Effects of Bacterial Blight on Soybean Yield

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ABSTRACT

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The effects of bacterial blight on soybean yield and 300-seed weight of two soybean cultivars, Wells II and Williams 79, were studied in 1981 and 1982. Inoculations at five soybean growth stages resulted in bacterial blight development at different levels in the plant canopy. A decrease in disease severity was observed at midseason during both years. In 1981, bacterial blight severity at R6 ranged from 0 to 36% for Wells II and from 0 to 29% for Williams 79. Yield and 300-seed weight of Wells II were significantly different between treatments in 1981, but only 300-seed weight was different in 1982. Compared with yield and 300-seed weight of control plots, reductions in yield and 300-seed weights of inoculated or naturally infected plots of Wells II in 1981 were 5–15% and 5–9%, respectively. In 1982, significant 300-seed weight reductions of 7.6 and 5.4% occurred when Wells II was inoculated at V3 and R3, respectively. Bacterial blight severity rated at R6 correlated negatively only with yield of Wells II ($r = -0.39$, $P = 0.05$) in 1981, whereas the severities rated at R4, R5, and R6 correlated negatively with 300-seed weight ($r = -0.53$ to -0.55, $P = 0.01$). In 1982, only 300-seed weight of Wells II correlated negatively with bacterial blight severity rated at each of three growth stages ($r = -0.39$ to -0.47, $P = 0.01$). Yield and 300-seed weight of Williams 79 did not differ significantly between treatments in either year.

Additional key words: *Glycine max, Pseudomonas syringae* pv. *glycinea*

Bacterial blight of soybean (*Glycine max* (L.) Merr.) caused by *Pseudomonas syringae* pv. *glycinea* (Coerper) Young, Dye, & Wilkie (*P. s. glycinea*) occurs worldwide and is the most common bacterial disease of soybean (15). Bacterial blight symptoms are particularly conspicuous on leaves and occasionally are found on stems, petioles, and pods (22). The bacteria overwinter in association with soybean seeds (9,12,16) and/or diseased plant debris (4,7,9,13) and initially infect soybean seedlings during emergence (3). The secondary inoculum produced on infected soybean seedlings is spread throughout the field by rainstorms. Rains also predispose soybean plants to bacterial blight infection by making extensive wounds through which the bacteria enter the leaves (2). *P. s. glycinea* remain viable for a considerable period on the surface of healthy soybean leaves (19,21). The epiphytic populations of the bacterium remain in a resident phase without causing symptoms when environmental conditions are unfavorable (18). However, when favorable conditions such as rainstorms prevail, the epiphytic population increases rapidly (2). This pattern of bacterial blight development in the field was described as a "horizontal layer pattern" by Daft and Leben (2). Yield reductions of 18–22% from this disease have been reported under conditions favorable for the disease (5,26). However, Daft and Leben (2) doubted that bacterial blight could cause serious soybean crop losses in Ohio. The objectives of our study were to investigate development of bacterial blight in the field and to determine effects of bacterial blight initiated at different soybean growth stages on yield and 300-seed weight of two commercial soybean cultivars during the two growing seasons of 1981 and 1982.

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MATERIALS AND METHODS

Field plots and soybean cultivars. The experiments were conducted at Urbana, IL, on a Drummer silty clay loam in 1981 and 1982. Planting dates were 26 May 1981 and 17 May 1982. The field used in 1981 had been planted to corn the previous year, but the field in 1982 had been a stone fruit orchard for at least 15 yr until 1981, when soybeans were planted. Wells II (maturity group II) and Williams 79 (maturity group III) were evaluated for disease severity and yield loss. Williams 79 is less susceptible in the field to *P. s. glycinea* than Wells II. However, both cultivars showed susceptible reactions (water-soaked lesions) when seedlings were inoculated in the greenhouse (E. W. Park and S. M. Lim, *unpublished*).

Inoculations. An isolate of *P. s. glycinea* was obtained from a naturally infected soybean cultivar Gnome plant at Urbana in 1980. The isolate was motile, rod-shaped, gram-negative, obligate aerobic, and oxidase-negative and produced fluorescent pigment on King's B medium (17). When soybean plants were inoculated in the greenhouse, typical bacterial blight symptoms (24) with water-soaked lesions developed 7 days after inoculation. The isolate was preserved by lyophilization (8) to maintain the pathogenicity of the isolate during the period 1981–1982. Inoculum was prepared from 2-day-old cultures of this isolate grown on King's B agar plates at 22–26 C. Cells were suspended in distilled water and adjusted turbidimetrically to a final concentration of about 10^7 colony-forming units per milliliter. Soybean plants were inoculated by spraying the inoculum until runoff at a pressure of 7 kg/cm^2 in 1981 and 4.2 kg/cm^2 in 1982. The spray pressure was lowered in 1982 because the high pressure in 1981 caused water-soaking or damage to some leaves.

