

Effects of Cropping Systems on Population Density of *Heterodera glycines* and Soybean Yield

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ABSTRACT

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We evaluated the effects of soybean planting date and maturity group (MG) on final population density of *Heterodera glycines* and yield in cultivars susceptible to *H. glycines* grown in monoculture and in rotations with 1 or 2 yr of nonhosts. Population density of eggs and eggs plus second-stage juveniles of *H. glycines* declined to barely detectable levels after 2 yr of nonhost culture. Population densities of this nematode were consistently greater ($P = 0.05$) for an MG VII cultivar than an MG V cultivar. Planting date had variable effects on final population density of *H. glycines*: early planting resulted in the highest nematode numbers in some years, whereas late planting was associated with significantly greater ($P = 0.05$) population densities in other years. Yields were higher ($P = 0.01$) when soybean followed 1 or 2 yr of nonhosts than in monoculture. Yields of an MG V cultivar grown in succession with an MG V cultivar were greater than those of an MG VII cultivar that followed an MG VII cultivar, either in monoculture or in a 1-yr rotation with a nonhost. The higher yield of the earlier-maturing MG V cultivar was the result of low equilibrium densities of *H. glycines* associated with a shorter growing season. Late planting (June) generally resulted in lower soybean yield than early (May) planting. Yield of an MG V cultivar planted late was generally equivalent to that of an MG VII cultivar planted in May when *H. glycines* was at damaging levels.

A significant portion of U.S. soybean (*Glycine max* (L.) Merr.) hectareage is infested with soybean cyst nematodes (*Heterodera glycines* Ichinohe). Damage caused by *H. glycines* varies from negligible to near crop failure, depending on its initial population density and local environmental and edaphic factors. Crop rotation, resistant cultivars, and nematicides have been employed to reduce yield suppression by this pest.

Rotation with nonhosts of *H. glycines*, such as corn (*Zea mays* L.) or grain sorghum (*Sorghum bicolor* (L.) Moench), has been an effective management strategy. Nonhost culture for 2 or 3 yr, however, is frequently required to reduce population densities of the parasite below levels damaging to soybean (5, 14, 16). Crops grown in rotation with soybean may have lower value, or the hectareage of the alternate crop may be restricted by government programs. Thus, economic or other factors make long-term rotations unfeasible for many growers. Nematicides generally are not cost-effective for nematode control in low-value crops.

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Several studies have shown that cultural practices can affect the population density of the soybean cyst nematode. Planting date had little effect on damage to soybean caused by *H. glycines* in Georgia (8). Subsequent research in Missouri indicated that population density of *H. glycines* declines significantly from April to mid-June in the absence of a host (11), which may limit its damage potential on soybean. June-planted soybeans tended to support more soybean cyst nematodes than May-planted crops in several studies (11-13). Local environmental factors may be responsible for the variable effect of planting date on final population density of *H. glycines* (13). Other research (7, 13) has shown that soybean maturity group (MG) affects final population densities of this nematode. Late-maturing cultivars supported more soybean cyst nematodes than early-maturing ones when compared within MGs V-VIII (7).

Our objective was to evaluate cropping systems and sequences in terms of their effects on the reproduction and survival of *H. glycines* in order to maximize soybean yield in the presence of this pest. Specifically, we attempted to determine the effects of soybean planting date, maturity group, and 1- and 2-yr nonhost rotations on *H. glycines* and yield.

MATERIALS AND METHODS

Treatments were selected to evaluate nonhost rotations and cropping systems that are currently used in much of the southeastern United States. Rotations of 0 yr (soybean monoculture), 1-yr non-

host (corn-soybean), and 2-yr nonhost (corn-corn-soybean or corn-grain sorghum-soybean) were included at the first level of complexity. Soybean maturity group effects were superimposed at the next level of complexity. Soybean MG V cultivars are considered early-maturing, whereas MG VII cultivars are considered late-maturing in North Carolina. An early-maturing cultivar susceptible to *H. glycines*, Deltapine 105 (MG V), was compared with a late-maturing *H. glycines*-susceptible cultivar, Deltapine 417 (MG VII). Lastly, each combination of rotation and maturity group had two planting dates, mid-May to early June and mid-June to late June, which correspond to full-season soybean and short-season soybean following a winter wheat crop. Late-planted soybean crops always followed a winter wheat crop planted in November of the previous year (Table 1). Integrity of maturity group and planting date effects was maintained because the plots received the same planting date and maturity group each time soybean was planted. Treatment sequences were repeated so that every combination of cropping system would appear in the rotation on a yearly basis (Table 1).

The experiment was initiated in 1986 in a grower's field in Washington County, NC, after a uniform planting of *H. glycines*-susceptible soybean in 1985. The soil type was an Arapaho Sand (88% sand, 9% silt, 3% clay), pH 5.4, organic matter 4.5%. Standard management practices for North Carolina were followed for each crop with regard to weed control and fertilization. Corn was planted in mid-April each year in selected plots. Grain sorghum was planted in May or June of each year. Soybean was planted in mid-May to early June (24 May 1988, 26 May 1989, 4 June 1990, and 20 May 1991) or in mid-June to late June (23 June 1988, 21 June 1989, 20 June 1990, and 17 June 1991) after wheat harvest. Plots were 15.2 m long and eight rows wide and were spaced 0.96 m apart; 7.6-m-wide alleys were placed between ends of plots to prevent the distribution of inoculum with tillage equipment. Plots were arranged in a randomized complete block design with four replications.

