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Impact of Planting 'Bell', a Soybean Cultivar Resistant to *Heterodera glycines*, in Wisconsin[1]

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Abstract: Although the soybean cyst nematode (SCN), *Heterodera glycines*, has been known to exist in Wisconsin for at least 14 years, relatively few growers sample for SCN or use host resistance as a means to manage this nematode. The benefit of planting the SCN–resistant cultivar Bell on a sandy soil in Wisconsin was evaluated in 1992 and 1993. A range of SCN population densities was achieved by planting 11 crops with varying degrees of susceptibility for 1 or 2 years before the evaluation. Averaged over nematode population densities, yield of 'Bell' was 30 to 43% greater than that of the susceptible cultivars, 'Corsoy 79' and 'BSR 101'. Counts of cysts collected the fall preceding soybean were more predictive of yield than counts taken at planting. Yields of all three cultivars were negatively related ($P < 0.001$) to cyst populations. Fewer ($P < 0.01$) eggs were produced on 'Bell' than on the susceptible cultivars. The annual (fall to fall) change in cyst population densities was dependent on initial nematode density for all cultivars in 1992 and for the susceptible cultivars in 1993. Yield reductions induced by the SCN under the conditions of this study indicate that planting a SCN-resistant cultivar in Wisconsin can be beneficial if any cysts are detected.

Key words: crop loss estimate, *Glycine max, Heterodera glycines*, resistance, soybean, soybean cyst nematode.

The soybean cyst nematode (SCN), *Heterodera glycines* Ichinohe, is distributed throughout the north central region of the United States and causes more yield reduction of soybean (*Glycine max* (L.) Merr.) in the region than any other disease (3). Infestations of SCN were first reported in the 1950s for Missouri and Illinois, in the 1960s for Indiana, in the 1970s for Iowa and Minnesota, and in the 1980s for Kansas, Nebraska, Ohio, Michigan, and Wisconsin (15). The estimated number of infested fields has increased in the region during the past 5 years (13,18), but the incidence of SCN still varies widely among states. For example, in Missouri all but one country with significant soybean production is known to be infested with SCN (15), whereas the currently recognized incidence of SCN in Wisconsin is limited to about 110 fields in 13 counties (Norgren, per. comm.).

The impact of SCN on yield of soybean was studied in several states in the north central region. Estimated thresholds for SCN-susceptible cultivars exposed to defined nematode inoculum levels for Iowa (12), Illinois (4), and Missouri (13) ranged from 10–200 eggs/100 cm^3 soil. These thresholds are well within the range of published egg counts from SCN-infested fields in the region and were confirmed with yield data collected from sites with indigenous SCN populations (12,16). Yields of SCN-resistant cultivars of soybean maturity group II were 6% to 63% higher than that of susceptible cultivars planted in Iowa (12) and Illinois (16). Variability in these data were attributed to nematode population densities, environmental factors (12), soil type, and soybean cultivars (16).

A number of early–maturing cultivars with resistance to SCN are available for the north central region. Although SCN-resistant cultivars have been used extensively in some portions of Illinois (23), it appears that many growers throughout the region are not using host resistance as a means to manage SCN. This is certainly the perception in Wisconsin and it provided the rationale for our study. We conducted two field trials in 1992 and 1993 to document the benefit of growing a SCN-resistant cultivar in a sandy soil typical of much of the SCN-infested hectarage in

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Wisconsin. Before our evaluation, we planted the research site with crops of varying degrees of susceptibility to SCN to create a range of initial nematode inoculum densities representative of commercial fields.