Experimental design. Treatments each year consisted of inoculations at five soybean growth stages (6) (Wells II at V3, V6, R2, R3, and R5 and Williams 79 at V3, V6, R1, R3, and R4 in 1981; Wells II at V3, V6, R3, R4, and R5 and Williams 79 at V2, V5, R1, R3, R4, and R5 in 1982), natural infection, and control. Control plots were protected with streptomycin sulfate (Agri-strep, Merck & Co., Inc., Rahway, NJ) mixed with water to a concentration of streptomycin of 100 μg/ml and sprayed until runoff at 7- to 10-day intervals with a tractor-mounted sprayer with hand-held nozzle guns operated at 2.8 kg/cm^2. Plants in plots to be inoculated were protected with weekly sprays of streptomycin until 2 wk before inoculations. Inoculation dates in 1981 were 15 June, 29 June, 9 July, 20 July, and 9 August; and in 1982, 8 June, 28 June, 14 July, 28 July, and 12 August.

The experiment in both years was a split-plot design arranged in randomized complete blocks with four replicates. The cultivars were whole plots with time of inoculation, natural infection, and control as subplots. Each subplot

consisted of six rows 6.1 m long and 76 cm apart. The seeding rate was about eight seeds per 30 cm of row. The center two rows of the six-row plots were inoculated, and the two remaining rows on each side were not inoculated to reduce interplot contaminations.

Disease and yield assessment. Disease severity in the center two rows of each plot was rated nine times in 1981 and eight times in 1982 at 7- to 12-day intervals after the first inoculation date by the Horsfall-Barratt scale (10). Ratings were converted to percent severity with the Elanco Conversion Tables (Elanco Products Co., Indianapolis, IN). The area-under-disease-progress-curve (AUDPC) for bacterial blight development in each plot was calculated according to the formula used by Shaner and Finney (23). The center two rows of all plots were trimmed to 4.6 m long, and soybeans were harvested from the trimmed rows. The moisture content of seed from each plot was measured with a seed moisture meter (Digital Moisture Computer: Burrows Model 700, Burrows Equipment Co., Evanston, IL). The total yield (q/ha) and the 300-seed weight (g) were adjusted to the basis of 1.3g/kg^{-1} moisture content.

The effects of the treatments in each year on soybean yield and 300-seed weight were determined on the basis of a linear model: $Y_{ijk} = m + C_i + B_j + e_{ij} + T_k + (CT)_{ik} + d_{ijk}$, where Y = yield or 300-seed weight, m = the grand mean, C = cultivar effects, B = block effects, and T = treatment effects, and e and d = the error terms for the whole plots and subplots, respectively. Correlations of yield and 300-seed weight with the AUDPC and bacterial blight severity at R4, R5, and R6 were computed for each cultivar. Results from 1981 and 1982 were not combined because inoculations were done at different growth stages of soybean plants and spray pressures for inoculations differed for the 2 yr.

RESULTS

Bacterial blight development. Bacterial blight occurred on young leaves of the top canopy where inoculum was sprayed. Leaves on the bottom canopy did not become diseased in spite of inoculation. The upward spread of bacterial blight was slow and occurred after rainstorms. In 1981, bacterial blight severity increased significantly on both cultivars (Fig. 1) 2–3 wk after plants were inoculated at R3 or earlier. Bacterial blight induced at different growth stages