Data for soybean yield and population density of *H. glycines* eggs at soybean harvest are from 1988 (the first-year rotations had been completed) to 1991.

Numbers of preplant eggs plus second-stage juveniles are from 1989 to 1991. Soybean yield was calculated from the center two rows of each plot, and soil samples for nematode assays were collected from these same rows. Samples were collected from all plots at corn planting in April and at soybean harvest in November of each year. Additional nematode samples were taken from soybean and grain sorghum plots when these crops were planted.

Soil samples taken for nematode analysis consisted of 15–20 cores, each 15 cm deep and 2.5 cm in diameter. Cores were composited, and a 250-cm³ subsample was processed by elutriation (3) and centrifugation (9) to collect cysts and second-stage juveniles. Cysts were crushed in a Ten Broeck homogenizer, and the eggs were extracted.

Soybean yield data were analyzed as a 3×2×2 factorial with three levels of rotation (0, 1, or 2 yr between soybean crops), two maturity groups, and two planting dates. Because there were no significant differences in nematode attrition or soybean yields following corn or grain sorghum, data for these two crops were pooled for analysis to provide additional information. Nematode data collected at soybean harvest from plots in which soybeans were grown that year were also analyzed as a 3×2×2 factorial with three cropping sequences (soybean monoculture or soybean following 1 or 2 yr of a nonhost crop), two planting dates, and two maturity groups. Data were analyzed over years with the PROC MIXED procedure (15) with replication (R) and R × MG × years × planting date as random effects. All other effects were considered fixed.

Data on nematode attrition following nonhost culture were analyzed as a 2×2×2 factorial with two levels of rotation (1 or 2 yr since the last soybean crop), two planting dates, and two maturity groups. Numbers of *H. glycines* eggs plus second-stage juveniles were analyzed in spring samples, whereas only numbers of eggs were analyzed at soybean harvest. Egg numbers are considered the more reliable indicator of population density, especially in the fall after eggs have entered diapause and the hatch of juveniles is very low (18). Spring estimates of population density, however, must include second-stage juveniles since these will likely survive to infect soybean plants. Numbers of eggs and the sums of eggs plus juveniles were transformed to log₁₀(x+1) to normalize the variance.

Analysis of variance (ANOVA) was the principal method of statistical analysis. Orthogonal polynomial contrasts were used to evaluate significant quadratic or linear effects of length of rotation on soybean yield or harvest densities of *H. glycines*. Yields from each planting date were regressed against

transformed (log₁₀[X+1]) preplant counts of eggs and juveniles per 500 cm³ of soil.

RESULTS

Eggs of *H. glycines* at the harvest sample date were generally at or below the minimum detectable level following 2 yr of nonhost culture (Fig. 1). One year of nonhost culture also resulted in low numbers of *H. glycines* eggs compared to soybean culture. Figure 1 shows that the effects of 1- and 2-yr nonhost rotations varied considerably over the duration of the experiment. For example, in 1990 (Fig. 1C) egg densities at soybean harvest were equivalent for 1 and 2 yr of nonhost culture. The relatively greater rates of survival after 2 yr in 1988 and 1989 compared to 1990 and 1991 are probably a result of higher population densities the year the cysts and eggs were produced. In general, neither planting date nor maturity group appeared to influence population densities of this nematode after 1 or 2 yr of nonhosts.

Numbers of *H. glycines* eggs at harvest following soybean culture were positively related ($P = 0.0001$) to the number of years of nonhost culture (Figs. 1 and 2, Tables 2 and 3). The lowest egg densities were generally associated with soybean monoculture.

The effect of soybean maturity group on *H. glycines* was consistent over the years studied. The MG VII cultivar resulted in significantly ($P = 0.0001$) more *H. glycines* eggs at soybean harvest than the MG V cultivar (Fig. 1) in every year except 1988; usually the differences in egg densities were twofold to fourfold.

The effects of planting date on egg numbers, though often significant, varied in direction depending on the year. The planting date-by-year interaction was significant ($P = 0.05$) (Table 3). Early planting resulted in greater harvest densities of *H. glycines* eggs for the MG VII cultivar in 1990 (Fig. 1C), whereas egg densities were generally greater in late plantings in other years (Fig. 1A and B, Table 2).

Nematode population densities in April of each year were approximately 50% lower than harvest densities the previous fall (Fig. 2). Effects of rotation, planting date, and maturity group on nematode levels were similar in spring and fall samples but were more pronounced in the harvest samples. Numbers of eggs plus juveniles declined from April to June (Table 4), but the decline varied considerably among years and between dates. The large variation associated with this measurement makes interpretation difficult.

Soybean yield responded positively ($P = 0.0003$) to rotation every year except 1988 (Fig. 3). Yields were adequately described by a quadratic model ($P = 0.0188$) (Tables 3 and 5) with respect to years of rotation. Maturity group also had significant effects on yield (Figs. 3 and 4, Tables 3 and 5). The MG V cultivar Deltapine 105 yielded more than the MG VII cultivar Deltapine 417, especially when grown in monoculture or in a 1-yr rotation with a nonhost (Figs. 3 and 4). The rotation-by-maturity group interaction was not significant, however (Table 5). Late planting generally had a negative impact on yield, although the planting date-by-year interaction was

Table 1. Rotation sequences of soybeans with nonhosts of *Heterodera glycines* in 1986–1991 in Washington County, NC^a

