# Impact of Crop Rotation and Tillage System on *Heterodera glycines* Population Density and Soybean Yield

S. R. KOENNING, Extension Specialist, D. P. SCHMITT, former Professor, and K. R. BARKER, Professor, Department of Plant Pathology, North Carolina State University, P. O. Box 7616, Raleigh, NC 27695-7616; and M. L. GUMPERTZ, Assistant Professor, Department of Statistics, North Carolina State University, P. O. Box 8203, Raleigh, NC 27695-8203

**ABSTRACT**

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The long-term effects of no-till planting practices and rotation on the population dynamics of the soybean cyst nematode (*Heterodera glycines*) and soybean yield were investigated in field experiments over a period of 8 yr. The experiment was a 2 × 4 factorial, comparing no-till vs. conventional tillage practices in four cropping patterns (continuous soybean, a 1-yr rotation of corn and soybean, a rotation of 2 yr of corn followed by soybean, and a corn-wheat/soybean double-cropping system). Treatments were arranged so that each combination occurred every year after 1986. Soybean after 1 yr of corn had higher yields ($P = 0.0001$) than soybean after soybean. Two years of corn between soybean crops resulted in soybean yields higher than those after 1 yr of corn in only 2 out of 6 yr. The yields of soybean in the corn, wheat/soybean double-cropping system, however, were generally similar to monoculture soybean. No-till practices had positive or no effects on soybean yield early in the study, but yields of no-till soybean were lower ($P = 0.01$) than conventionally tilled soybean after several years because weed pressure was greater in no-till plots. Population densities of *H. glycines* were greater ($P < 0.10$) in conventionally tilled plots than in no-till plots in 1988 and 1990–1992. Numbers of *H. glycines* fluctuated in an unpredictable manner from year to year, possibly because of unidentified biological control agents or excessive moisture in certain years. *H. glycines* population densities declined in a predictable manner when a nonhost was planted.

Additional keywords: conservation tillage, ecology

A major constraint on soybean (*Glycine max* (L.) Merr.) production in North Carolina is the soybean cyst nematode (SCN), *Heterodera glycines* Ichinohe. Tactics for managing this pathogen include the use of resistant cultivars, crop rotation, and other cultural practices (24,26). No-till production may affect nematode communities through alterations in soil chemical and physical properties, changes in weeds and other pest populations, or as a result of cover crops that may be utilized.

Conservation tillage has increased in the United States because soil erosion is suppressed, soil moisture holding capacity is improved, fuel expenditures for tillage operations are reduced (5), and because of government mandates. The impact of changes in tillage and other cultural practices on nematode communities is not well understood (14,19,20). Additionally, conservation tillage results in other changes in the agroecosystem that may affect soil biota. Cover crops, planting dates, crop rotation, and soybean maturity group also can influence population densities of plant-parasitic nematodes (2,13,14).

Nematode-response data to tillage systems have been variable. Numbers of plant-parasitic nematodes were greater in no-till than in conventionally tilled corn in Iowa (27). Population densities of both plant-parasitic nematodes and fungivorous nematodes also were greater under a no-till regime than with conventional tillage during the summer in one Georgia study (20). Still, reports from Tennessee, Alabama, and Mississippi (6,9, 16,28) indicate that *H. glycines* numbers may be suppressed in no-till compared to conventional tillage, and that soybean yields may benefit. Researchers in Tennessee (2) found lower densities of SCN second-stage juveniles associated with winter wheat than with full-season soybean and suggested that wheat might be toxic to *H. glycines*. Tillage and planting date effects could not be separated in this study, however. Planting date, which may be altered by cropping systems, can have a significant impact on residual numbers of *H. glycines*, but the time of sampling is critical (13). Other research showed that while planting date often has significant effects on final population densities of *H. glycines*, the magnitude and direction of the effect were likely influenced by environment (10,13,14). Researchers in Kentucky (9) concluded that SCN population densities were affected by wheat residue and that the tillage regime effects were of secondary importance. Nematicide treatments did not effect soybean seed yield increases in no-till soybean in North Carolina (25). Research conducted in Georgia and Florida generally showed minimal effects of tillage on population densities of plant-parasitic nematodes (8,18,19). Due to the soilborne nature of this parasite, variation in soil texture and/or genesis seems likely to modify the influence of tillage regimes on nematode communities and their associated impact on crops.

