Efficacy of Benomyl for Controlling Septoria Brown Spot of Soybeans

J. K. Pataky and S. M. Lim

Graduate research assistant, and associate professor and research plant pathologist, Department of Plant Pathology, University of Illinois, and Agricultural Research, Science and Education Administration, U.S. Department of Agriculture, Urbana 61801.

Present address of senior author: Department of Plant Pathology, North Carolina State University, Raleigh 27650.

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ABSTRACT

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The effects of benomyl applied at three reproductive growth stages on Septoria brown spot of soybean were evaluated in the field for 2 yr. Apparent brown spot infection rates were lowered in plots of inoculated soybeans following benomyl sprays at the R1, R3, and R6 soybean growth stages. Brown spot was less severe when any schedule of benomyl applications included a spray at R3 or when applications were made at both R1 and R6. Brown spot severity at R7 and area under the disease progress curve (AUDPC) were highest for unprotected-inoculated plants, naturally infected plants, and plants that received a single spray at R1 or at R6. Reduction of brown spot during early and midreproductive stages may increase yields when brown spot would otherwise be severe and when potential yields are high.

Additional key words: disease control, *Glycine max*, *Septoria glycines*, disease losses.

Brown spot of soybeans, which is caused by *Septoria glycines* Hemmi, is a common foliar disease that occurs throughout the growing season in the midwestern USA (3,14). Brown spot is a compound interest type of disease (17). The pathogen spreads from lower to upper leaves in warm, humid weather (5). Moderate to severe infection causes premature defoliation. Soybean yield reductions ranging 12–34% have resulted from artificial inoculations with *S. glycines* (12,18,21). With natural infection, yield reductions in experimental plots have been about 8% (12). Currently, brown spot is the most prevalent foliar disease of soybeans in Illinois (14). Preliminary data from the Illinois soybean monitoring program indicate that brown spot development differs between years and regions of the state, probably as a result of differing environments (S.M. Lim, *unpublished*).

Over 3,600 plant introductions and cultivars have been evaluated for brown spot resistance by Lim (11) or by Young and Ross (20). They reported a nonchlorotic lesion type. Resistance cannot, however, be distinguished by this reaction and no resistance to brown spot is presently available. In the absence of host resistance, control of brown spot in experimental plots has been achieved through benomyl (Benlate 50W) sprays (1,12,15). Control of other *Septoria* species with benomyl also has been reported (10,19).

Current benomyl label recommendations state that it should be applied to soybeans at the R3 to R4 growth stage with an additional application 14–21 days later. Investigations of benomyl effects on soybean yields have shown that yield response differs in relation to number and timing of benomyl applications (6,7), presence of the pathogen (8), conditions favorable for infection by foliar pathogens (1), and irrigation (15).

The objectives of this study were to evaluate the effect of benomyl applications at different reproductive growth stages on the epidemic development of brown spot, and to determine the effect of brown spot development at different reproductive growth stages on soybean yields.

MATERIALS AND METHODS

Cultivar Williams soybean plants were planted in a Drummer silty clay loam at Urbana and in a Cisne silt loam at Brownstown at the rate of 37.5 seeds per square meter in rows spaced 75 cm apart. Planting dates were 26 May 1978 and 23 May 1979 at Urbana, and 22 May 1979 at Brownstown. All fields had been planted to corn the previous year. Each of 40 plots per location was six rows wide and 6.7 m. long.

Four replications of 10 treatments were arranged in a randomized complete block design. In eight treatments, plants were inoculated at the V4 growth stage (4) with a spore suspension of an Illinois isolate of *S. glycines* (ATCC 38699). Applications of benomyl (Benlate 50% WP formulation of methyl-1-[butylcarbamoyl]-2-benzimidazolecarbamate) were made in these eight treatments at all possible combinations of three reproductive growth stages (R1, R3, and R6). Benomyl was applied with a hand-held spray gun at 1.12 kg/ha. Two treatments did not include inoculation with *S. glycines*. One served as a check of natural infection and the other was the protected control in which plants received the three benomyl sprays.

