, apparent infection rates in all inoculated plots were similar, and the a values also were similar.

TABLE 2. Regression coefficient (b) and correlation coefficients (r) of linear regression of logit severity of brown spot on two soybean cultivars and time

	Wells				Williams			
Inoculation date	Growth stage	a[a]	b[b]	r	Growth stage	a	b	r
1977								
24 Jun	V8[c]	−2.00	0.06	0.99	V7	−1.70	0.04	0.85
10 Jul	R3	−4.62	0.12	0.95	R2	−4.15	0.09	0.94
22 Jul	R4	−6.23	0.13	0.99	R3	−8.42	0.14	0.99
2 Aug	R5	−23.14	0.43	0.99	R4	−13.20	0.21	0.96
15 Aug	R6	···	0.03	···	R5	−26.37	0.39	0.99
1978								
29 Jun	V8	−4.75	0.07	0.99	V7	−5.63	0.09	0.99
14 Jul	R3	−5.07	0.10	0.98	R2	−4.87	0.09	0.94
28 Jul	R4	−5.19	0.07	0.96	R3	−6.02	0.09	0.99
9 Aug	R5	−5.50	0.08	0.97	R4	−6.37	0.11	0.99
24 Aug	R6	−5.81	0.08	0.99	R5	−6.32	0.10	0.99
Natural infection		−5.57	0.09	0.95		−6.26	0.10	0.99

[a] Scaling factor that partly fixed the position of the line that describes the regression of disease progress on time.
[b] The slope of the regression line which is the same as Vanderplank's (9) apparent infection rate (r).
[c] The growth stage (2) at the inoculation date.

Significant differences in yield and 300-seed weight were observed between soybeans inoculated at various growth stages and soybeans in control plots (Table 1). Differences were greater in 1977. When 1977 yields for control plots and inoculated plots were compared, inoculated plots had yield reductions of 12 − 34% for Wells and 13 − 32% for Williams. In 1978, inoculated plots had

TABLE 3. Correlation coefficients (r) and regression coefficients (b) for brown spot severity and reduction in yield and 300-seed weight of soybeans

Variables		1977				1978			
		Wells		Williams		Wells		Williams	
X	Y	r	b	r	b	r	b	r	b
AUBC[a]	Yield reduction (%)	0.89**[c]	0.11 ± 0.06[e]	0.91**	0.10 ± 0.04	0.75**	0.27 ± 0.07	0.62**	0.13 ± 0.04
AUBC	300-seed wt reduction (%)	0.36	0.02 ± 0.01	0.46	0.20 ± 0.02	0.87**	0.15 ± 0.04	0.17	0.03 ± 0.04
Severity[b] (%)	Yield reduction (%)	0.78**	0.22 ± 0.08	0.75**	0.26 ± 0.13	0.72**	0.42 ± 0.10	0.56**	0.37 ± 0.11
Severity (%)	300-seed wt reduction (%)	0.67*[d]	0.12 ± 0.04	0.39	0.10 ± 0.05	0.84**	0.27 ± 0.04	0.25	0.10 ± 0.10
AUBC	Severity (%)	0.84**	···	0.76**	···	0.94**	···	0.91**	···
300-seed weight (g)	Yield (q/ha)[f]	0.88**	0.73 ± 0.16	0.76**	1.30 ± 0.29	0.66**	0.89 ± 0.11	0.53**	0.53 ± 0.33

[a]Area under brown spot progress curve.
[b]Severity of brown spot rated at soybean growth stage R6.
[c]** $P \leqslant 0.01$.
[d]* $P \leqslant 0.05$.
[e]Standard error of the regression coefficient.

yield reductions of 13 – 30% for Wells and 16 – 22% for Williams. For uninoculated plots in which natural infection occurred, yield reductions were about 8% for both cultivars, and yields differed significantly from those of control plots. When yields of naturally infected plots and inoculated plots were compared, inoculated plots had yield reductions of 5 – 23% for Wells and 9 – 16% for Williams. Reductions in 300-seed weight of inoculated Wells were greater in 1977 than in 1978, whereas seed weight reductions of Williams were similar for 1977 and 1978.