1986	1987	1988	1989	1990	1991
Soy(V,E)	Soy(V,E)	Soy(V,E)	Soy(V,E)	Soy(V,E)	Soy(V,E)
Soy(VII,E)	Soy(VII,E)	Soy(VII,E)	Soy(VII,E)	Soy(VII,E)	Soy(VII,E)
Soy(V,L)-W	Soy(V,L)-W	Soy(V,L)-W	Soy(V,L)-W	Soy(V,L)-W	Soy(V,L)
Soy(VII,L)-W	Soy(VII,L)-W	Soy(VII,L)-W	Soy(VII,L)-W	Soy(VII,L)-W	Soy(VII,L)
Corn	Soy(V,E)	Corn	Soy(V,E)	Corn	Soy(V,E)
Soy(V,E)	Corn	Soy(V,E)	Corn	Soy(V,E)	Corn
Corn	Soy(VII,E)	Corn	Soy(VII,E)	Corn	Soy(VII,E)
Soy(VII,E)	Corn	Soy(VII,E)	Corn	Soy(VII,E)	Corn
Corn-W	Soy(V,L)	Corn-W	Soy(V,L)	Corn-W	Soy(V,L)
Soy(V,L)-W	Corn-W	Soy(V,L)-W	Corn-W	Soy(V,L)-W	Corn
Corn-W	Soy(VII,L)	Corn-W	Soy(VII,L)	Corn-W	Soy(VII,L)
Soy(VII,L)-W	Corn-W	Soy(VII,L)	Corn-W	Soy(VII,L)	Corn
Corn-W	Sorg	Soy(V,E)	Sorg	Corn	Soy(V,E)
Sorg	Soy(V,E)	Corn	Corn	Soy(V,E)	Sorg
Soy(V,E)	Corn-W	Sorg	Soy(V,E)	Sorg	Corn
Corn-W	Sorg	Soy(VII,E)	Sorg	Corn	Soy(VII,E)
Sorg	Soy(VII,E)	Corn	Corn	Soy(VII,E)	Sorg
Soy(VII,E)	Corn-W	Sorg	Soy(VII,E)	Sorg	Corn
Corn-W	Sorg-W	Soy(V,L)	Sorg	Corn-W	Soy(V,L)
Sorg-W	Soy(V,L)	Corn	Corn-W	Soy(V,L)	Sorg
Soy(V,L)	Corn-W	Sorg-W	Soy(V,L)	Sorg	Corn
Corn-W	Sorg-W	Soy(VII,L)	Sorg	Corn-W	Soy(VII,L)
Sorg-W	Soy(VII,L)	Corn	Corn-W	Soy(VII,L)	Sorg
Soy(VII,L)	Corn-W	Sorg-W	Soy(VII,L)	Sorg	Corn

^aSoy denotes soybean; Sorg denotes grain sorghum. Soybean cultivars of maturity group V (early-maturing) or VII (late-maturing) were planted early (E) (mid-May to early June) or late (L) (mid-June to late June). W signifies that wheat was planted in the rotation.

significant (Table 3). Late planting resulted in high yields in 1989 (Fig. 3B) but generally low yields in other years (Fig. 3A, C, and D).

Initial population density of *H. glycines* (eggs and second-stage juveniles) was significantly negatively related to soybean yield for every year except 1988 (Table 6). Slopes of the regressions were generally equivalent for the early versus late planting within a given year except in 1989, when a significantly ($P=0.0094$) steeper slope was obtained with early planting compared to late planting. The primary difference between early and late planting was the position of the y intercept; early planting resulted in a higher yield, indicating the greater yield potential of the full-season crop as opposed to the short-season crop.

DISCUSSION

The decline of populations of *H. glycines* in the absence of a host has been well documented (5,14,16,18). Overwinter survival of this nematode generally ranges from 60 to 100% (18). Egg and second-stage juvenile survival in our study was about 50%. We attribute much of this decrease to redistribution of the population during fall cultivation. Fall samples were collected in the plant row,

where populations are most dense (1,4), but spring samples were taken after cultivation. Simple rotation effects on egg numbers of *H. glycines* were in agreement with previous research (5).

The decline in numbers of soybean cyst nematode eggs and juveniles from April to soybean planting was consistent with earlier work (11) but difficult to interpret because of the large variance between dates and among years. Although sampling errors may be responsible for much of the observed variation, further research is needed to evaluate environmental factors that may influence this decline.

Nonhost culture for 2 yr suppressed egg densities of *H. glycines* to barely detectable levels or below, whereas after 1 yr of nonhost culture, egg levels were low but detectable. Corn and grain sorghum had similar effects on attrition of this nematode. We did not expect these two crops to differ because earlier research indicated that cotton, corn, and grain sorghum had similar effects on the decline of *H. glycines* (5). Harvest population densities of *H. glycines* were much higher when soybean followed 1 or 2 yr of nonhosts than in soybean monoculture. This result was also expected because the reproductive rate of *H.*

glycines is density-dependent (5); minimal damage to soybean as a result of lower initial nematode population density allowed unlimited reproduction by this pathogen.

Limited data are available on the effects of soybean maturity group on *H. glycines* (7,13). Our results establish the predictability of the influence of maturity group: the later-maturing cultivar had consistently higher *H. glycines* levels. The mechanism involved is relatively simple. Later-maturing cultivars have longer growing seasons. The growing season for late-maturing cultivars is extended from early to late fall, when soil temperatures have declined and conditions are optimal for reproduction by *H. glycines* (2).