Inoculum was produced by culturing *S. glycines* on potato-dextrose agar at 22–26 C for 2–3 wk. Cultures were comminuted in tap water and filtered through several layers of cheesecloth. Inoculum concentration was adjusted to approximately 10^6 spores per milliliter. Inoculations were made with a pressurized sprayer (5.6 kg/cm^2) on 23 June 1978 and 20 June 1979 at Urbana and 23 June 1979 at Brownstown. Soybeans were sprayed until runoff.

Disease evaluations were made every 7–14 days from inoculation

TABLE 1. Brown spot severity[a] at soybean physiological maturity (R7) and area under the disease progress curve (AUDPC)[b] for brown spot on Williams soybeans at Urbana and Brownstown

Treatment applications[a]	Plant reprod. stage at benomyl applications[c]	Severity (%) Urbana 1978	Severity (%) Urbana 1979	Severity (%) Brownstown 1979	AUDPC Urbana 1978	AUDPC Urbana 1979	AUDPC Brownstown 1979
PT[d]	R1, R3, R6	13.4	9.3	22.2	301	295	705
NI[d]		54.7	59.1	59.1	1,193	1,774	1,314
IN[e]	R1, R3, R6	37.5	9.1	22.3	946	327	579
IN	R1, R3	41.4	23.4	34.7	1,045	548	703
IN	R3, R6	44.9	21.0	26.3	1,389	1,165	884
IN	R1, R6	52.2	30.5	37.0	1,362	1,006	1,067
IN	R1	67.4	57.8	69.3	1,759	1,273	1,287
IN	R3	46.9	34.4	33.7	1,513	1,203	847
IN	R6	61.1	45.3	47.9	1,848	2,209	1,436
IN		71.3	72.1	71.1	2,278	2,413	1,674
F.L.S.D.[f] ($P = 0.05$)		11.8	7.9	13.2	186	253	335

[a] Severity expressed as the percentage of the total leaf area diseased.
[b] AUDPC determined according to the formula presented by Shaner and Finney (16).
[c] Benomyl applied at 1.12 kg/ha at R1, R3, and/or R6 soybean growth stages (4).
[d] PT (protected) and NI (natural infection) plots were not inoculated.
[e] IN = inoculated with *Septoria glycines* (ATCC 38699) at the V4 growth stage.
[f] Fisher's Least Significant Difference.