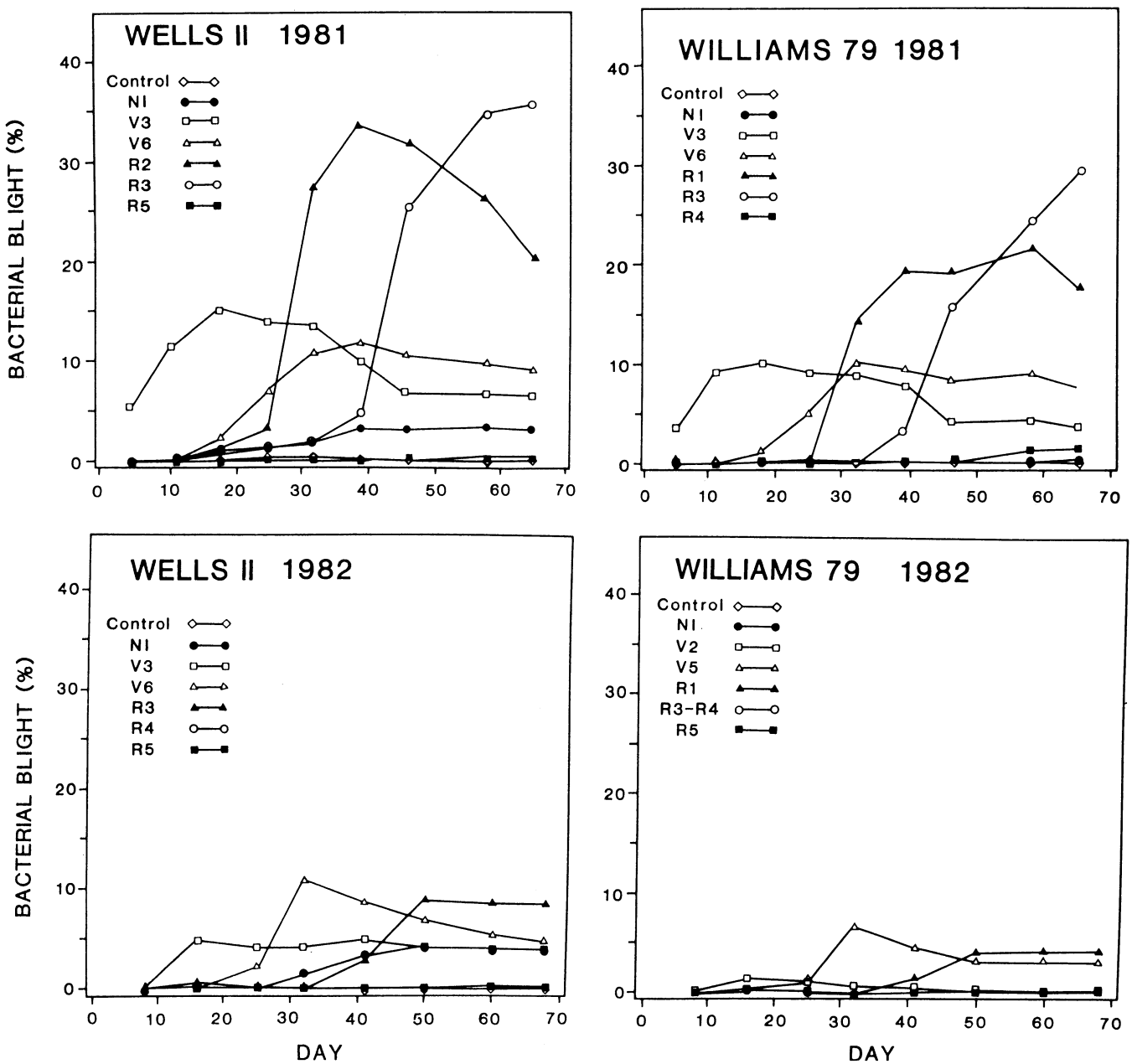

Fig. 1. Bacterial blight development on soybean cultivars Wells II and Williams 79, which were inoculated at five growth stages, naturally infected (NI), and control (protected with streptomycin) in 1981 and 1982.

of soybean plants progressed differently (Fig. 1). Late-season inoculations after streptomycin applications did not cause epidemic development of bacterial blight on either cultivar after R3. In 1982, disease severity in inoculated plots of both cultivars was not as high as in 1981. Disease severity on Wells II increased significantly after inoculations before or at R3 in 1982, but when Williams 79 was inoculated at the late R3 (R3–R4), there was no significant development of bacterial blight compared with control plots. Natural infection on Wells II was about 3–4% and at trace levels on Williams 79 for both years.

Bacterial blight severity at R6 and AUDPC values are presented in Table 1. In both years, there were significant differences in the severities and AUDPC values among treatments. In 1981, bacterial blight severities at R6 were highest on both cultivars inoculated at R3 and the highest AUDPC value of each cultivar occurred when Wells II soybeans were inoculated at R2 and Williams 79 were inoculated at R1. In 1982, Wells II and Williams 79 inoculated at R3 and R1, respectively, had the highest severity at R6, whereas the highest AUDPC values occurred when Wells II and Williams 79 were inoculated at V6 and V5, respectively. The severity at R6 and the AUDPC values were low in plots protected and inoculated later than R3 for both cultivars in both years.