The effects of planting date on *H. glycines* are more difficult to interpret. Planting date had significant effects on final population densities, but the effects varied from year to year. We noted similar variation in other research conducted over a number of years in several locations (13). A likely explanation of this phenomenon is that different environments associated with planting dates affected nematode population development differently. A second explanation is that date of soybean

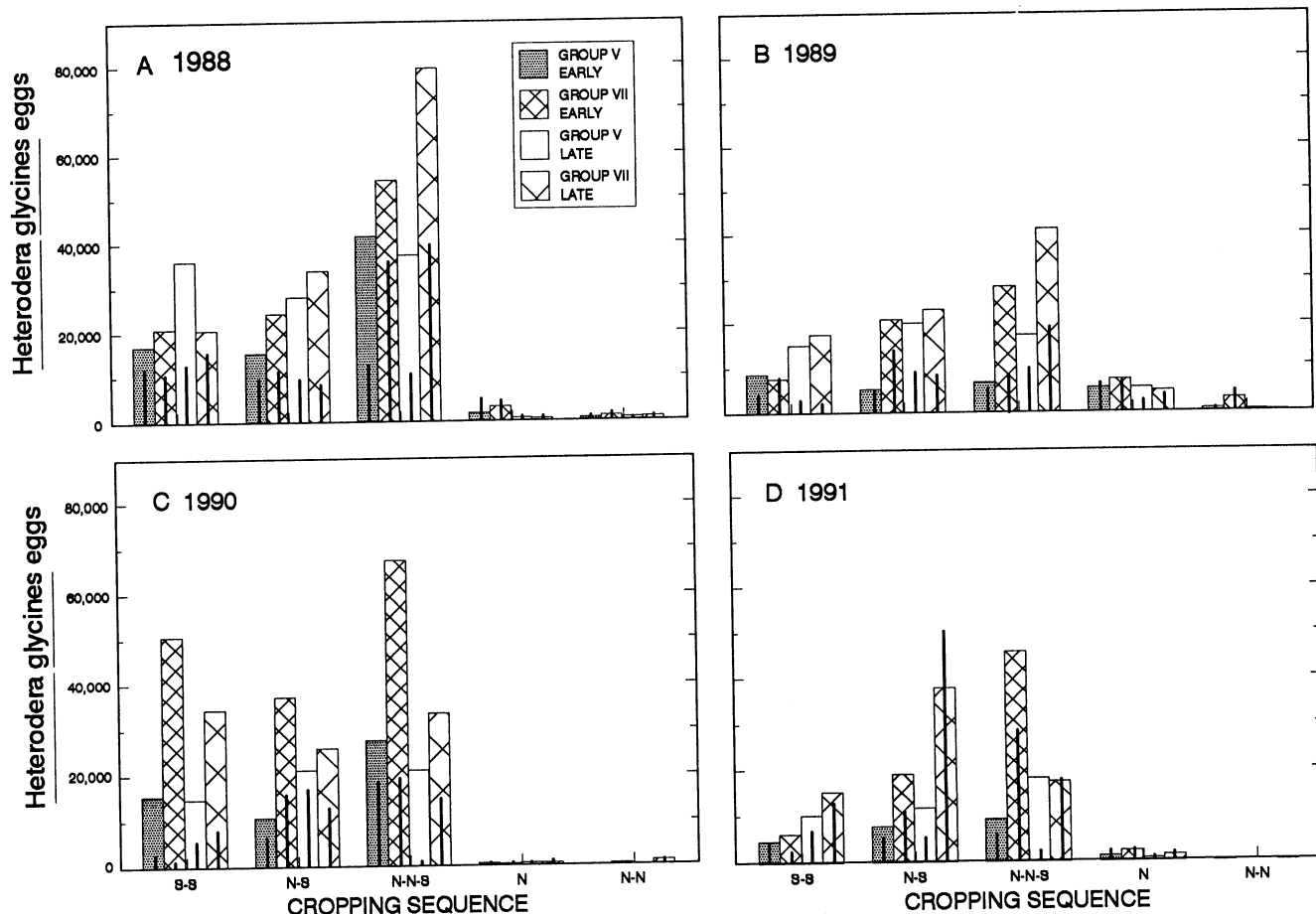


Fig. 1. Eggs of *Heterodera glycines* per 500 cm³ of soil at harvest of *H. glycines*-susceptible soybeans in 1988–1991 (A–D). Cultivars of maturity group V (early-maturing) or VII (late-maturing) were planted early (mid-May to early June) or late (mid-June to late June) in rotations with nonhosts for 0, 1, or 2 yr. Cropping sequence S-S = soybean monoculture, N-S = soybean following 1 yr of nonhost culture, N-N-S = soybean after 2 yr of nonhost culture, N = 1-yr nonhost culture, and N-N = 2-yr nonhost culture. Lines within bars indicate standard deviations.

planting can affect *H. glycines* reproduction rates in another important way. Egg numbers of this nematode usually decline from April to June (11). The reduction in egg population density limits damage to soybean and thus can encourage

higher rates of reproduction for this nematode. Lastly, late planting does shorten the growing season, but not to the extent that an earlier maturity group does. The general rule is that a 3-day delay in planting delays harvest by 1 day,

whereas an MG V cultivar matures about 4 wk before an MG VII cultivar. Thus, while both maturity group and planting date influence the length of the growing season, maturity group has the greater influence. Maturity group has reproducible effects on nematode population densities because later maturity extends the growing season to a period when conditions usually favor nematode reproduction. Planting date does not appear to have reproducible effects on nematode population densities, perhaps because it affects not only the length of the growing season but also density-dependent reproductive rates, and this interaction may result in an environment either more or less favorable for reproduction of *H. glycines*.