Materials and Methods

Studies were conducted at the Hancock Research Station in a site discovered to be infested with *H. glycines* race 3 in 1990. The soil was a Plainfield loamy sand (92% sand, 5% silt, 3% clay, <1% organic matter; pH 6.1). Two adjacent blocks within the infested site were planted with 11 different crops in 1991 to establish a gradient of SCN population densities. The dimensions of each block were 81 × 18.5 m. The following crops were planted in 7.4 × 18.5 m contiguous strips: hairy vetch (*Vicia villosa* Roth), white clover (*Trifolium repens* L.), alsike clover (*Trifolium hybridum* L.) (seed sources for these three crops had no variety designation and should be regarded as "common"), 'Arlington' red clover (*Trifolium pratense* L.), 'Oneida' alfalfa (*Medicago sativa* L.), 'Dairyland 1103' (1991) and 'Pioneer 3965' (1992) corn (*Zea mays* L.), 'Perfection 77' pea (*Pisum sativum* L.), 'Early Gallatin' snap bean (*Phaseolus vulgaris* L.), 'Bell' soybean, 'Corsoy 79' soybean, and 'BSR 101' soybean. Based on published reports (19), SCN populations were expected to increase on 'Corsoy 79' and 'BSR 101' soybean, snap bean, pea, alfalfa, and hairy vetch. Populations were expected to decrease or remain stable on corn, white clover, red clover, and the SCN-resistant cultivar Bell. The host status of alsike clover was uncertain, as it was considered to be a susceptible host by some authors (6) but not others (20). Rotation crops were grown for one (east block) or two (west block) years before planting soybean. All rotation crops were planted on the same day; 30 May 1991 and 6 May 1992. Plots were irrigated twice weekly. The soybean cultivars were harvested on 1 October 1991 and 15 October 1992. The site was disked and plowed in the spring.

For sampling purposes, the strips of crops were each subdivided into three contiguous plots (33 plots total), hereafter referred to as rotation plots. Soil samples composed of six cores taken 22 cm deep were collected from the center rows of the rotation plots immediately after planting and before harvest from the east block in 1991 and from the west block in 1991 and 1992 to determine SCN population densities. Cysts were extracted from 100-cm^3 subsamples by a wet-sieving technique using nested sieves with openings of 841-µm and 180-µm. Cysts retained on the 180-µm sieve were counted using a stereomicroscope. Numbers of eggs were estimated from samples collected in the west block during the fall of 1992 as follows: the first 10 cysts encountered during counting were reserved and later crushed to release and count the eggs within. The 10 individual egg counts from each sample were averaged and then multiplied by the total number of cysts to estimate the total egg population for that sample. Frequency distributions of nematode population densities were plotted for each rotation crop. Data were not analyzed because the spatial arrangement of the rotation crops did not conform to a design appropriate for statistical analyses.

Three soybean cultivars, Corsoy 79, Bell, and BSR 101, were evaluated in the east block in 1992 and in the west block in 1993. Because *Phialophora gregata* (Allington & Chamberlain) Gams, the causal agent of brown stem rot, was also indigenous to the site, the three cultivars were selected so as to best identify the impact of SCN; 'Corsoy 79' is susceptible to both SCN and brown stem rot, 'Bell' (14) is resistant to both organisms, and 'BSR 101' (24) is susceptible to SCN but resistant to brown stem rot. All three cultivars were planted within each of the 33 sampling plots. The order of placement within each plot was randomly assigned. Thus, in the year of soybean evaluation, 99 smaller plots (2 × 7.4 m), hereafter referred to as soybean plots. Soybean was planted in rows spaced 17.5-cm apart on 6 May 1992 and 14 June 1993. Herbicides were applied at recommended rates twice before emergence (alachlor, linuron) in 1992 and 1993 and after emergence (bentazon) in 1993. The site was irrigated twice weekly. Harvest dates were 15 October 1992 and 26 October 1993. Yields were standardized to 13% moisture. In 1993, data were collected for plant height at harvest and relative lodging (scale = 1–5, where 1 = all plants erect and 5 = all plants on the ground).

Samples were collected in the spring and fall immediately after planting and before harvest, respectively. For the east block, samples were collected from the 99 soybean plots in the spring and fall of 1992, immediately after planting and before harvest, respectively. For the west block, samples were collected from the 33 rotation plots in the spring immediately after planting soybean and from the 99 soybean plots in the fall of 1993. Each sample was composed of 10 soil cores collected to a depth of 20 cm from the inner four rows within each plot. Cysts were counted from 100-cm^3 subsamples in the spring and fall; eggs were counted only in the fall as described for the rotation crops.