Yield and seed weight reduction. Mean yield reductions and mean 300-seed weight reductions of inoculated or naturally infected plots of Wells II in 1981 were about 5–15 and 5–9%, respectively, compared with yield and 300-seed weight of control plots (Table 2). In 1981, protected plots produced the highest yield and 300-seed weight on both cultivars. Greatest reductions in yield (14.8%) and seed weight (9.3%) occurred in Wells II inoculated at R3. Seed weight reductions of all inoculated and naturally infected plots of Wells II were significant, but no significant yield reductions occurred in plots inoculated at V6 and R2. In 1982, yield of Wells II did not differ significantly among all the treatments, although significant seed weight reductions occurred in Wells II inoculated at V3 and R3 (Table 2). There were no significant differences in yield and seed weight of Williams 79 among treatments in both years.

Bacterial blight severity at R4, R5, and R6 and AUDPC values were negatively correlated with 300-seed weight of Wells II. All correlation coefficients (r) were highly significant ($P = 0.01$), although they were relatively low ($r = -0.48$ to -0.55 in 1981 and $r = -0.39$ to -0.47 in 1982). The highest negative correlation ($r = -0.55$, $P = 0.01$) of seed weights with disease severity was obtained with severity at R4 and R5 in 1981 and AUDPC ($r = -0.47$, $P = 0.01$) in 1982. Only the disease severity at R6 of Wells II was negatively correlated ($r = -0.39$, $P = 0.05$) with yield in 1981.

Table 1. Bacterial blight severity at growth stage R6 and the area-under-disease-progress-curve (AUDPC) of bacterial blight development on soybean cultivars Wells II and Williams 79 in 1981 and 1982

	Wells II			Williams 79		
Year	GS[a]	Serv. (%)[b]	AUDPC[c]	GS	Serv. (%)	AUDPC
1981	Control[d]	0.3	0.1	Control	0.1	0.0
	NI[e]	3.4	1.3	NI	0.4	0.1
	V3	6.9	6.2	V3	3.4	4.2
	V6	9.3	4.6	V6	7.4	3.7
	R2	20.3	10.9	R1	17.3	6.8
	R3	35.9	7.7	R3	29.3	5.0
	R5	0.6	0.1	R4	1.3	0.2
FLSD[f] ($P = 0.05$)		2.6	0.7	···	2.6	0.7
1982	Control	0.0	0.0	Control	0.1	0.0
	NI	3.8	1.3	NI	0.1	0.0
	V3	3.9	2.4	V2	0.1	0.4
	V6	4.6	3.1	V5	2.9	1.7
	R3	8.4	2.2	R1	4.1	1.0
	R4	0.3	0.1	R3–R4	0.2	0.1
	R5	0.1	0.0	R5	0.0	0.0
FLSD ($P = 0.05$)		1.2	0.5	···	1.2	0.5

[a] Growth stage of soybean plants (6) at which plants were inoculated.
[b] Bacterial blight severity at R6.
[c] AUDPC $= 1/2\Sigma_{i=1}^{k}[(Y_i + Y_{i+1})(t_{i+1}) - t_i)]$, where Y = the proportion of diseased leaf area at time t, i = the day of rating, and k = number of successive ratings.
[d] Control plots that were protected with streptomycin at 100 μg/ml of H_2O.
[e] Naturally infected plots.
[f] Fisher's protected least significant difference.

Table 2. Soybean yield and 300-seed weight of soybean cultivars Wells II and Williams 79 in 1981 and 1982

	Wells II			Williams 79		
Year	GS[a]	Yield (q/ha)	Seed wt (g)	GS	Yield (q/ha)	Seed wt (g)
1981	Control[b]	40.0	58.0	Control	37.2	59.5
	NI[c]	35.7	54.6	NI	35.6	58.6
	V3	36.8	55.1	V3	35.3	58.7
	V6	37.8	55.0	V6	36.2	57.8
	R2	38.0	53.7	R1	37.2	57.9
	R3	33.9	52.6	R3	36.8	56.9
	R5	36.1	54.8	R4	36.1	58.5
FLSD[d] ($P = 0.05$)		2.7	2.0	···	2.7	2.0
1982	Control	30.1	48.6	Control	27.2	56.6
	NI	29.0	47.0	NI	27.2	54.9
	V3	26.7	44.8	V2	30.9	56.5
	V6	33.1	46.7	V5	31.0	54.7
	R3	28.9	45.8	R1	28.2	57.7
	R4	28.2	49.3	R3–R4	27.3	55.1
	R5	28.3	48.7	R5	29.9	54.7
FLSD ($P = 0.05$)		NS[e]	2.0	···	NS	2.0

[a] Growth stage of soybean plants (6) at which plants were inoculated.
[b] Control plots which were protected with streptomycin (100 μg/ml, H_2O).
[c] Naturally infected plots.
[d] Fisher's protected least significant difference.
[e] Nonsignificant.

