Effect of Four Years of Continuous Cropping of Maturity Group II Soybeans Resistant to Brown Stem Rot on Brown Stem Rot and Yield

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ABSTRACT

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Incidence and severity of brown stem rot (BSR) of soybeans were progressively reduced by long-term cropping with the maturity group II BSR-resistant A3 germ plasm line. BSR incidence remained high and severity fluctuated with long-term cropping of the BSR-susceptible cultivar Coles. Yield increases averaged 16.7% greater for four susceptible cultivars that were grown after the land had been cropped for 4 yr with the BSR-resistant A3 germ plasm than for land that had been cropped with the BSR-susceptible cultivar Coles. Average yields for four BSR-resistant lines also increased with cropping of the BSR-resistant soybean, but the yield increases were smaller (8.3%).

Brown stem rot (BSR) of soybeans, caused by *Phialophora gregata* (Allington & Chamberlain) W. Gams, was first reported from Illinois in 1948 (1). The pathogen and disease have become widely established. In 1977, the disease was found in 94.5% of fields surveyed in northern Iowa, where the problem was previously considered unimportant (9).

Crop rotation has been the principal recommendation for controlling the disease since it was discovered (1). Dunleavy and Weber (3) reported that 4 yr of continuous corn were effective in reducing incidence and increasing yields. Although these methods of control were known, the disease continued to spread (9). Subsequently, the development of resistance has been emphasized for control of BSR.

Resistance to BSR was first reported by Chamberlain and Bernard (2). In 1977, a superior soybean line with high yield and resistance to BSR was identified after it had been tested on infested land for 3 yr. Because the yield of the line was not considered significantly higher than currently available cultivars on uninfested land or in the Regional Uniform Soybean Tests, the line was released as a resistant germ plasm and identified as A3 (10). In 1981, BSR 301, the first of a series of BSR-resistant cultivars, became available for commercial production (5,6). The most recent in the series of these BSR-resistant cultivars is BSR 101 in maturity group I, which became available for commercial production in 1987 (11). Other soybean cultivars with BSR resistance are becoming available for production. Because other names are being used, the BSR-resistant cultivars can be identified by their descriptions.

During the development of BSR-resistant soybeans, BSR incidence was observed to decrease after a few years where resistant populations were grown for screening purposes. On the basis of this observation, we hypothesized that BSR-resistant soybeans could be grown over long periods of time to reduce BSR incidence and possibly also to control the disease. This report is on an experiment conducted to determine the effectiveness of long-term cropping of BSR-resistant soybeans for control of BSR.

MATERIALS AND METHODS

The experiment was conducted at the Northern Research Center, Kanawha, Iowa. The land had previously been used for the Regional Uniform Soybean Tests and had been variously rotated with oats and corn. High incidence of BSR had been observed in the soybeans of the regional tests in this field during the 2 yr preceding the initiation of this experiment. The soil type was Clarion-Nicollet sandy loam. The field was fall plowed in 1977 and 1978 and offset disked in 1979 and 1980. Herbicides used included chloramben (Amiben), trifluralin (Treflan), and alachlor (Lasso) at recommended rates for the soil type and weather conditions. Cultivation and hand-weeding were also necessary to maintain weed-free plots.

The germ plasm line A3 and the cultivar Coles were used as the resistant and susceptible soybeans, respectively. Both are of maturity group II, but A3 matures a few days earlier than Coles. Coles is approximately 7.6 cm taller than A3. Both are susceptible to *Phytophthora megasperma* Drechs. f. sp. *glycinea* Kuan & Erwin race 1. The two soybeans were grown in a randomized complete block design of two 15.2 × 33.3 m main

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plots in four replications. The main plots were further subdivided into 25 subplots, each consisting of four rows 76 cm apart and 6.1 m long. Alleys between subplots were 0.6 m wide. Disease and yield data were obtained from 9 of the 25 subplots in the centers of the main plot. The other 16 subplots were border plots or buffer zones to avoid adjacent main plot effects (Fig. 1). The second and third rows of each subplot were trimmed to 4.8 m before harvest for yield. The harvested soybeans were dried to 13% moisture before weighing. Disease data were obtained from plants in the two outside rows of the four-row subplots.