Soybean plots were monitored for disease, particularly brown stem rot. The severity of foliar symptoms diagnostic for brown stem rot was evaluated using the Horsfall-Barratt scale (7) of 0–11 on a weekly basis from the date of symptom onset. An area under the disease progress curve (AUDPC) was calculated for each cultivar (7).

Data were analyzed using regression and one-way analysis of variance programs of Minitab (10). Counts of cysts and eggs were transformed to $\log_{10}(x)$ or $\log_{10}(x + 1)$, respectively, to normalize the variance. Yields of the three soybean cultivars were regressed against counts of cysts from samples collected in the fall and spring before planting soybean. Performance of the cultivars was compared by testing for differences in the intercepts and slopes generated by regression analysis of soybean yields versus fall cyst densities. Analyses based on egg counts were also conducted for the 1993 soybean crop grown in the west block. Data from three plots where no eggs were detected in the fall were not included in this analysis because samples collected during the soybean year showed that SCN were present. Host suitability of the cultivars was compared by testing for difference in final egg population densities using analysis of variance. The annual (Pf/Pi) change in nematode population densities associated with each cultivar was computed by dividing counts of cysts or eggs at soybean harvest by the number present the previous fall. Density dependency of the annual change was tested by regressing $\log_{10}$(Pf/Pi) values on $\log_{10}$(Pi) values.

RESULTS

A range of SCN population densities was achieved by planting different crops for 1 or 2 years (Figs. 1,2). Coefficients of variability (CV) in cyst counts averaged over the entire block were lower after 1 (13%) year than after 2 (32%) years. There was more variability in egg counts (CV = 46%) than in cyst counts after 2 years of planting the 11 rotation crops. Numbers of cysts (1991 and 1992) and eggs (1992) were very high on the SCN-susceptible

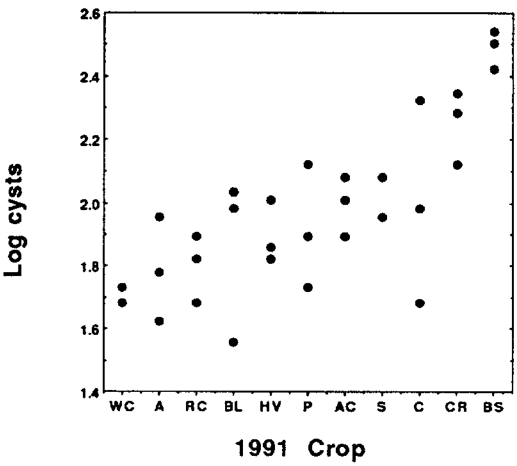

FIG. 1. Cyst densities of *Heterodera glycines* in October 1991 following 1 year of white clover (WC), alsike clover (AC), red clover (RC), alfalfa (A), corn (C), pea (P), hairy vetch (HV), 'Bell' soybean (BL), snap bean (S), 'Corsoy 79' soybean (CR), or 'BSR-101' soybean (BS). Each point represents the population density in one replicate plot.

