Epidemiology

Effect of crop rotation and tillage system on sclerotinia stem rot on soybean[1]

D.S. Mueller, G.L. Hartman, and W.L. Pedersen

Abstract: Sclerotinia stem rot (SSR) of soybean is a major disease in the North Central region of the United States. A 3-year study was done to determine if crop rotation and tillage, moldboard plowing then mulch tillage (MP + MT), mulch tillage (MT), and no-till (NT), affected the population density of sclerotia and apothecia, incidence of SSR, and soybean yield. Crop rotation did not significantly affect the number or distribution of sclerotia or SSR incidence, but did affect the number of apothecia and the yield. The highest number of apothecia per square metre was observed in the plots in the continuous soybean rotation. Tillage affected both the number and distribution of sclerotia in the soil profile. Moldboard plowing lowered the number of sclerotia per litre of soil, compared to MT and NT plots, and buried the sclerotia deeper than 10 cm into the soil. Tillage did not affect the total number of apothecia observed, but moldboard plowing did delay emergence of apothecia compared to no-till. The MP + MT plots had the lowest disease incidence and the highest yield, while the NT plots had the highest disease incidence and the lowest yields. One year of moldboard plowing will bury sclerotia at least 10 cm in soil and delay the production of apothecia. How this affects SSR development depends on the other factors involved with disease development.

Key words: sclerotinia stem rot, soybean, crop rotation, mulch tillage, moldboard plowing, no-till.

Résumé : Le pourridié sclérotique (PS) du soja est une maladie importante dans la région Centre Nord des États-Unis. Une étude de 3 ans fut effectuée en vue de déterminer si la rotation et le travail du sol, le labour avec une charrue à versoirs suivi de l'enfouissement (LCV + E), l'enfouissement (E) et le semis direct (SD), affectaient la densité de population de sclérotes et d'apothécies, l'incidence du PS et le rendement du soja. La rotation n'a pas influencé significativement le nombre et la distribution des sclérotes ou la fréquence du PS, mais a influencé le nombre d'apothécies et le rendement. Le plus grand nombre d'apothécies par mètre carré fut observé dans les parcelles à culture continue de soja. Le travail du sol a affecté le nombre et la distribution des sclérotes dans le profil pédologique. L'utilisation de la charrue à versoirs a diminué le nombre de sclérotes par litre de sol par rapport aux parcelles E et SD et a enfoui les sclérotes à plus de 10 cm dans le sol. Le travail du sol n'a pas affecté le nombre total d'apothécies observées, mais le labour avec charrue à versoirs a retardé l'émergence d'apothécies par rapport au semis direct. Les parcelles LCV + E affichaient la plus faible fréquence de maladie et le plus haut rendement, alors que les parcelles SD avaient la plus haute fréquence de maladie et les plus faibles rendements. Une année de labour avec une charrue à versoirs enfouira les sclérotes à au moins 10 cm dans le sol et retardera la production d'apothécies. Comment cela affectera le développement du PS dépend des autres facteurs du développement de la maladie.

Mots clés : pourridié sclérotique, soja, rotation des cultures, enfouissement, labour avec charrue à versoirs, semis direct.

Introduction

Sclerotinia stem rot (SSR) of soybean (*Glycine max* (L.) Merr.), caused by *Sclerotinia sclerotiorum* (Lib.) de Bary, is a major disease in the North Central region of the United States (Chun et al. 1987; Grau et al. 1994; Grau and Bissonnette 1974; Grau and Radke 1984; Workneh and Yang 2000). Sclerotinia stem rot was ranked as the second most important soybean disease in the United States in 1994 (Wrather et al. 1997) and fourth most important from

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[1]Trade and manufacturer's names are necessary to report factually on available data; however, the USDA neither guaranties nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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1996 to 1998 (Wrather et al. 2001). Chamberlain (1951) first reported SSR in Illinois in 1946 and it has since been reported in various regions in northern Illinois. In 1996, an epidemic was reported in east-central Illinois (Hartman et al. 1998; Hoffman et al. 1998).