In 1981, the BSR-resistant germ plasm line A3 and the BSR-susceptible cultivar Coles had been cropped on the same main plots for 4 yr. Brown stem rot incidence had decreased significantly with the long-term cropping of A3 but not with Coles. It was then that the subplots within the main plots of the four replicated blocks were planted with six additional soybean lines—three resistant (A77-116013, A78-125029, and A78-227013) and three susceptible (cvs. Weber, Hardin, and Pride B216). Line A78-227013 was subsequently released as BSR 201 in maturity group II (8). The six soybean lines plus A3 and Coles were randomly planted in the eight central subplots around the center subplot of each main plot (Fig. 1). The center four-row subplot was divided into two two-row plots of A3 and Coles that provided the fifth year of data on long-term cropping of the resistant A3 and the susceptible Coles soybeans. The experiment in 1981 thus became a split-plot experiment, with the main plots being the cropping history in a randomized complete block design of four replications and the split plots being the soybean lines and cultivars.

Brown stem rot data were taken at the R7 soybean growth stage (4) and consist of averages of 10 plants for each subplot. BSR incidence was the percentage of plants infected among those sampled. BSR severity was determined by pulling plants, splitting the stems longitudinally, measuring the extent of browning up the stem, and dividing by the plant height. Plots were harvested 10 days after physiological maturity or when 95% of the pods browned.

All data were analyzed following standard procedures for analysis of variance (ANOVA) using the PC SAS program (SAS Institute, Inc., Cary, NC). Conservative degrees of freedom were used for testing the year effects in the nonrandomizable repeated measures portion of the experiment.

RESULTS

After the BSR-resistant germ plasm line A3 was grown continuously from 1977 to 1981, the incidence of brown stem rot decreased from 80.0 to 20.0% and the severity decreased from 49.5 to 5.3% (Fig. 2). Where the BSR-susceptible cultivar Coles was grown for 5 yr, BSR incidence remained high or increased insignificantly from 96.3 to 98.8% and the severity varied from 93.5 to 48.5%. Both cultivar and year effects were significant ($P = 0.01$) for BSR incidence and severity (Table 1). The cultivar × year interaction was significant ($P = 0.01$) for BSR incidence but not for severity. The difference in BSR incidence between the resistant A3 and the susceptible Coles soybeans was significantly greater during the later years of the experiment than in the earlier years. Slopes of BSR incidence through the 5 yr of the experiment were estimated and found to be significantly different between A3 ($b = -13.23$) and Coles ($b = 1.05$). The difference in BSR severity between the resistant and susceptible soybeans did not change significantly as the experiment progressed but tended to decrease for both genotypes. Slopes of BSR severity through the 5 yr were not significantly different between A3 ($b = -10.20$) and Coles ($b = -6.75$).

Yields of A3 averaged 134.4, 302.4, and 369.6 kg/ha more than those of Coles in 1978, 1979, and 1981, respectively (Fig. 3). The yield of Coles was only slightly greater than that of A3 the first year of the experiment (1977). Yields of both Coles and A3 were severely reduced in 1980 by a tornado that heavily damaged the field after disease data were obtained and before harvest was possible. As the experiment progressed, the difference in yield between A3 and Coles increased, with the greatest significant difference obtained in 1981. Cultivar differences were significant ($P = 0.05$) for yield when all 5 yr were analyzed together as a

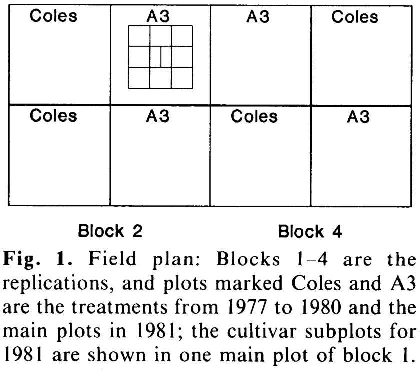

Fig. 1. Field plan: Blocks 1–4 are the replications, and plots marked Coles and A3 are the treatments from 1977 to 1980 and the main plots in 1981; the cultivar subplots for 1981 are shown in one main plot of block 1.