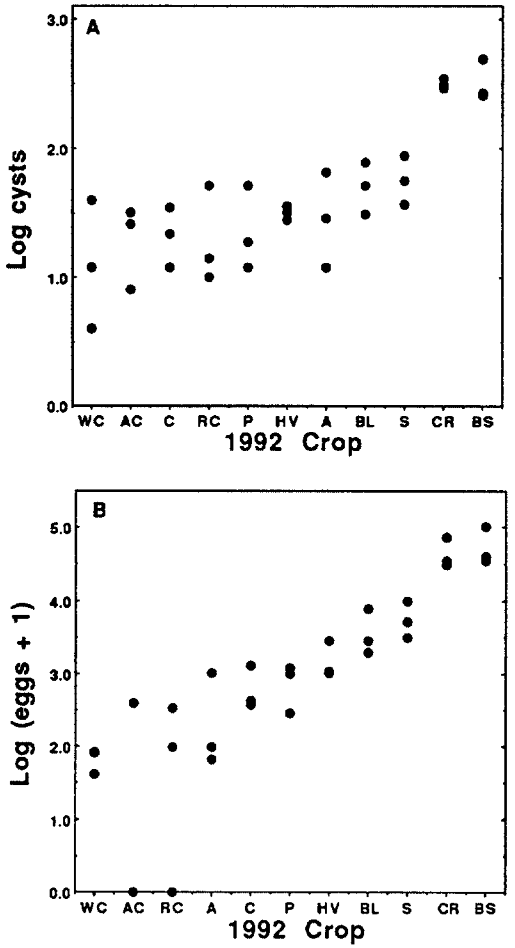

FIG. 2. Cyst (A) and egg (B) densities of *Heterodera glycines* in October 1992 following 2 years of white clover (WC), alsike clover (AC), red clover (RC), alfalfa (A), corn (C), pea (P), hairy vetch (HV), 'Bell' soybean (BL), snap bean (S), 'Corsoy 79' soybean (CR), or 'BSR-101' soybean (BS). Each point represents the population in one replicate plot.

soybean cultivars. Cyst counts associated with the other crops ranked according to host status with one exception; counts of cysts for corn samples were high in 1992 compared to those for other nonhost crops. The numbers of cysts in alsike clover plots remained high after 1 year (Fig. 1), but were comparable to the numbers present in nonhost plots after 2 years (Fig. 2).

The susceptible soybean crops suffered considerable damage during the 1 or 2 year rotation period preceding the evaluation. In 1991, yields of 'Corsoy 79', 'BSR 101', and 'Bell', were 1,200, 1,120, and 2,520 kg/ha, respectively, for the east block and 1,480, 1,540, and 2,550 kg/ha, respectively, for the west block. In 1992 (west block), the respective yields were 180, 510, and 1,740 kg/ha for the three cultivars.

Averaged over SCN population densities, 'Bell' yielded 43% more than 'Corsoy 79' and 30% more than 'BSR 101' in 1992 (Fig. 3) and 30% more than both cultivars in 1993 (Fig. 4). There was a negative relationship (P = 0.0001) between yield and nematode densities the previous fall for all cultivars. Regression equations corresponding to Figs. 3 and 4 are presented in Table 1. The intercepts of the regression lines, which reflect differences in the yield response of the cultivars to SCN, were different. The estimated intercept for 'Bell' was greater (P = 0.001) than 'Corsoy 79' in 1992 and 1993 and greater than 'BSR 101' in 1993. The slopes of the regression lines, which indicate the sensitivity of the cultivars to increasing population densities of SCN, were not different among the three cultivars.

Counts of cysts in the fall preceding a soybean crop were more predictive of yield than counts taken at the time of planting. In 1992, correlation coefficients ranged from −0.62 to −0.74 for fall-based analysis (Table 1) of the three soybean cultivars

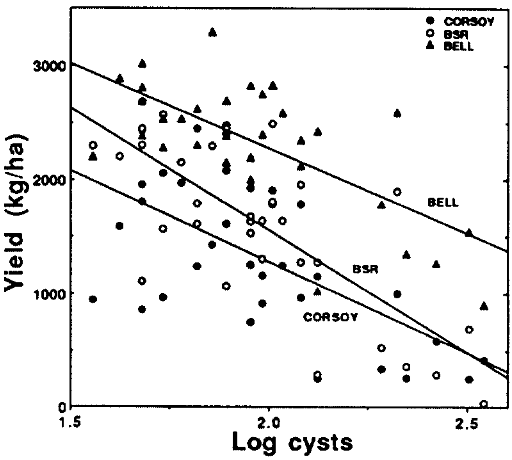

FIG. 3. Yields of soybean cultivars resistant ('Bell') or susceptible ('Corsoy 79', 'BSR 101') to *Heterodera glycines* in 1992 versus $\log_{10}$(eggs + 1) in October 1991.