Conditions that affect growth of *S. sclerotiorum* include soil moisture (Grau et al. 1994; Weiss et al. 1980), 70–120 h of continuous plant surface wetness (Boland and Hall 1988a; Chun et al. 1987; Grau and Radke 1984; Grau et al. 1994), and cool canopy temperatures associated with early canopy closure (Abawi and Grogan 1975; Boland and Hall 1988a; Grau et al. 1994; Weiss et al. 1980). Soilborne sclerotia need cool and wet soil conditions to germinate and produce apothecia, which produce ascospores that germinate in extended wet conditions. Ascospores use the flower petals as a source of nutrients and produce mycelia (Abawi and Grogan 1975; Boland and Hall 1988a). Cool and wet conditions are conducive for mycelia to colonize senescing flowers and spread to lateral branches and the main stem (Abawi and Grogan 1975; Caesar and Pearson 1983; Tanrikut and Vaughan 1951).

Sclerotia are known to survive in the soil for 3 to 5 years (McLean 1958; Schwartz and Steadman 1978). So current crop rotation systems in Illinois (corn–soybean) appear to have minimal effect on SSR (Adams 1975; Kurle et al. 2001; Schwartz and Steadman 1978). However, soybean growers have changed many cultural practices to maximize yields and meet conservation mandates, e.g., early planting dates, reduced row spacing, higher plant populations, and reduced tillage. Reduced tillage practices directly influence soil moisture and soil temperature (Sumner et al. 1981). For example, no-till soils tend to be cooler and wetter at planting, often resulting in reduced emergence and lower final plant stands (Oplinger and Philbrook 1992; Unger and McCalla 1980).

The objectives of this study were to investigate the effect of crop rotation and three tillage systems on the number and distribution of sclerotia in the soil and subsequent effects on apothecia development, SSR incidence, and soybean yield.

Materials and methods

Plots were established in a commercial field near the Northern Illinois Agronomy Research Center, Dekalb, Ill., which had an epidemic of SSR in 1994. The distribution of SSR in the field in 1994 was unknown. The field soil was a silt loam with an organic matter content of 4.5%. The field had been cropped previously in a corn–soybean rotation and tillage was normally conducted using a spring chisel plow. Two management practices, crop rotation and tillage, were examined in a strip plot arrangement with cultivars randomized within each subplot. There were four replications. One main effect was the tillage treatments (moldboard plowing followed by mulch tillage (MP + MT), mulch tillage (MT), and no-till (NT)). In the fall of 1994, MP + MT plots were plowed to a depth of 20–25 cm. The MP + MT plots were not plowed again during this study. In the spring of 1995, 1996, and 1997, the MP + MT plots were tilled with a John Deere model 714 mulch tiller to a depth of 12–15 cm prior to planting. The MT plots were tilled with the mulch tiller in the spring prior to planting in all three years. The NT plots received no tillage prior to planting. The second main effect was crop rotations (corn–corn–soybean, soybean–corn–soybean, and continuous soybean), and the within each of the tillage by crop rotation plots were either soybean cultivars or corn. In 1995, all soybean plots were planted to the 'BSR 101' (susceptible to SSR). In 1996, soybean plots were planted to either 'BSR 101' or 'NK S19-90' (Syngenta Seeds, Golden Valley, Minn.) (moderately resistant) (Dann et al. 1998). In 1997, plots were planted to three soybean cultivars, BSR 101, NK S19-90, and NK S21-20 (unknown resistance). These plots were used to evaluate the effect of the crop rotation on SSR. All soybean cultivars were planted with a John Deere 750 no-till drill, 19-cm row spacing, at approximately 494 000 viable seeds per hectare. Planting dates in 1995, 1996, and 1997 were 15 May, 21 June, and 16 May, respectively. The corn hybrid, Dekalb 580, was used in both 1995 and 1996. Corn plots were planted with a John Deere 7100 planter, 76-cm row spacing, at approximately 66 000 kernels/ha. Rainfall was collected at the Northern Illinois Agronomy Research Center, approximately 1.5 km from the plots.