DISCUSSION

Weather conditions in Urbana from early June to late August were similar in 1981 and 1982 (Table 3). The AUDPC and the disease severity at R6 for naturally infected plots of each cultivar were about the same in 1981 and 1982, indicating environmental conditions for bacterial blight development were similar in both years. The greater bacterial blight development in inoculated plots in 1981 than in 1982 was probably due to higher pressure of inoculum spray in 1981 (7 kg/cm^2) than in 1982 (4.2 kg/cm^2), because environmental conditions were similar in both years and aggressiveness of the lyophilized bacterial culture was not changed during 1981–1982.

The development of bacterial blight on the top of the canopy after inoculations and the slow spread to newly formed leaves resulted in the "horizontal layer pattern" (2) of blight development. Consequently, inoculations at various growth stages of soybean plants induced bacterial blight development at different

levels of the canopy. A decrease in bacterial blight severity during the midseason was observed in plots where bacterial blight development was initiated at the vegetative or early reproductive stages (R1–R2) of soybean plants and probably is due to the loss of old diseased leaves and a rapid growth of plants compared with slow development of bacterial blight. The effect of rapid increase in the total leaf area and the defoliation of diseased plants on visual disease ratings is unavoidable because disease severity, expressed as a percentage or proportion of diseased leaf area, is a relative value of the total leaf area of the plant. High temperature (above 30 C) during the daytime in midseason may have also slowed bacterial blight development, since *P. s. glycinea* grows best at 22–26 C (1). Because of a significant decrease in disease severity in many plots at midseason, bacterial blight development in this study could not be characterized by fitting asymptotic growth functions (e.g., the logistic, Gompertz, and Weibull functions) that can describe disease development as a population growth of lesions (20).

Bacterial blight did not affect yield and 300-seed weight of Williams 79, which is known to be less susceptible to *P. s. glycinea* than Wells II. However, 14.8 and 9.3% reductions in yield and 300-seed weight, respectively, of Wells II when plants were severely infected (36% at R6) suggest that bacterial blight may cause substantial yield reductions if susceptible cultivars are grown under conditions favorable for bacterial blight development. Although inoculation at R1 or R3 of Williams 79 in 1981 resulted in relatively severe infection, reductions in 300-seed weight and yield were not significant. This indicates that Williams 79 is relatively tolerant compared with Wells II under severe infection of *P. s. glycinea*.

The correlations of bacterial blight with 300-seed weight were greater than with yield of Wells II, suggesting bacterial blight affects soybean yield by reducing seed weights. In the case of brown spot of soybean caused by *Septoria glycines*, soybean yield loss occurred through a reduction in seed weight (22).

Under natural conditions, bacterial blight usually occurs early in the growing season, which may not cause serious soybean yield reduction because of the ability of soybean plants to compensate for the loss of photosynthetic area by rapid expansive growth during the vegetative growth stage. A simulated defoliation study (25) demonstrated that the loss of photosynthetic area at the vegetative growth stage had little effect on soybean yield but that removal of leaves at R3 significantly reduced soybean yield. The inoculation at R3 of bacterial blight on Wells II in 1981 resulted in severe bacterial blight development at R6 on the ninth through the 13th of a total of 17–20 nodes. This suggests that the reductions in yield and seed weight of Wells II inoculated at R3 may have been due to severe loss of photosynthetic leaf area in the middle canopy. Johnston and Pendleton (11) obtained greater yield reduction by removing leaves from the middle canopy than from the upper or lower canopy when soybean cultivar Amsoy plants had 18 nodes. The close relationships between soybean yield and plant canopy levels where loss of leaf area occurs may have resulted in the low correlations between soybean yield and bacterial blight severity. Bacterial blight is a predominant foliar disease of soybean in Illinois and may cause a significant yield reduction on susceptible cultivars when conditions are favorable for the development of bacterial blight.

Table 3. Important weather conditions for bacterial blight development from the first inoculation day[a] until 20 August[b]

Year	Temperature (C)		Number of days with	
	Mean	Av. max.[c]	Above 30 C[d]	Rain
1981	22.6	27.6	16	45
1982	22.6	27.7	19	41

[a] First inoculation day: 15 June 1981 and 8 June 1982.
[b] Data were obtained from the monthly summary of local climatological data from the Illinois Water Survey.
[c] Average daily maximum temperature.
[d] Number of days with maximum temperatures above 30 C.

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