In both years, the highest correlation coefficients (r) for both cultivars were found between yield reduction and AUBC values (Table 3). The r values of yield reduction and disease severity at stage R6 also were highly significant. Because there were no significant differences among the regression coefficients (b) for yield reductions, combined data of both cultivars over years were used to calculate linear regression equations for the estimation of yield reductions based on AUBC values and on disease severity at stage R6: $\hat{Y} = 11.49 + 0.09$ X in which $\hat{Y}$ = predicted percent yield reduction, X = AUBC value, r = 0.73** ($P \leqslant 0.01$, df = 76); and $\hat{Y} = 8.33 + 0.32$ X in which $\hat{Y}$ = predicted percent yield reduction, X = brown spot severity at stage R6, r = 0.64** ($P \leqslant 0.01$, df = 70). The r values of 300-seed weight and AUBC value were not significant in either year except for Wells in 1978 (r = 0.87**) (Table 3). The r values of 300-seed weight and brown spot severity at stage R6 were highly significant in both years for Wells but not for Williams. Brown spot severity at stage R6 and the AUBC value were highly correlated, as were yield and 300-seed weight.

DISCUSSION

Both soybean growth stage and weather conditions have considerable influence on the development of brown spot. Weather conditions at the Agronomy South Farm in 1977 favored the spread of *S. glycines*; and brown spot severities were relatively similar in plots of Wells and Williams when the cultivars were inoculated and evaluated at corresponding growth stages. In 1978, however, little precipitation and frequent temperatures above 27 C during July and August resulted in less severe brown spot epidemics in the earlier maturing cultivar wells. The apparent infection rates of brown spot in all inoculated plots were similar in 1978 regardless of the time of inoculation, whereas in 1977, the apparent infection rates were higher in both cultivars when inoculations were made at growth stages R4 and R5. These results indicate that brown spot can be severe on both early- and late-maturing soybeans when conditions are favorable for disease development; however, brown spot is more severe on the late-maturing soybeans under less favorable conditions.

Periodical observations of farmers' soybean fields during the past three growing seasons generally agree with observations of naturally infected soybean plots in this study. Brown spot has a long duration, and severe epidemics occur during late growth stages, which coincide with the period of dry matter accumulation in the soybeans.

Results from both years indicate that yield reductions caused by brown spot epidemics are very high. When yields in plots inoculated at early growth stages were compared with those of plots inoculated at late growth stages, naturally infected plots, or control plots, yields of both cultivars inoculated at early growth stages were significantly reduced. Yield reductions resulted from brown spot epidemics because no other foliar diseases were severe enough (X < 10%) to affect yields in all of the plots. Also, Horn et al (4) reported that there are no significant differences in yield and maturity of benomyl-treated and nontreated soybean plants in the absence of diseases.

Results indicate that the relationship between the severity of brown spot and yield reduction in soybeans can best be expressed by the regression of yield reduction on AUBC values and on severity at growth stage R6. However, both regression equations exhibited some inability to account for the time of infection (ie, early light infection) as related to yield reduction. For instance, in 1978 the AUBC values and the severity of brown spot at R6 for naturally infected Williams plots were similar to those observed for plots inoculated at R3 and R5. There were significant differences in yield reduction among these plots because of differences in the time of infection and the amount of infection relative to the growth stage; however, expected yield reductions obtained from either model did not differ. The inability of the area under disease progress curve to distinguish between early light infection and late severe infection has been discussed elsewhere (6). In relation to low brown spot severities, these equations, based on combined data of the cultivars over years, either overestimate or underestimate yield reduction depending upon the time of infection and the time of disease rating.

Further study is needed to test and improve these equations for the estimation of yield reduction. Both approaches of AUBC and severity at stage R6 can be tested and improved by comparing different AUBC values and levels of severity in relation to precisely defined soybean growth stages throughout several growing seasons.

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