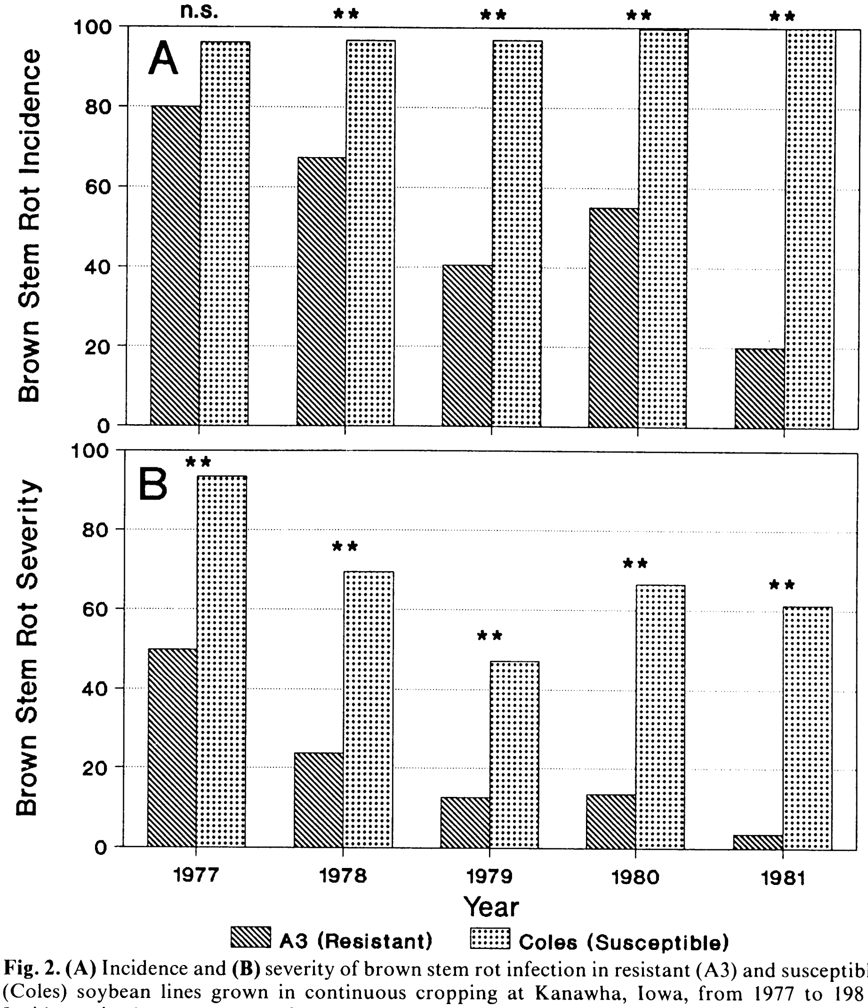

Fig. 2. (A) Incidence and **(B)** severity of brown stem rot infection in resistant (A3) and susceptible (Coles) soybean lines grown in continuous cropping at Kanawha, Iowa, from 1977 to 1981. Incidence is the percentage of plants sampled showing stem browning, and severity is the percentage of plant stem in which browning is involved. Values are means of four replications; n.s. = means of A3 and Coles not significantly different, ** = means significantly different ($P = 0.01$).

repeated measures experiment (Table 1). The year effect was highly significant ($P = 0.01$), as was the cultivar × year interaction. There was a significantly greater difference in yield between the two soybeans in the later years of the experiment than in the earlier years. The slopes of soybean yield through the 5 yr of the experiment were estimated and not found to be significantly different between A3 ($b = -74.68$) and Coles ($b = -120.06$).