Rotation effects on soybean yield were striking except in the 1988 season. High yields for soybean monoculture in 1988 were a result of low *H. glycines* population densities associated with severe damage by this pest in 1987 (*data not shown*). Rotations with nonhosts for 1 or 2 yr resulted in yield increases of 10–40% for 1989–1991 compared to soybean monoculture. These results concur with previous research (5,14,16), but earlier studies often showed twofold to threefold yield increases with rotation. Although monoculture and rotation were different, the 1-yr rotation was not very different from the 2-yr rotation with respect to yield. The quadratic relationship between years of rotation and soybean yield indicates that growers reach a point of diminishing returns from

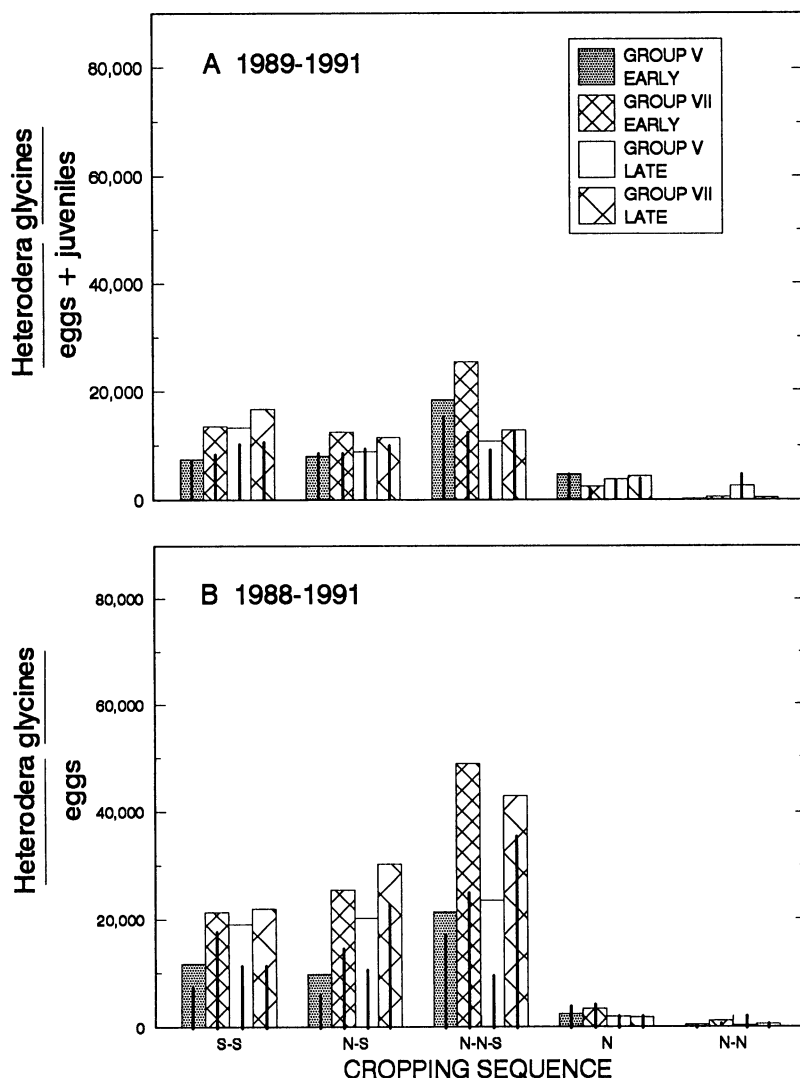


Fig. 2. Mean preplant populations of *Heterodera glycines* eggs and second-stage juveniles (A) (1989–1991) and mean harvest populations of eggs (B) (1988–1991) per 500 cm³ of soil when *H. glycines*-susceptible soybean cultivars were grown in rotations with nonhosts for 0, 1, or 2 yr. Cultivars of maturity group V (early-maturing) or VII (late-maturing) were planted early (mid-May to early June) or late (mid-June to late June). Cropping sequence S-S = soybean monoculture, N-S = soybean following 1 yr of nonhost culture, N-N-S = soybean following 2 yr of nonhost culture, N = 1-yr nonhost culture, and N-N = 2-yr nonhost culture. Lines within bars indicate standard deviations.

Table 2. Analyses of variance ($P > F$) for transformed ($\log_{10}[X + 1]$) egg densities of *Heterodera glycines* at soybean harvest in a factorial experiment with rotations of 0, 1, or 2 yr (soybean monoculture, 1 or 2 yr of nonhost culture), two soybean maturity groups (V vs. VII), and two planting dates (mid-May to early June vs. mid-June to late June) from 1988 to 1991

Factor	$P > F$			
	1988	1989	1990	1991
Rotation (R)	0.0138	0.1957	0.0051	0.0152
Rotation linear	0.0041	0.1203	0.1212	0.0043
Rotation quadratic	0.6319	0.3744	0.0035	0.7334
Maturity (M)	0.4563	0.0390	0.0001	0.0172
Planting (P)	0.0653	0.0009	0.1010	0.1622
R × M	0.8954	0.1715	0.5497	0.9073
R × P	0.8697	0.5817	0.2858	0.2978
M × P	0.4604	0.5546	0.0181	0.0756
R × M × P	0.1338	0.6720	0.6029	0.2988

Table 3. Analyses of variance ($P > F$) over years (including orthogonal polynomial contrasts for rotation) for transformed ($\log_{10}[X + 1]$) egg numbers of *Heterodera glycines* per 500 cm³ of soil at soybean harvest in plots where soybean was grown and for soybean yield from 1988 to 1991^a