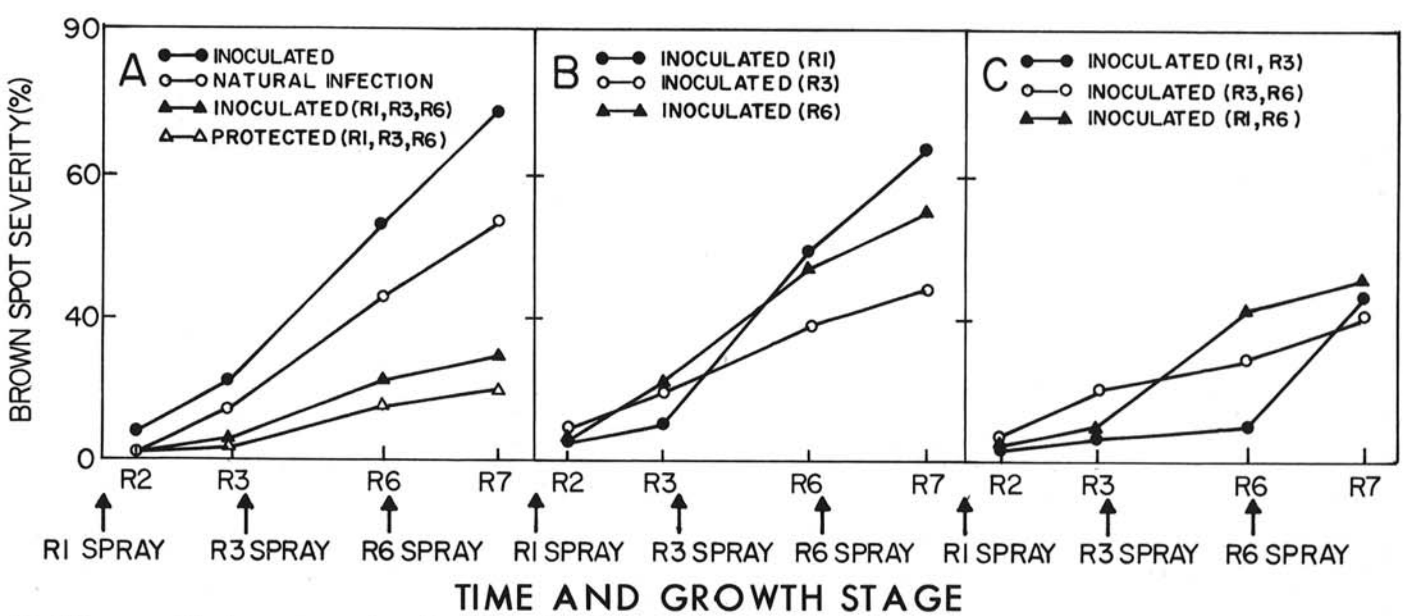

Fig. 1. Brown spot development on soybeans in relation to inoculation at the fourth vegetative (V4) growth stage with *Septoria glycines* and number and timing (soybean reproductive growth stages) of benomyl sprays: **A,** inoculated at V4 and not sprayed; not inoculated and not sprayed (natural infection); inoculated and sprayed at R1, R3, and R6; and not inoculated and sprayed at R1, R3, and R6; **B,** inoculated at V4 and sprayed at either R1, R3, or R6; and **C,** inoculated at V4 and sprayed at R1 and R3, R3 and R6, or R1 and R6. Brown spot severities are means of trials in Illinois at Urbana in 1978 and 1979 and at Brownstown in 1979.

to harvest maturity. Brown spot severity was measured as the percentage of the total leaf area diseased using a modified Horsfall-Barratt rating system (9). Ratings were converted with the Elanco conversion tables (Elanco Products Co., Indianapolis, IN 46140). Area under the disease progress curve (AUDPC) was calculated according to the formula presented by Shaner and Finney (16). Apparent infection rates (17) were determined for periods corresponding to early (R2–R3), middle (R3–R6), and late (R6–R7) stages of reproductive growth.

The center 4.6 m of the middle four rows of each six-row plot were harvested for yield. Yields were measured as grams per plot and converted to quintals per hectare (q/ha). Harvested soybeans were dried to 8% moisture and 300-seed weights were determined. Percent yield reductions were determined by comparisons within replications of actual yields (in grams per plot) of diseased plots to yields obtained in protected plots, according to the formula: yield reduction (%) = ([yield from protected plots − yield from diseased plots]/ yield from protected plots) × 100. Seed weight reductions were similarly determined.

Rainfall data were obtained from the Agronomy South Farm at Urbana and the Agronomy Research Station at Brownstown where the experiments were conducted.

TABLE 2. Mean apparent infection rates[a] for Septoria brown spot on Williams soybeans

Treatment	Plant reprod. stage at benomyl applications[b]	Infection rates (r) R2-R3[c]	R3-R6[c]	R6-R7[c]
PT[d]	R1, R3, R6	0.14	0.04	0.02
NI[d]		0.13	0.07	0.04
IN[e]	R1, R3, R6	0.04	0.06	0.02
IN	R1, R3	0.05	0.06	0.03
IN	R3, R6	0.07	0.02	0.02
IN	R1, R6	0.06	0.08	0.02
IN	R1	0.04	0.10	0.05
IN	R3	0.08	0.03	0.03
IN	R6	0.08	0.05	0.02
IN		0.08	0.08	0.05

[a] Apparent infection rates (17) means of trials at Urbana in 1978 and 1979 and at Brownstown in 1979.
[b] Benomyl applied at 1.12 kg/ha at R1, R3, and/or R6 growth stages (4).
[c] Early (R2–R3), mid (R3–R6), and late (R6–R7) reproductive growth periods.
[d] PT (protected) and NI (natural infection) plots were not inoculated.
[e] Inoculated with *Septoria glycines* (ATCC 38699) at the V4 stage.