Sclerotia population and distribution

Twenty soil cores, 25 cm deep, were obtained from each plot prior to planting in 1996 and 1997. The entire soil sample was air dried, weighed, and soaked in warm water for 10 min before washing through a No. 18 sieve (1-mm pore size). All debris were washed into a plastic container and allowed to dry. The sclerotia were manually removed from the debris and counted. To determine the vertical distribution of sclerotia, an additional 25 cores of soil from each plot were collected in 1997 and divided into depths of 0–2.5, 2.5–10, and 10–25 cm. Sclerotia were extracted from the subsamples of soil as previously described. All sclerotia were surface sterilized with NaOCl (0.53%) for 2 min and placed on potato dextrose agar to test viability. Sclerotia were considered viable if they produced mycelia and additional sclerotia of *S. sclerotiorum*.

Apothecia counts

Apothecia were counted in two randomly selected 1-m^2 locations within each plot. Multiple apothecia from the same sclerotium were counted individually. Apothecia were counted on 15 August in 1996, when the soybean plants were at the R4 to R5 growth stage. In 1997, apothecia were counted on 23 July (R3 to R4 growth stage), 6 August (R5 growth stage), and 21 August (R6 growth stage).

Sclerotinia stem rot ratings

The incidence of SSR was assessed on 22 August 1995, 18 September 1996, and 22 September 1997. In 1995 and 1996, disease was assessed by a visible estimation in the center of each plot, while SSR was assessed in 1997 by counting the total number of plants and the number of diseased plants in two randomly selected 1-m^2 locations within each plot. Plants were considered diseased if mycelia and (or) sclerotia were present in or on the stem and lateral branches.

Seed yield

Plots were mechanically harvested on 14, 21, and 2 October in 1995, 1996, and 1997, respectively. The area harvested

Table 1. Analyses of variance for disease incidence of sclerotinia stem rot on soybean and seed yield in 1997.

Source of variation	df	Mean square[a] Disease incidence	Yield
Replicate	3	0.010	3 239
Tillage	2	0.510*	89 686*
Replicate × tillage	6	0.015	3 633
Rotation	2	0.018	50 311
Replicatex rotation	6	0.021	12 124
Rotation × tillage	4	0.019	10 143
Cultivar	2	0.236*	11 229
Cultivar × rotation	4	0.017	5 512
Cultivar × tillage	4	0.009	12 813
Cultivar × rotation × tillage	8	0.007	6 001
Residual error	66	0.012	9 420

Note: Cultivars used were NK S21-20, BSR 101, and NK S19-90.
[a]Replicate × tillage was the error term used to test the main effect of tillage. Replicate × rotation was the error term for the main effect of rotation. The other terms were tested using residual error.
*F value significant at $P = 0.01$.

Table 2. Effect of crop rotation on density of sclerotia and apothecia of *Sclerotinia sclerotiorum*, incidence of sclerotinia stem rot (SSR), and yield of soybean in 1996 and 1997, combined across all tillage systems.

Year	Crop rotation	Density of sclerotia in soil (L^{-1})	Total no. of apothecia (m^{-2})[a]	SSR incidence (%)[b]	Yield (kg ha^{-1})
1996	Soybean–soybean	1.6	4.8	<1	2050
	Soybean–corn	2.6	6.2	—	—
	Corn–corn	2.3	6.6	—	—
$LSD_{0.05}$		ns	ns	—	—
1997	Soybean–soybean–soybean	2.5	7.9	11.9	3790
	Soybean–corn–soybean	3.5	2.2	10.5	3720
	Corn–corn–soybean	3.6	1.8	11.2	3750
$LSD_{0.05}$		ns	2.0	ns	ns

Note: Tillages systems were no-till, mulch tillage, and moldboard plow. ns, not significant.
[a]Apothecia numbers are the average of three dates: 23 July and 6 and 21 August 1997.
[b]Sclerotinia stem rot ratings were taken on 18 September 1996 and 22 September 1997. Incidence was calculated by counting the total number of plants and the number of diseased plauts iu two randomly selected 1-m^2 locations within each plot.

per plot each year was 1.5 × 21 m. Seed moisture was calculated and seed masses were adjusted to 13% moisture.