Factor ^b	$P > F^c$	
	<i>H. glycines</i> eggs	Soybean yield
Rotation (R)	0.0000	0.0001
Rotation linear	0.0000	0.0001
Rotation quadratic	0.1962	0.0188
Maturity (M)	0.0000	0.0008
Planting (P)	0.0017	0.0122
Year (Y)	0.0000	0.0028
R × Y	0.3718	0.0005
M × P	0.0396	0.8784
P × Y	0.0036	0.0001
M × Y	0.2901	0.1054

^aThe analyses were 3×2×2 factorials over 4 yr with three levels of rotation (0 yr [soybean monoculture], 1 yr of nonhost culture [corn-soybean], or 2 yr of nonhost culture [corn-corn-soybean or corn-grain sorghum-soybean]), two planting dates (early vs. late), and two maturity groups (V vs. VII).

^bInteractions are not presented if $P > 0.10$.

^cAll F tests are approximate; PROC MIXED (15) was used, with replication and replication × maturity group × years × planting date as random effects.

rotation beyond 1 or 2 yr of nonhost culture. In other work, 2 or even 3 yr of rotation with a nonhost were necessary to maximize soybean yield in the presence of *H. glycines* (5,14,16).

There are several explanations for this discrepancy. Environmental factors and

differences in locations are obvious sources of variation among experiments. A further source of variation may be the time frame viewed. Early experiments on rotation were conducted shortly after this pathogen was discovered in North Carolina (14,16). Damage caused by this

pest may be less severe now than it was 30 yr ago as a result of the increase in antagonists to *H. glycines* and shifts in the prevalent races (18). We cannot document this aspect in North Carolina, but work with other crops and pathogens has demonstrated an increase in antagonists that resulted in disease suppression after several years (6). In addition, soils suppressive to *H. glycines* have been identified in Arkansas (10).

Differences in yield of soybeans of different maturity groups were related to associated *H. glycines* densities. Evidence for this hypothesis consists of results from the ANOVA showing consistent maturity group effects and correlations that demonstrated the inverse relationship between preplant nematode population density and yield. The cultivars Deltapine 105 and Deltapine 417 were selected because of their susceptibility to *H. glycines* and similar yield potential. An MG VII cultivar should outyield an MG V cultivar at least occasionally, other factors being equal, because flowering and pod fill occur at different times for cultivars of different maturity groups, and thus periodic drought stress will affect the yield of cultivars of different maturity groups differently. The consistency with which the MG V cultivar outyielded the MG VII cultivar in the current study suggests that the response is the result of lower equilibrium densities of *H. glycines* in plots planted with the MG V cultivar.

Delayed planting tended to result in lower soybean yield except in 1989. Slopes of the regressions of preplant densities of *H. glycines* on yield were not significantly different between planting

Table 4. Change in population density of *Heterodera glycines* (eggs plus second-stage juveniles per 500 cm³ of soil) per day from corn planting in mid-April to mid-May soybean planting and from corn planting to mid-June soybean planting from 1988 to 1991^a

Year	April-May		April-June	
	Change in <i>H. glycines</i> /day	SD	Change in <i>H. glycines</i> /day	SD
1988	-40	146	-15	30
1989	-30	127	-160	190
1990	-25	51	-71	89
1991	183	285	-87	135

^aData are means of 14 observations; SD = standard deviation.