Crop rotation with nonhosts of SCN is a recommended practice in many areas where *H. glycines* suppresses soybean yield. Early work on rotation showed that 2 or more years of a nonhost crop were necessary to prevent yield suppression by SCN (7,21,23). More recent work showed that 2-yr rotations were necessary to maximize soybean yield, and also demonstrated the inverse relationships between SCN density and yield (7). Subsequent research conducted in North Carolina showed little benefit in extending rotations beyond 1 or 2 yr, especially if tactics that minimized population increase or suppressed the preplant population density (Pi) of *H. glycines* were employed (14).

Monitoring nematode population changes must be done after considering all aspects of the life cycle of nematode and plant (1,24,26). Some confusion that exists regarding tillage and cropping systems effects on nematodes may relate to the different extraction techniques used. Further opportunities for misconception involve the stage of the life cycle used to determine population levels. Second-stage juveniles are often used as a measure of the total *H. glycines* population density. Numbers of juveniles in the soil, however, do not correlate well with cyst or egg population densities (3). The SCN egg population density is considered the best predictor of soybean yield (3).

Cropping systems and cultural practices such as tillage need to be evaluated

Current address of second author: Department of Plant Pathology, University of Hawaii, St. John's 309A, 3190 Maile Way, Honolulu, Hawaii 96822.

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regionally in terms of their impact on pest populations as well as on productivity. This research was initiated to develop a better understanding of the influence of cropping systems and tillage on *H. glycines* population densities and soybean yield. Specific objectives included evaluation of the long-term effects of no-till soybean production practices, crop rotation, and a corn-wheat/soybean double-cropping system on soybean yield and *H. glycines* population dynamics.

## MATERIALS AND METHODS

This study, located on the Tidewater Research Station (NCDA) near Plymouth, North Carolina, was initiated in 1985 and continued through 1992 in a field naturally infested with *H. glycines*. The plots were established in a Portsmouth fine sandy loam (fine, loamy over sandy or sandy-skeletal, mixed, thermic, Typic Umbraquults) with 75% sand, 21% silt, 4% clay, and 4.2% organic matter. This 2 × 4 factorial experiment involved no-till vs. conventional tillage practices in four cropping patterns (continuous soybean monoculture, a 1-yr rotation of corn and soybean, a rotation of 2-yr corn followed by soybean, and a 1-yr corn-wheat/soybean [double-crop rotation system]) arranged in randomized complete blocks with four replications. Treatments were arranged so that every rotation sequence occurred each year after 1986. For this crop rotation study, eight sequences were required (one for continuous soybean monoculture, two for the corn-soybean rotation, three for corn-corn-soybean rotation, and two for the corn-wheat/soybean double-cropping system) in order to have soybean yield for each cropping pattern each year. Consequently, there were 16 plots in each block. No-till plots received no tillage during the course of the study, whereas conventional tillage plots were disked yearly, after which beds were formed with a ripper-bedder. Soybean cv. Deltapine 417 was planted in selected plots in mid-May of each year, except in the corn-wheat-soybean rotation, which was planted in mid- to late June after the wheat harvest. Plots were 7.3 × 15.2 m with eight rows spaced 91 cm apart. Wheat was planted in selected plots with a drill after conventional-tillage plots were disked to prepare a seedbed. Soybean yield was determined from the center two rows of each plot in November or December of each year.

Soil samples for nematode assays were collected at corn planting in April, and at soybean harvest from all plots. Soil cores were taken to a depth of 15–20 cm and were 2.5 cm in diameter. Numbers of SCN cysts, eggs, and second-stage juveniles (J2s) were determined from composite soil samples taken from the center two rows of each plot. Samples were processed by elutriation (4) and centrifugation (11) to collect cysts and second-stage juveniles. Cysts were enumerated and crushed with a Ten-Broeck homogenizer to release eggs from cysts.

All data were subjected to mixed effects Analysis of Variance (PROC MIXED; 22), including cropping pattern (rotation), tillage regime, and years as fixed main effects and all first- and second-order interactions. The effects of replication and the replication × tillage × sequence (rotation) interactions were included as random effects. A sequence term was included in the model to account for the fact that treatments did not occur in the same plots every year. Least squares means for nematode numbers and yield generated through this procedure are presented in graphs. Soybean yield also was analyzed without data from the corn/wheat/soybean rotation treatment in order to develop orthogonal polynomial contrasts with years of rotation as a quantitative variable. Yield of the short-season soybean crop was analyzed with other data in order to use orthogonal contrasts to compare cropping systems. A transformation, $\log_{10}(X+1)$, was used for nematode numbers to standardize the variance prior to statistical analyses. Nematode numbers following a soybean crop were analyzed separately from numbers following a corn crop because these data represent the effects of two separate biological processes.