Statistical analysis

Sclerotial and apothecial counts, SSR incidence, and seed yield values were analyzed using PROC GLM (SAS Institute Inc. 1996) to perform an ANOVA. Replicate × rotation was the error term used to test the main effect of crop rotation and replicate × tillage was the error term used to test the main effect of tillage. The other terms were tested by residual error. Pearson's correlation (PROC CORR) was used to analyze the relationship between sclerotia and apothecia counts, SSR incidence, and yield.

Results

There were no significant interactions between tillage and crop rotation for number of sclerotia or apothecia, incidence of SSR, or yield (Table 1) for any year, therefore only main effects were presented. Also, over 99% of the sclerotia were viable, so only the number of viable sclerotia were analyzed and presented.

Cultivar and crop rotation

In 1995 and 1996, there was less than 1% incidence of SSR on plants in all plots (Table 2). However, in 1997 there was a significant difference among the three soybean cultivars for disease incidence (Table 1). 'NK S21-20' had the highest incidence of SSR at 17.2%, while 'BSR 101' and 'NK S19-90' had 8.3 and 8.1%, respectively (data not shown). Since the cultivar × tillage and cultivar × crop rotation interactions were not significant, values for number of sclerotia, number of apothecia, SSR incidence, and yield with respect to crop rotation and tillage were averaged across the three cultivars.

Crop rotation did not affect the number of sclerotia or apothecia, incidence of SSR, or yield in 1996 (Table 2). However, crop rotation did affect the number of apothecia in 1997. The highest number of apothecia per square metre was observed in the continuous soybean plots, compared to

Table 3. Effect of tillage management on density of sclerotia and apothecia of *Sclerotinia sclerotiorum*, incidence of sclerotinia stem rot (SSR), and yield of soybean in 1995, 1996, and 1997, combined across all crop rotations.

Year	Tillage system	Density of sclerotia in soil (L^{-1})	Total no. of apothecia (m^{-2})[a]	SSR incidence (%)[b]	Yield (kg ha^{-1})
1995[c]	No-till	—	—	<1	3180
	Mulch tillage	—	—	<1	4130
	Moldboard plow	—	—	<1	4300
$LSD_{0.05}$		—	—	ns	150
1996	No-till	2.1	5.5	<1	2060
	Mulch tillage	2.4	9.5	<1	2100
	Moldboard plow	2.0	2.5	<1	2000
$LSD_{0.05}$		ns	3.2	ns	ns
1997	No-till	3.6	4.6	15.9	3700
	Mulch tillage	3.7	3.4	12.6	3770
	Moldboard plow	2.3	3.8	5.2	3790
$LSD_{0.05}$		1.2	ns	2.9	50

Note: Moldboard plow was performed in the fall of 1994 and mulch tillage in the spring of 1995, 1996, and 1997. ns, not significant.
[a]Apothecia numbers are the average of three dates: 23 July and 6 and 21 August 1997.
[b]Sclerotinia stem rot ratings were taken on 22 August 1995, 18 September 1996, and 22 September 1997. Incidence was calculated by counting the total number of plants and the number of diseased plants in two randomly selected 1-m^2 locations within each plot.
[c]Data were not collected on sclerotia and apothecia in 1995.

Table 4. Distribution of sclerotia of *Sclerotinia sclerotiorum* in soil from three tillage systems in 1997, combined across all crop rotations.