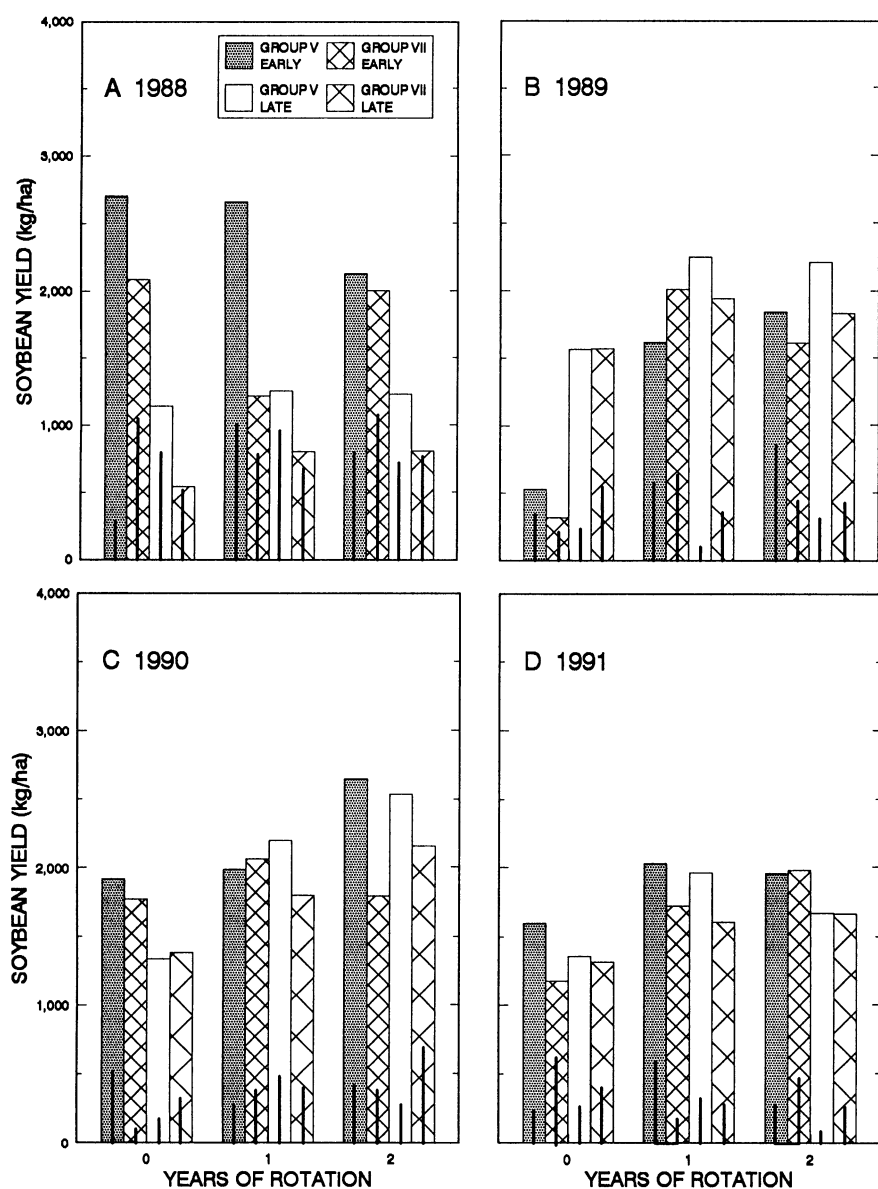


Fig. 3. Seed yield (kg/ha) in 1988-1991 (A-D) of soybean cultivars susceptible to *Heterodera glycines* grown in the presence of the nematode in rotations with nonhosts for 0 yr (soybean monoculture), 1 yr (corn or sorghum culture), or 2 yr (corn-corn-soybean or corn-grain sorghum-soybean). Cultivars of maturity group V (early-maturing) or VII (late-maturing) were planted early (mid-May to early June) or late (mid-June to late June). Lines within bars indicate standard deviations of the means.

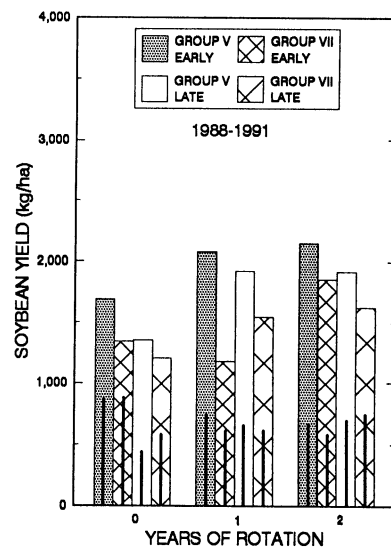


Fig. 4. Mean seed yield (kg/ha) from 1988 to 1991 of soybean cultivars susceptible to *Heterodera glycines* grown in rotations with nonhosts for 0, 1, or 2 yr. Cultivars of maturity group V (early-maturing) or VII (late-maturing) were planted early (mid-May to early June) or late (mid-June to late June). Lines within bars indicate standard deviations of the means.

dates except in 1989, indicating that the damage potential per nematode tended to remain static across planting dates. Because *H. glycines* levels are lower when planting is delayed, the yield of late-planted soybean should be reduced less by nematode damage than the yield of early-planted soybean. However, although delayed planting may limit damage caused by *H. glycines* because of nematode attrition, lower yield potential as a result of late planting may negate this benefit.

The use of cultural practices to manage *H. glycines* is an interesting and environmentally sound approach. The current research demonstrates the feasibility and some of the advantages and disadvantages of using early-maturing *H. glycines*-susceptible cultivars or late planting dates as tactics for managing this nematode. Earlier-maturing cultivars can shift the equilibrium densities of this pest to lower levels, thus boosting soybean yield in subsequent years. Delayed planting can limit damage from *H. glycines* because of attrition but may result in lower yield because of a higher probability of late-season drought stress. Early-maturing soybean cultivars may also be more subject to drought stress because of their shorter flowering and pod-filling period. Early-maturing cultivars can be planted late and still provide

adequate yields provided certain criteria are met. The current recommendation in North Carolina is to select a cultivar for late planting that will reach 0.9 m in height and still provide a closed canopy (E. J. Dunphy, *personal communication*). This goal can be achieved with many early-maturing cultivars, especially with narrow row spacings.

The aforementioned disadvantages can be overcome if growers can diversify their cropping systems. A full-season soybean crop can be grown on portions of land that can be rotated. Where rotation with nonhosts for two or more years is feasible, maturity group is unimportant as far as management of *H. glycines* is concerned. If cultivars with resistance to *H. glycines* are available, then a rotation of nonhost-resistant cultivar-nonhost-susceptible cultivar, as has been recommended in North Carolina for almost two decades (17), still offers much over simple 1-yr rotations with nonhosts. Rotations that are shorter than 2 yr should employ an early-maturing soybean cultivar to minimize buildup of *H. glycines*. Soybean planting should be delayed on land subject to the shortest rotations because these fields are most subject to damage.

These guidelines allow growers considerable flexibility in that they minimize risk from drought and may spread out

planting and harvest operations. Such options are valuable to growers in the southeastern United States, but their geographic area of application may be limited. Growers in the northern United States may have less flexibility in planting dates and choice of maturity group. Research on the use of cultural practices to manage *H. glycines* probably should be regionalized and must take into account the population dynamics and ecology of *H. glycines*.

Much progress has been made in managing soybean yield suppression caused by *H. glycines*. This nematode still presents significant challenges to researchers, plant breeders, and extension personnel because of its wide distribution and high survival rates. Future research should focus on vulnerable periods in the life cycle of this pest in order to find ways to minimize its reproduction and survival.