After 4 yr of long-term cropping of BSR-resistant A3 and BSR-susceptible Coles, incidence and severity of the disease were significantly lower ($P = 0.01$) where the resistant genotype had been grown than where the susceptible genotype had been grown (Fig. 2). In 1981, when the four BSR-resistant genotypes and the four BSR-susceptible genotypes were grown, the incidence and severity of the disease were significantly lower ($P = 0.01$) with the resistant lines than with the susceptible cultivars (Table 2). Incidence of BSR for resistant lines averaged 39.4% where A3 had been grown and 81.9% where Coles had been grown (Table 3). Incidence of BSR for susceptible cultivars averaged 70.0% where A3 had been grown and 96.9% where Coles had been grown (LSD [0.05] = 15.1). Severity of BSR for resistant genotypes averaged 15.5% where A3 had been grown and 43.6% where Coles had been grown. Severity of BSR for susceptible cultivars averaged 40.9% where A3 had been grown and 72.8% where Coles had been grown (LSD [0.05] = 11.2). The cropping history × soybean cultivar interactions for incidence and severity of BSR were not statistically significant (Table 2).

Yields for the BSR-resistant and BSR-susceptible genotypes were higher ($P = 0.01$) after 4 yr of BSR-resistant A3 than after 4 yr of BSR-susceptible Coles (Tables 2 and 4). Yield differences for BSR-resistant lines averaged 265.3 kg/ha greater (8.3%) after the BSR-resistant A3 than after the BSR-susceptible Coles, whereas yield differences for BSR-susceptible soybeans averaged 511.4 kg/ha greater (16.7%) after A3 than after Coles. The cropping history × soybean cultivar interaction for yield was statistically significant ($P = 0.05$). Where the susceptible Coles had been grown, the yield mean for the BSR-susceptible cultivars was lower (3,064.2 kg/ha) than the mean for the BSR-resistant lines (3,178.5 kg/ha). Where the resistant A3 had been grown, the yield mean for the BSR-susceptible cultivars was higher (3,575.6 kg/ha) than the mean for the BSR-resistant lines (3,443.8 kg/ha) (LSD [0.05] = 104.7).

Table 1. Analysis of variance for brown stem rot disease and yield data for A3 and Coles soybeans from 1977 to 1981

		Mean squares[a]		
		Brown stem rot		
Source of variation	df	Severity (%)	Incidence (%)	Yield (kg/ha)
Block	3	45.17	6.43	2,720.60
Cultivar	1	21,902.40**	20,611.60**	140,929.59*
Error A	3	57.33	5.13	7,880.44
Year	4 [1][b]	2,234.40**	981.31**	2,554,689.61**
Block × year	12 [3]	65.83	32.58	10,585.23
Cultivar × year	4 [1]	158.90	1,211.66**	102,768.08**
Error B	12 [3]	67.83	55.20	10,582.52

[a]* = Exceeding the 0.05 probability level, ** = exceeding the 0.01 probability level.
[b]Numbers in brackets are conservative degrees of freedom used for testing the repeated measures portion of the experiment.

Table 2. Analysis of variance for brown stem rot disease and agronomic data for eight soybean lines in 1981[a]

		Mean squares[b]		
		Brown stem rot		
Source of variation	df	Severity (%)	Incidence (%)	Yield (kg/ha)
Block	3	759.85	818.23	126,723.97
Cropping history	1	14,358.03*	19,251.56*	2,412,829.95**
Error A	3	566.60	1,622.40	63,829.02
Cultivar	7	3,185.71**	1,971.21**	141,107.07**
Type (R vs. S)[c]	(1)[d]	11,886.45**	8,326.56**	164,419.3 **
A3 Coles vs. Intr.[e]	(1)	4,712.4 **	875.52	47,786.14
History × cultivar	7	289.65	287.28	59,860.09*
History × type	(1)	59.29	976.56	134,047.52**
Error B	42	199.47	272.69	21,488.74

[a]Mean squares for cultivar and for cropping history × cultivar interaction have been subdivided.
[b]* = Exceeding the 0.05 probability level, ** = exceeding the 0.01 probability level.
[c]Resistant vs. susceptible soybean genotype.
[d]Numbers in parentheses are degrees of freedom for subdivided effects.
[e]Genotypes cropped in the long-term portion of the experiment (A3 and Coles) vs. newly introduced soybean lines and cultivars.