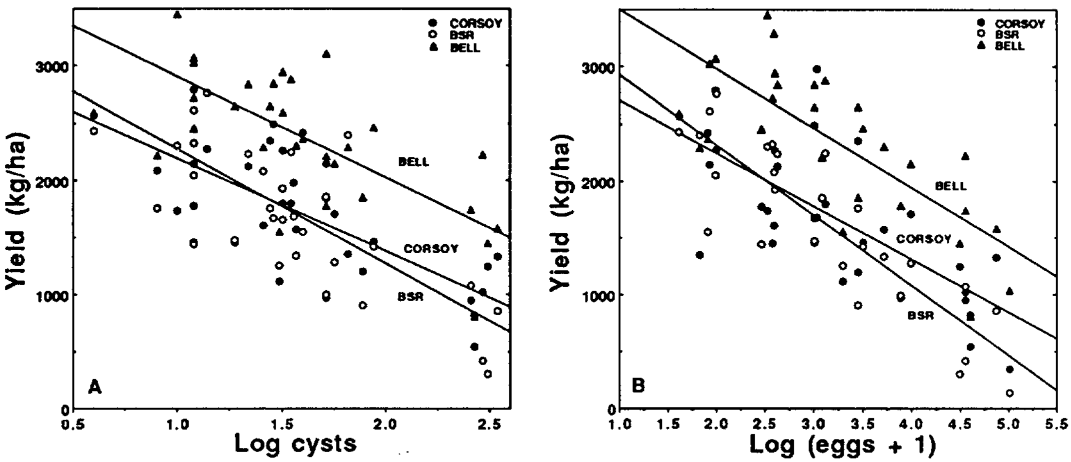

FIG. 4. Yields of soybean cultivars resistant ('Bell') or susceptible ('Corsoy 79', 'BSR 101') to *Heterodera glycines* in 1993 versus $\log_{10}$(cyst) (A) or $\log_{10}$(eggs + 1) (B) in October 1992.

and 0.55 to 0.74 for the spring-based analysis (data not shown). Correlation coefficients ranged from −0.69 to −0.72 for the fall-based analysis (Table 1) and −0.53 to -0.64 for the spring-based analysis in 1993 (data not shown). Regressions using egg counts had higher r^2 values than analyses based on cyst counts in 1993 (Table 1).

TABLE 1. Relationship of growth and yield of three soybean cultivars to base 10 logarithmic transformed counts of cysts (×1) or eggs (×2) of *Heterodera glycines* per 100 cm^3 soil in the fall preceding soybean crops grown in 1992 and 1993.

Cultivar	Regression equation†	r^2
	1992	
Corsoy 79	Yield = 4,490 − 1.60×1	0.38
BSR 101	Yield = 5,840 − 2.15×1	0.55
Bell	Yield = 5,250 − 1.49×1	0.45
	1993	
Corsoy 79	Yield = 3,010 − 0.82×1	0.52
	Yield = 3,120 − 0.46×2	0.56
	Height = 94 − 17.17×1	0.41
	Height = 101 − 1.27×2	0.61
	Lodging = 2.31 − 0.59×1	0.26
	Lodging = 2.43 − 0.35×2	0.32
BSR 101	Yield = 3,280 − 1.00×1	0.47
	Yield = 3,540 − 0.62×2	0.76
	Height = 90 − 17.29×1	0.40
	Height = 98 − 11.64×2	0.65
	Lodging = 2.46 − 0.55×1	0.26
	Lodging = 2.79 − 0.40×2	0.59
Bell	Yield = 3,860 − 0.91×1	0.52
	Yield = 4,020 − 0.52×2	0.57
	Height = 87 − 13.58×1	0.39
	Height = 92 − 8.41×2	0.50
	Lodging = 3.12 − 0.79×1	0.66
	Lodging = 3.12 − 0.40×2	0.56

† Units for yield, height, and lodging are kg/ha, cm, and 1–5 rating, respectively. *P* values were 0.0001 for the regression analysis of yield and height and 0.01 for lodging.

Plant height at harvest in 1993 was related (P = 0.0001) to nematode population densities for all three soybean cultivars (Table 1). Estimates of the slope and intercepts describing this relationship did not differ among cultivars. Plant lodging was also negatively related to nematode population densities. As was the case for yield and plant height, the lodging response of the three cultivars to increasing levels of SCN were similar. Tests for differences among the estimated intercepts showed more lodging associated with 'Bell' than 'Corsoy 79'.