	Number of sclerotia in soil (L^{-1})		
Tillage depth (cm):	0–2.5	2.5–10	10–25
No-till	0.8	2.9	0.3
Mulch tillage	3.2	3.0	0.2
Moldboard plow[a]	0.3	0.4	2.2
$LSD_{0.05}$	2.1	1.9	0.6

[a]Moldboard plow was preformed in the fall of 1994 and mulch tillage in the spring of 1995, 1996, and 1997.

the soybean–corn–soybean and corn–corn–soybean crop rotations.

Tillage

There was no effect of tillage on the number of sclerotia in 1996; however, there was a significant effect ($P < 0.05$) of tillage on the number of sclerotia in 1997. The MP + MT plots had the lowest number of sclerotia with 2.3 L^{-1} soil, while the MT and NT plots had 3.7 and 3.6 L^{-1}, respectively (Table 3). There also was a significant effect on the vertical distribution of sclerotia in the soil profile (Table 4). MT plots had the highest number of sclerotia in the highest tier of soil; NT and MT plots had higher number of sclerotia in the middle tier of soil than MP + MT; and MP + MT plots had the most sclerotia in the lowest tier of soil (Table 4). However, the number of sclerotia was not significantly correlated with the number of apothecia, disease incidence, and yield.

In 1996, there was a significant effect of tillage on the number of apothecia (Table 3). The lowest number observed was in the MP + MT plots, with 2.5 apothecia/m^2. No-till and MT plots had respectively 5.5 and 9.5 apothecia/m^2. There was no significant effect of tillage on total apothecia number in 1997, however, there were differences in apothecia numbers on individual sampling dates. More apothecia were observed in the NT plots on the earliest sampling date (23 July) compared to the MT and MP + MT plots (Fig. 1). On 6 August, there was no significant difference among the tillage systems. On 21 August, the highest apothecial counts per square metre were in the MP + MT plots and the lowest apothecial counts were in the NT plots (Fig. 1).

Tillage had a significant effect on yield in 1995 and on disease incidence in 1997 (Table 1). In 1995 and 1996, incidence of SSR was less than 1% in all plots. In 1995, moldboard plowed plots had the highest yields and NT plots had the lowest yields. In 1996, soybean yields were low for all tillage treatments. In 1997, MP + MT plots had the lowest disease incidence (5.2%), while NT plots had the highest (15.9%) (Table 3); however, yield and disease incidence were not significantly correlated. Disease incidence was positively correlated to apothecia counted on 6 August ($r = 0.39$, $P < 0.05$) but not on 23 July and 21 August.

Discussion

Because of low levels of disease throughout the study, conclusions on the effect of tillage and crop rotation on SSR incidence and its subsequent effect on yield may not be as important as the effect of tillage and crop rotation on sclerotia populations and apothecia development. It is not uncommon for SSR to exceed 40% in a field and to approach 100% in individual plots (Hartman et al. 1998; Hoffman et al. 1998; Kurle et al. 2001). The most disease in this study was an average of 11.2% in 1997.

Previous studies have shown that crop rotations with corn or oat did not reduce sclerotial populations (Adams 1975; Kurle et al. 2001; Schwartz and Steadman 1978) or apothecial numbers (Kurle et al. 2001). In our study, there were no differences among the three cropping sequences for SSR incidence or yield. The additional year of corn should have, in theory, allowed many of the sclerotia to germinate and (or) degrade, but there were still enough sclerotia present in the

Fig. 1. Number of apothecia (m^{-2}) from three tillage systems in 1997. NT, no-till; MT, mulch tillage; and MP + MT, moldboard plow followed by mulch tillage. Bars headed by same letter do not differ significantly ($P < 0.05$).