RESULTS

Brown spot symptoms appeared on lower leaves in early July as soybeans were beginning reproductive growth. Brown spot epidemics differed in severity and progress as a result of differences in inoculations and timing of fungicide sprays (Fig. 1). The most severe brown spot epidemics occurred in plots where plants had been inoculated and not protected with benomyl. By stage R6, over 50% of the total leaf area was diseased on plants in these plots, and severity at R7 was >70% (Table 1). The least amount of brown spot occurred on uninoculated plants that had been sprayed three times with benomyl. Severity at R7 ranged from 9.3 to 22.2% in these protected plots. Brown spot development in plots of naturally infected soybeans was less than that in unprotected-inoculated plots, but much greater than that in protected plots. Severity in naturally infected plots was >50% at R7.

In the plots in which soybeans were inoculated and sprayed with benomyl, brown spot severity at R7 was greatest in those that had received a single spray at R1 or R6 (Table 1). There were no differences in severity on plants at R7 among inoculated plots that received two benomyl sprays or plots that received a single spray at R3, except at Urbana in 1979 when plots sprayed at R1 and R3 showed less brown spot than plots sprayed at R3, and plots sprayed at R3 and R6 showed less brown spot than plots sprayed at R3 or at R1 and R6.

The range of AUDPC values between treatments was greater at Urbana than at Brownstown (Table 1). AUDPC values were highest in plots of unprotected-inoculated plants and lowest in plots of protected plants. All plots that were sprayed twice had significantly lower AUDPC values than plots in which the soybean plants were sprayed only at R6. AUDPC values for plots that had received two sprays at R1 and R6 or at R3 and R6 were not statistically different than those that had received a single spray at R3. AUDPC values were significantly greater for plots sprayed at R6 than for those sprayed at R3.

Although the brown spot epidemics in inoculated and fungicide-protected plots varied in intensity (ie, severity, AUDPC) between locations and years, brown spot development in relation to benomyl applications was similar over locations and years. From R2 to R3, mean apparent infection rates over all trials were lowest in plots where soybeans were inoculated and sprayed with benomyl at R1 (Table 2). During the period from R3 to R6, infection rates were lowest for plots of inoculated plants that had received an R3 spray, but had not been sprayed at R1. Infection rates from R3 to R6 were highest for plots that were sprayed at R1 but not at R3. From R6 to R7 (physiological maturity), infection rates were

TABLE 3. Yield, 300-seed weight, and yield and seed weight reductions due to Septoria brown spot on Williams soybeans in Illinois

Treatment	Plant reprod. stage at benomyl applications[a]	Urbana 1978 Yield (q/ha)	Seed wt (gm)	Yield[b] red.	Seed wt[b] red.	Urbana 1979 Yield (q/ha)	Seed wt (gm)	Yield[b] red.	Seed wt[b] red.	Brownstown 1979 Yield (q/ha)	Seed wt (gm)	Yield[b] red.	Seed wt[b] red.
PT[c]	R1, R3, R6	30.8	60.5	···	···	36.4	60.5	···	···	26.5	44.5	···	···
NI[c]		30.5	59.1	1.2	2.2	32.7	57.1	10.2	5.7	26.6	44.6	−0.4	−0.3
IN[d]	R1, R3, R6	30.9	60.6	−0.3	−0.3	34.7	60.6	4.5	−0.2	28.8	46.5	−10.0	−4.7
IN	R1, R3	31.2	61.1	−1.5	−1.0	34.7	60.0	4.5	0.9	25.3	44.1	3.7	0.8
IN	R3, R6	31.5	61.5	−2.5	−1.7	35.4	60.7	2.6	−0.3	27.8	46.3	− 5.3	−4.1
IN	R1, R6	31.1	60.6	−1.1	−0.2	34.4	59.4	5.3	1.8	25.9	44.0	2.0	1.1
IN	R1	32.3	59.8	−5.0	1.1	34.1	58.2	6.4	3.8	27.5	45.3	− 3.8	−1.7
IN	R3	30.2	58.5	2.2	3.3	34.5	59.5	5.2	1.6	27.6	45.3	− 4.5	−1.8
IN	R6	30.2	58.6	2.1	3.2	33.5	58.7	7.8	2.9	23.5	42.2	10.9	5.2
IN		30.4	57.8	1.4	4.3	31.6	55.3	13.1	8.6	26.1	43.5	1.2	2.3
F.L.S.D.[e] ($P = 0.05$)		N.S.[f]	2.19	N.S.	3.62	1.83	0.95	4.91	1.55	N.S.	N.S.	N.S.	N.S.
C.V.[g] (%)		5.9	2.5			3.7	1.1			9.7	5.2		