Final cyst and egg population densities were comparable for the two SCN-susceptible cultivars and they were greater (P = 0.05) than that supported by 'Bell' (Table 2). In 1993, variability in the log-transformed egg and cyst counts was similar for the two susceptible cultivars (CV = 9 and 11%, respectively for egg and cyst counts), but not the resistant cultivar (CV = 29% for cyst counts and 78% for egg counts). In general, SCN population densities at harvest were lower in the west block in 1993 after 2 years rotation than in the east block in 1992 after 1 year rotation.

The annual (October to October)

TABLE 2. Mean population densities of *Heterodera glycines* eggs and cysts per 100 cm^3 soil and area under the disease progress curve (AUDPC) for brown stem rot (BSR) disease at harvest of three soybean cultivars planted in 1992 and 1993.

	1992			1993		
Cultivar	Eggs	Cysts	BSR	Eggs	Cysts	BSR
Corsoy 79	30,941	226	103	15,748	161	43
BSR 101	38,107	260	5	12,735	135	0
Bell	5,093	86	2	1,140	76	0

Counts of eggs and cysts were different (P = 0.05) for the SCN-resistant ('Bell') versus susceptible ('BSR 101' and 'Corsoy 79') cultivars. AUDPC values were different (P = 0.01) for the BSR-resistant ('Bell' and 'BSR 101') versus susceptible ('Corsoy 79') cultivars.

change in cyst densities in 1992 and egg densities in 1993 were negatively density dependent for all three cultivars (Table 3), i.e., the slopes of the regression lines comparing yearly change to initial densities were significant ($P < 0.001$). Density dependency was also demonstrated for the annual change in cyst densities associated with 'Corsoy 79' and 'BSR 101' in 1993, but not for 'Bell'. Correlation coefficients were higher for the two susceptible cultivars than the resistant cultivar. Using cysts as the population unit in 1992, r^2 values averaged 70% for the susceptible cultivars and 30% for 'Bell'. In 1993, r^2 values for eggs averaged 88% for the susceptible cultivars and 37% for 'Bell'. The r^2 values for cysts averaged 28% for the susceptible cultivars in 1993; slopes of the regression lines were not significant for 'Bell'.

TABLE 3. Relationship of the change ($\log_{10}$ [Pf/Pi]) in population density of *Heterodera glycines* cysts (×1) or eggs (×2) from October preceding a soybean crop to harvest of the soybean crop (October) versus the initial population density ($\log_{10}$ [Pi]).

Cultivar	Regression equation	r^2
	1992	
Corsoy 79	Y = 2.43 − 1.05×1	.74
BSR 101	Y = 2.22 − 0.92×1	.66
Bell	Y = 1.14 − 0.64×1	.30
	1993	
Corsoy 79	Y = 1.30 − 0.31×1	.25
	Y = 3.51 − 0.75×2	.88
BSR 101	Y = 1.24 − 0.32×1	.30
	Y = 3.51 − 0.77×2	.88
Bell	Y = 0.42 − 0.08×1	.01
	Y = 0.95 − 0.22×2	.37

P values were 0.01 for all equations except for 'Bell' cyst (×1) populations in 1993.

Both 'Bell' and 'BSR 101' were resistant to brown stem rot disease (Table 2). Computation of the AUDPC showed a low severity (<5) of leaf symptoms on these cultivars in 1992 and no presence of leaf symptoms in 1993. Corresponding AUDPC values for 'Corsoy 79' were 103 in 1992 and 43 in 1993. Regressions of yields on AUDPC values for the plots planted with 'Corsoy 79' were significant in 1992 (r^2 = 26.4, P = 0.002), but not 1993.

DISCUSSION

Yield of the SCN-resistant cultivar Bell was considerably greater than two susceptible cultivars in SCN-infested plots. Evaluations of the same cultivars in noninfested plots at the Hancock Research station concurrent to our study indicated that the higher yield of 'Bell' was due to the suppression of SCN; averaged over 1992 and 1993, yields for 'Bell', 'BSR 101', and 'Corsoy 79' were 2,627, 3,099, and 3,031 kg/ha, respectively, in the noninfested site (17). Given that a natural infestation of SCN was manipulated using crops common to Wisconsin, the extent of yield suppression may reflect the impact of SCN in infested commercial fields. The 30 to 43% yield difference between 'Bell' and the susceptible cultivars is higher than that reported for Iowa (12), and may reflect the influence of soil type. Yield reductions due to SCN were greatest in sandy soils in Illinois (16) and North Carolina (22), with damage thresholds approximately equal to detection thresholds.