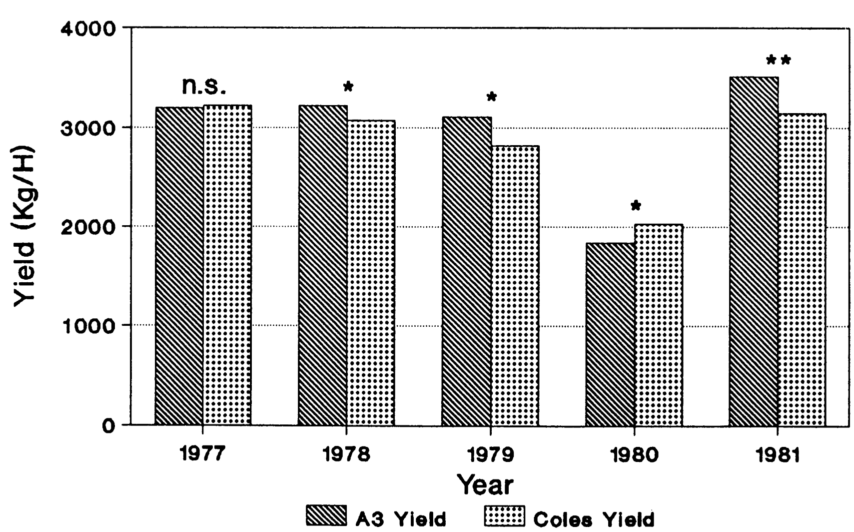

Fig. 3. Yields of soybean lines resistant (A3) and susceptible (Coles) to brown stem rot and grown in continuous cropping at Kanawha, Iowa, from 1977 to 1981. Values are means of four replications; n.s. = means of A3 and Coles not significantly different, * = means significantly different ($P = 0.05$), ** = means very significantly different ($P = 0.01$).

DISCUSSION

A significant conclusion that can be made from this study is that brown stem rot can be progressively reduced by growing resistant soybeans and, therefore, the growing of nonhost crops in a rotation is no longer the only method of control. The use of resistance has long been recognized as the most efficient method for plant disease control, particularly in field crops. In the use of resistance, however, many problems have occurred historically that subsequently required extensive studies on the nature, use, and management of resistance (6). Brown stem rot resistance seems no different and provides another example of resistance with possible unique features, based on the findings of this study. The findings not only

Table 3. Brown stem rot incidence and severity in resistant and susceptible soybeans after continuous cropping of resistant A3 and susceptible Coles for 4 yr at Kanawha, Iowa, in 1981

	Brown stem rot[a]			
	Incidence (%)[b]		Severity (%)[c]	
Soybeans	Coles	A3	Coles	A3
Resistant				
A3	70.0	20.0	31.0	6.8
A77-116013	75.0	32.5	38.5	8.1
A78-125029	90.0	65.0	69.5	36.4
BSR 201	92.5	41.0	35.3	10.8
Means[d]	81.9	39.4	43.6	15.5
Susceptible				
Coles	97.5	75.0	43.5	32.0
Hardin	90.0	62.5	69.4	46.4
Pride B216	100.0	75.0	84.6	38.9
Weber	100.0	67.5	93.5	46.1
Means[d]	96.9	70.0	72.8	40.9