[a] Benomyl applied at 1.12 kg/ha at R1, R3, and/or R6 growth stages (4).
[b] Percentage yield and seed weight reductions based on comparisons within replications to protected plots. Percentage yield reduction preceded by a negative sign indicates yield was greater than that from protected plots (eg, negative yield reduction).
[c] PT (protected) and NI (natural infection) plots were not inoculated.
[d] IN = inoculated with *Septoria glycines* (ATCC 38699) at V4 soybean growth stage.
[e] Fisher's Least Significant Difference.
[f] N.S. = not significant.
[g] Coefficient of variation.

lowest for plots that had received R6 sprays.

Mean yields of all treatments were 30.9 ± 1.8, 34.2 ± 1.3, and 26.2 ± 2.6 q/ha at Urbana in 1978, Urbana in 1979, and Brownstown in 1979, respectively (Table 3). Mean 300-seed weights (gms) for these trials were 59.8 ± 1.5, 59.0 ± 0.7, and 44.6 ± 2.3. Differences among treatments in yield occurred at Urbana in 1979, but not at Brownstown in 1979 or Urbana in 1978. Yield reduction for the unprotected-inoculated treatment at Urbana in 1979 was 13.1% and seed weight reduction was 8.6%. In plots of naturally infected plants, yield and seed weight reductions were 10.2 and 5.7%, respectively. Yield reduction in plots of inoculated soybeans sprayed at R6 was significantly greater than in those sprayed at R3 and R6.

DISCUSSION

Benomyl applications controlled brown spot by slowing the rate of disease development. Apparent infection rates of inoculated soybeans were lowered following benomyl applications; however, control was not effective if infection rates were lowered only during early or late reproductive growth as was the case in plots where soybeans had received a single benomyl application at R1 or at R6. When soybeans were sprayed only at R6, brown spot epidemics were severe because the disease developed unsuppressed throughout most of the reproductive growth period. When soybeans were sprayed only at R1, infection rates were increased from R3 to R6, resulting in severe brown spot. Although brown spot severity for soybeans sprayed only at R1 did not exceed that of unprotected-inoculated plants, the rapid increase of disease from R3 to R6 reduced the usefulness of control during early reproductive stages. Increased infection rates following the loss of fungicide effectiveness have been discussed by Berger (2). Brown spot infection rates were not, however, increased from R6 to R7 as a result of fungicide control during R3 to R6, even though infection rates for plots of plants sprayed only at R1 remained high. Conceivably, different rates of brown spot progress following the loss of fungicide effectiveness resulted from differences in environment, soybean physiology, and/or growth stage at the time fungicide protection was lost. Also, environment and soybean physiology may have affected the rate of benomyl degradation and thus altered the period of time for which benomyl was effective against *S. glycines*.