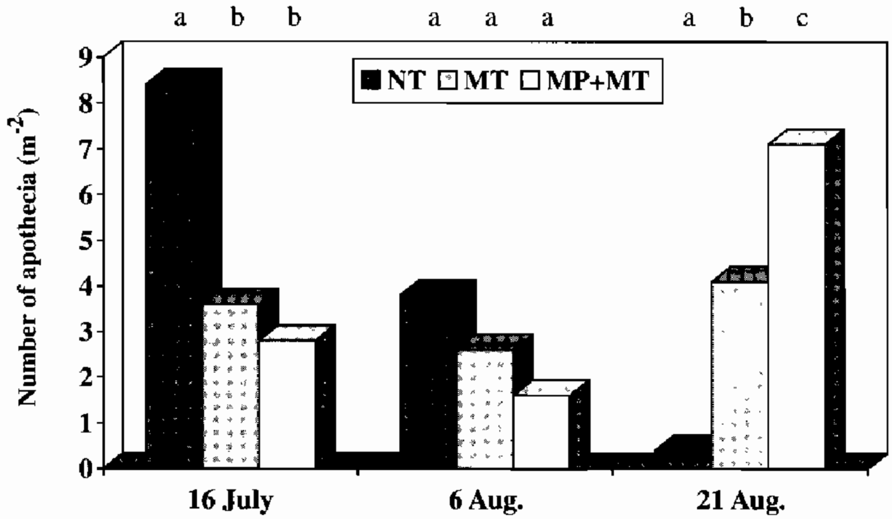
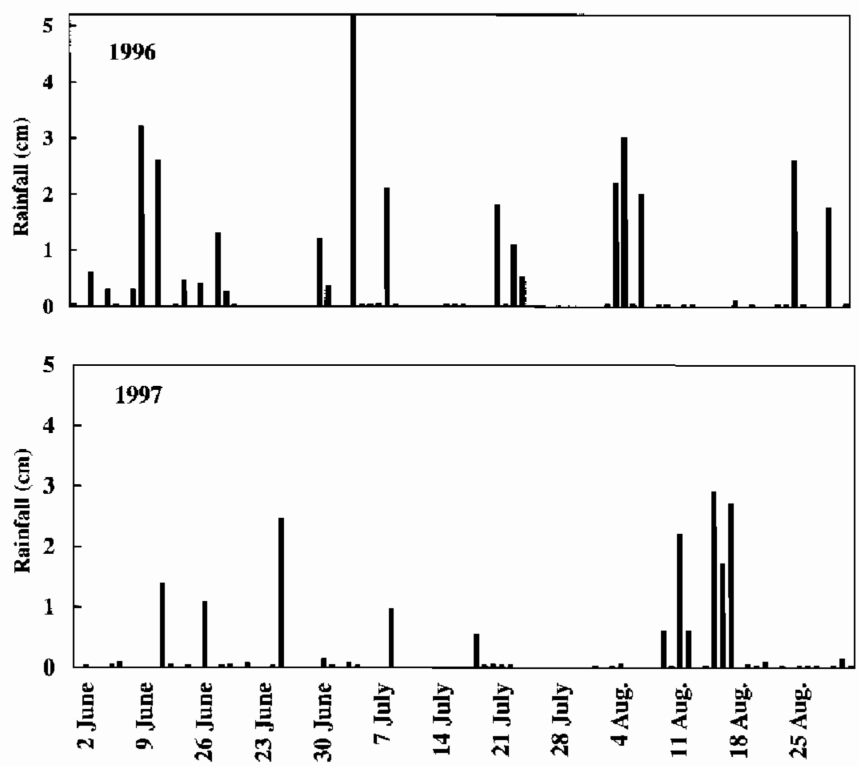


Fig. 2. Daily rainfall (cm) for Dekalb, Illinois, from 1 June to 31 August 1996 and 1997.



soil in 1997 to germinate and produce apothecia. Crop rotation may not affect SSR because sclerotia can survive and remain viable for 3 to 5 years in the soil (McLean 1958; Schwartz and Steadman 1978) and there are often alternate hosts, especially weed species found in nonhost crops (Boland and Hall 1994).