[a]Values are means of 10 plants from each of four replications.
[b]Main plot cropping history differences were significant ($P = 0.05$) for incidence among cultivars, LSD = 23.6, C.V. = 22.9. Soybean cultivar differences were significant ($P = 0.01$) for incidence within cropping history, LSD = 30.0, C.V. = 22.9. Cropping history × soybean cultivar interactions for incidence were not statistically significant.
[c]Main plot cropping history differences were significant ($P = 0.05$) for severity among cultivars, LSD = 22.7. C.V. = 32.7. Soybean cultivar differences were significant ($P = 0.01$) for severity within cropping history, LSD = 20.2, C.V. = 32.7. Cropping history × soybean cultivar interactions for severity were not statistically significant.
[d]Incidence means for resistant and susceptible soybean lines were significantly different ($P = 0.01$) within a cropping history, LSD = 11.8. Incidence means between cropping histories for resistant or susceptible lines were significantly different ($P = 0.01$), LSD = 15.1. Severity means for resistant and susceptible soybean lines were significantly different ($P = 0.01$) within a cropping history, LSD = 10.1. Severity means between cropping histories for resistant or susceptible lines were significantly different ($P = 0.01$), LSD = 11.2.

Table 4. Yields of soybean lines resistant and susceptible to brown stem rot and grown after 4 yr of continuous cropping of resistant A3 and susceptible Coles soybeans at Kanawha, Iowa, in 1981

	Yield after continuous cropping of:[a]		
Soybeans	Coles (kg/ha)	A3 (kg/ha)	Yield difference[b] (kg/ha)
Resistant			
A3	3,314.4	3,510.7	+196.3
A77-116013	3,007.5	3,195.7	+188.2
A78-125029	3,195.0	3,589.0	+393.9
BSR 201	3,197.1	3,479.7	+282.7
Means[c]	3,178.5	3,443.8	+265.3
Susceptible			
Coles	3,140.9	3,485.5	+344.5
Hardin	2,962.8	3,431.0	+468.2
Pride B216	3,248.5	3,797.7	+549.2
Weber	2,904.7	3,588.3	+683.6
Means[c]	3,064.2	3,575.6	+511.4

[a]Values are means of four replications. Soybean cultivar differences within a cropping history were significant for yield, LSD = 209.4. LSD for cropping history means for a particular cultivar was 345.81. Cropping history × soybean cultivar interaction for yield was statistically significant ($P = 0.05$).
[b]LSD for yield difference between cropping history for soybean cultivars was 341.06 (C.V. = 59.7).
[c]Yield means for resistant and susceptible soybean lines were significantly different ($P = 0.05$) within a cropping history, LSD = 104.7. Yield means between cropping histories for resistant and susceptible lines were significantly different ($P = 0.01$), LSD = 116.9.

further corroborate past observations with BSR-resistance by demonstrating less disease in the BSR-resistant soybeans, but they support the hypothesis that incidence and severity of BSR decrease with long-term cropping of BSR-resistant soybeans. Furthermore, susceptible soybeans were found to have lower incidence and severity of BSR and significantly higher yields when grown on land where the disease was reduced by growing resistant soybeans.

Frequent or uninterrupted soybean production has been indicated as a factor in the development of BSR. Our results here indicate that there is an interaction between the cultivars (susceptible Coles and resistant A3) and years for incidence of BSR and soybean yield. Long-term cropping of a BSR-susceptible cultivar perpetuates BSR, whereas cropping of BSR-resistant soybeans reduces incidence of the disease and increases yield of both resistant and susceptible cultivars in subsequent years. Thus, it critical to be more specific as to the characteristics of cultivars, especially in regard to resistance or susceptibility to BSR, when cultivars are selected for a particular field.

Resistance to diseases in plants has been variously reported and described but is generally understood to be a phenomenon in which the plant has less disease. BSR-resistant soybean plants also have less BSR and accordingly are no different from what is usually expected with resistance. It may be logical that a disease would decrease after long-term cropping of a resistant cultivar as a result of the plants having less disease. If plants have less disease, then the crop residues will contain fewer propagules to cause the disease the following year. It is therefore possible that the reduction in incidence of BSR is due to a decrease in the amount of inoculum present in the environment. Once BSR is no longer a problem, BSR-susceptible soybeans often produce significantly higher yields than BSR-resistant soybeans (7); this was further established in our study. BSR-resistant soybeans could be grown for up to 5 yr continuously, after which newly released higher-yielding susceptible soybeans can be grown to provide the highest yields.

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