The SCN-resistant cultivar Bell produced higher yields than the susceptible cultivars regardless of nematode population levels, but it too was negatively affected by high numbers of SCN. Francl and Dropkin (5) also found a significant negative relationship between initial SCN population densities and yield for the SCN-resistant cultivar Forrest in Missouri. These results indicate that even though there is an advantage to planting SCN-resistant cultivars, soybean yields may be unacceptable if SCN pressure is too great.

Some soybean plants in this study were coinfected by the vascular pathogen, *Phialophora gregata.* Brown stem rot can reduce soybean seed yields, and one of the most reliable methods for determining yield reduction is to compare the performance of cultivars resistant and susceptible to *P. gregata* (8). Our finding that the SCN-resistant cultivar Bell also expressed resistance to *P. gregata,* was consistant with yield trials conducted by Oplinger et al., (17), and has not been reported by other researchers. Yields of 'Bell' and the BSR-resistant cultivar BSR 101 were not comparable in our study, however, as would be expected if BSR was a major yield factor. The impact of brown stem rot in SCN-infested plots in an Iowa study was also minimal compared to the effect of SCN (12). In 1992, there was a yield benefit from planting 'BSR 101' as compared to the BSR-susceptible cultivar Corsoy 79, but the gain was much less than that associated with the SCN-resistant cultivar Bell. In 1993, yields of the BSR-resistant and -susceptible cultivar were not different. The decline in brown stem rot severity in 1993 following 2 years of rotation crops supports previous studies on the value of crop rotation for suppressing this disease (1).

Final population levels of SCN decreased as initial population densities increased, as has been reported for other studies (5,9). While density dependency was observed for both cyst and egg populations for the susceptible cultivars, the increase in cyst populations associated with 'Bell' was invariant for Pi in the second year of the study. One explanation for this finding may be that the high population densities achieved by 2 years of planting susceptible crops was equal to the carrying capacity of 'Bell', so that the number of nematodes infecting roots was similar over the range of population densities represented. This explanation was supported by a greenhouse trial (unpubl.) where we detected fewer nematodes in stained roots of 'Bell' as compared to the other cultivars at a single level of Pi.

Our study illustrates the value of crop rotation for managing SCN. Although SCN were not eliminated after 2 years of a nonhost crop, few nematodes were recovered from nonhost plots as compared to plots planted continuously with susceptible soybean. Our observations support the contention (19) that alsike clover is not a host to SCN. Although no statistical analyses were performed, the ranking of the nonhost crops for numbers of cysts recovered was different for the 1– and 2–year rotations, which implies that the decline of SCN population densities differed among nonhost crops.

Although there is a large body of literature describing control options and benefits for SCN (11,21), more information is needed to support decision-making in the northern United States. One of the greatest constraints for managing SCN in Wisconsin and Minnesota is the relatively late date a frost-free soil sample can be obtained in the spring. The high correlations between SCN cyst counts in October and yield reduction the subsequent year are encouraging for fall-based crop loss models.

Soybean yield reduction in Wisconsin due to the SCN is estimated at less than 1% (15), as compared to 4% for Illinois, Indiana, and Missouri (15). The perceived low impact of SCN is not only due to the limited number of reported infestations, but to the lack of significant above-ground symptoms. Plants were not visibly stunted in 1993 even though the yield gain of planting the SCN-resistant 'Bell' was 30%. A discrepancy between the apparent and actual yield reduction caused by SCN is common in the north central region and underscores the role SCN-resistant cultivars have in identifying as well as managing SCN infestations. Use of the SCN-resistant cultivar Forrest saved an estimated $401 million from 1975 to 1980 (2). Although an economic analysis has not been done for the north central region, our study indicates a yield benefit of planting a SCN-resistant cultivar on sandy soils, even when SCN cyst densities are at the detection threshold level.

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