Heavy rains in late May and early June in 1996 (Fig. 2) delayed planting until 21 June. This led to poor canopy closure during flowering, which is one important condition necessary for apothecial and disease development (Abawi and Grogan 1975; Boland and Hall 1988b; Grau et al. 1994; Weiss et al. 1980). Apothecia were found in 1996, but not until the very end of flowering. This may explain why there was less than 1% incidence of SSR in all the plots even in the presence of apothecia. In 1997, adequate early season rain caused a dense canopy to develop, but there were no timely rains throughout flowering except near the end (9 August through 16 August). Thus, there was only moderate disease development, with an average of 11.2% in the entire field. At no time during the study did disease levels approach the epidemic levels of disease of 1994.

The website Crop diseases in corn, soybean, and wheat of Purdue University, Department of Botany and Plant Pathology (2001) recommends "deep plowing to bury sclerotia, then working soil shallow for 5+ years to keep sclerotia below soil surface" for control of SSR. In this study, the MP + MT tillage system was similar to Purdue's recommendation for control of SSR. Plowing has been reported to reduce apothecia number compared with surface cultivation in rapeseed (Williams and Stelfox 1980); however, the effect was not maintained the following year. Previous reports also have indicated that plowing was not an effective method in reducing the incidence of disease caused by *Sclerotinia* spp. (Kurle et al. 2001; Steadman 1983; Subbarao et al. 1996). In Wisconsin, moldboard-plowed plots were tilled every year, allowing a mixing of the soil and sclerotia throughout the soil profile (Kurle et al. 2001). In our study, sclerotia were buried by plowing in the first year, but were subsequently kept below 10 cm of soil by shallow tillage. The lower disease incidence in MP + MT plots in 1997 may have occurred because moldboard plowing reduced sclerotial levels in the upper 10 cm of soil and MT kept sclerotia from reaching the upper soil profile. In addition, several reports have shown that burying sclerotia reduces their survival (Imolehin and Grogan 1980; Merriman 1976; Merriman et al. 1979).

Burying sclerotia may also lower or delay the development of apothecia. Buried sclerotia may produce stipes, but form fewer apothecia because stipes need sunlight to mature into an apothecium. Most of the apothecia that emerged from buried sclerotia in the MP + MT plots did so after flowering in 1997, which ended mid-August. Sclerotia need saturated or near-saturated soil to produce apothecia (Abawi and Grogan 1975). Soil moisture retention is greater in no-till than mulch-tilled soils, so the small amount of rainfall in July 1997 (Fig. 2) may have provided enough moisture in the no-till plots to allow for more apothecial production. The drier soils in the MP + MT and MT plots may have needed the heavy rains in mid-August (Fig. 2) before sclerotia could germinate to form apothecia. Sclerotia in the NT soil were either closer to the surface or the moisture level was more conducive for apothecial development earlier in the season.

Workneh and Yang (2000) observed less SSR in soybean in no-till fields than minimum-till and conventional-till fields. They suggested that there were less disease in no-till soils because of higher microbial activity leading to sclerotia degradation. In fact, over 30 species of fungi and bacteria have been implicated by various workers as antagonists or mycoparasites of *Sclerotinia* spp. (Adams and Ayers 1979). Our study would support that observation, as fewer sclerotia were found in the upper 2.5 cm of soil in the no-till plots compared to the mulch-tilled plots. However, the sclerotia that were still present produced apothecia early in the season (Fig. 1), leading to a small increase in SSR incidence relative to the MT (Table 3).

Sporadic occurrence of SSR in soybean may be due to the sensitivity of *S. sclerotiorum* to environmental factors (Pennypacker and Risius 1999). Many times SSR can be found at a location, and no trace of it in the following years. The window of infection for SSR is rather limited and dependent on the timing of favorable weather conditions, host flowers, and ascospore showers. In the studied field, there was an epidemic in 1994. In 1995 and 1996, there was less than 1% SSR incidence, although sclerotia were found in most of the plots in 1996. This makes it hard to identify if no-till, mulch tillage, or moldboard plowing will affect SSR in individual fields. It does appear that 1 year of moldboard plowing will bury sclerotia at least 10 cm in soil and delay the production of apothecia. How this affects SSR development depends on the other factors involved with disease development.

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