Due to the early-season spread of brown spot in Illinois and the defoliating nature of the disease, infection during early and midreproductive growth stages may decrease yields. In a study that simulated the effects of progressive defoliation from the lower to upper soybean canopy, such as would result from *S. glycines* infection, Lockwood et al (13) reported that removal of leaves from the lower two thirds of the canopy at early flowering resulted in approximately 20% yield reduction. More severe progressive defoliation resulted in greater yield reductions. Similar results were observed in this study at Urbana in 1979. Yield reductions were greatest for unprotected inoculated plants, naturally infected plants, and inoculated plants sprayed at R6. In all of these plots, brown spot epidemics developed rapidly from R1 to R6 and AUDPC values were significantly higher than other treatments. Yield reductions were, however, lower than those reported in other investigations of brown spot (12,18,21).

In relation to other investigations of benomyl effects on foliar diseases of soybeans, this study further suggests that soybean yield increases derived from benomyl applications may be related to periods of rainfall and high potential yields. Ross (15) reported that benomyl applications increased yields in irrigated plots, but not in nonirrigated plots. Backman et al (1) reported that yield increases occurred as a result of benomyl applications when periods of recurrent rainfall occurred during reproductive growth of soybeans. In this study, rainfall was adequate at all locations in July, during flowering and pod formation (Fig. 2); however, lack of rainfall at Brownstown during pod-filling stages, August–September 1979, probably resulted in reduced yields and minimum effects of brown spot and benomyl. Brown spot epidemics were less intense at Brownstown as indicated by lower AUDPC values and yield differences were not significant. At Urbana in 1978, rainfall occurred during pod-filling stages; however, yields in protected plots were 5.8 q/ha less than in 1979. No yield differences occurred at Urbana in 1978, which suggests that the effects of brown spot and the benefits of benomyl applications may be greatest when yield potentials are highest.

This study indicates that brown spot can be reduced by a schedule of benomyl applications that includes a spray at R3 or by sprays at both R1 and R6, and that reduction of brown spot during early and midreproductive stages may increase yields when brown spot would otherwise be severe and when potential yields are high. Consequently, studies of environmental factors that influence early-season brown spot development and searches for brown spot resistance in which the rate of disease development is lowered before and during pod-fill should be considered.

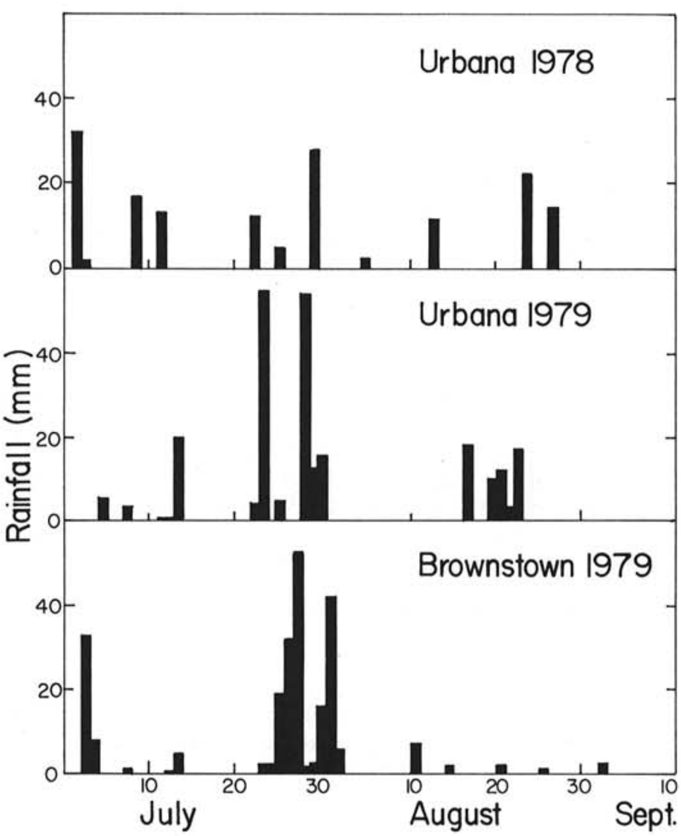

Fig. 2. Daily rainfall during soybean flowering, pod formation, and pod filling in Illinois at Urbana in 1978 and 1979, and at Brownstown in 1979.

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