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LITERATURE CITED

- Alston, D. G., and Schmitt, D. P. 1987. Population density and spatial pattern of *Heterodera glycines* in relation to soybean phenology. *J. Nematol.* 19:336-345.
- Alston, D. G., and Schmitt, D. P. 1988. Development of *Heterodera glycines* life stages as influenced by temperature. *J. Nematol.* 20:366-372.
- Byrd, D. W., Jr., Barker, K. R., Ferris, H., Nusbaum, C. J., Griffin, W. E., Small, R. H., and Stone, C. A. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. *J. Nematol.* 8:206-212.
- Francl, L. J. 1986. Spatial analysis of *Heterodera glycines* populations in field plots. *J. Nematol.* 18:183-189.
- Francl, L. J., and Dropkin, V. H. 1986. *Heterodera glycines* population dynamics and relation of initial population to soybean yield. *Plant Dis.* 70:791-795.
- Gerlagh, M. 1968. Introduction of *Ophiobolus graminis* into new polders and its decline. *Neth. J. Plant Pathol.* 74, Suppl. 2.
- Hill, N. S., and Schmitt, D. P. 1989. Influence of temperature and soybean phenology on dormancy induction of *Heterodera glycines*. *J. Nematol.* 21:361-369.
- Hussey, R. S., and Boerma, H. R. 1983. Influence of planting date on damage to soybean caused by *Heterodera glycines*. *J. Nematol.* 15:253-258.
- Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. *Plant Dis. Rep.* 48:692.
- Kim, D. G., and Riggs, R. D. 1992. Biological control. Pages 133-142 in: *Biology and Management of the Soybean Cyst Nematode*. R. D. Riggs and J. A. Wrather, eds. The American Phytopathological Society, St. Paul, MN.
- Koenning, S. R., and Anand, S. C. 1991. Effects of wheat and soybean planting date on *Heterodera glycines* population dynamics and soybean yield with conventional tillage. *Plant*

Table 5. Analyses of variance ($P > F$) of soybean yield for main effects and interactions in a 3×2×2 factorial experiment with three levels of rotation (0, 1, or 2 yr), two planting dates (early vs. late), and two soybean maturity groups (V vs. VII), with orthogonal polynomial contrasts for effects of years of rotations, 1988-1991

Factor	$P > F$			
	1988	1989	1990	1991
Rotation (R)	0.7462	0.0001	0.0003	0.0003
Rotation linear	0.6671	0.0001	0.0001	0.0005
Rotation quadratic	0.5302	0.0002	0.5970	0.0026
Maturity (M)	0.0001	0.3215	0.0317	0.0643
Planting (P)	0.0001	0.0001	0.3011	0.1330
R × M	0.1639	0.4920	0.1510	0.3412
R × P	0.1568	0.0069	0.1217	0.5267
M × P	0.4007	0.3928	0.7814	0.6019
R × M × P	0.1663	0.2994	0.2861	0.5938

Table 6. Regression equations for log₁₀-transformed preplant density of eggs plus second-stage juveniles of *Heterodera glycines* (P_i) versus soybean yield (kg/ha) for each planting date and year, 1988-1991

Year	Planting	Regression equation ^a	Correlation coefficient	$P > F$
1988	First planting	$y = 2563 - 135 \log_{10}(P_i + 1)$	0.08	0.7072
	Second planting	$y = 1191 - 113 \log_{10}(P_i + 1)$	0.22	0.3092
1989 ^b	First planting	$y = 2632 - 458 \log_{10}(P_i + 1)$	0.64	0.0008
	Second planting	$y = 2124 - 116 \log_{10}(P_i + 1)$	0.40	0.0510
1990	First planting	$y = 2411 - 224 \log_{10}(P_i + 1)$	0.52	0.0094
	Second planting	$y = 1856 - 266 \log_{10}(P_i + 1)$	0.56	0.0046
1991	First planting	$y = 2603 - 208 \log_{10}(P_i + 1)$	0.62	0.0012
	Second planting	$y = 2354 - 216 \log_{10}(P_i + 1)$	0.63	0.0020

^aData for each equation comprised 24 observations.

^bSlopes are significantly ($P = 0.05$) different for 1989 only.

- Dis. 75:301-304.
12. Koenning, S. R., Anand, S. C., and Myers, G. O. 1992. An alternative method for evaluating soybean tolerance to *Heterodera glycines* in field plots. *J. Nematol.* 24:177-182.
 13. Koenning, S. R., Barker, K. R., and Schmitt, D. P. 1991. Effects of soybean maturity group and time of planting on *Heterodera glycines* final population density and soybean yield. (Abstr.) *J. Nematol.* 23:536.
 14. Ross, J. P. 1962. Crop rotation effects on the soybean cyst nematode population and soybean yields. *Phytopathology* 52:815-818.
 15. SAS Institute. 1992. SAS Technical Report P-229 SAS/STAT Software Changes and Enhancements. SAS Institute, Cary, NC.
 16. Sasser, J. N., and Uzzell, G., Jr. 1991. Control of the soybean cyst nematode by crop rotation in combination with a nematicide. *J. Nematol.* 23:344-347.
 17. Schmitt, D. P. 1991. Management of *Heterodera glycines* by cropping and cultural practices. *J. Nematol.* 23:348-352.
 18. Schmitt, D. P., and Riggs, R. D. 1989. Population dynamics and management of *Heterodera glycines*. *Agric. Zool. Rev.* 3:253-269.