## RESULTS AND DISCUSSION

One or two years of a nonhost crop (corn) resulted in very low numbers of *H. glycines* eggs and juveniles (Pf) at soybean harvest every year (Fig. 1). Population densities of *H. glycines* were lower ($P = 0.0279$) after 2 yr of corn than after 1 yr of corn (Table 1). Numbers of SCN eggs and juveniles following a soybean crop fluctuated greatly on a yearly basis (Fig. 1). The year's component of the combined Analysis of Variance was significant, as were the tillage × year and rotation × year interactions (Table 1). SCN numbers were lower in no-till plots than in conventional till plots

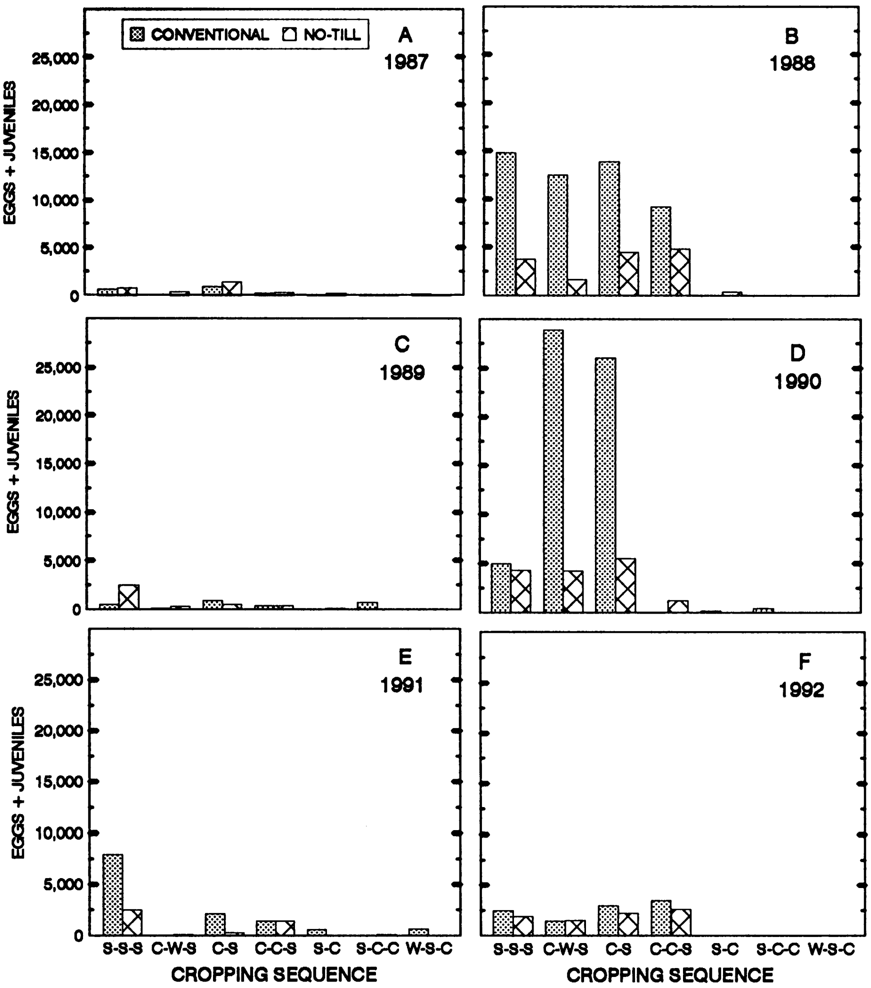


**Fig. 1.** Final population densities of *Heterodera glycines* eggs + juveniles per 500 cm$^3$ of soil at soybean harvest from 1987 to 1992. Conventional tillage consisted of yearly disking followed by bedding with a ripper-bedder, whereas no-till plots had received no tillage since 1985. Cropping sequence S-S-S = soybean monoculture, C-W-S = corn-wheat-soybean, C-S = corn-soybean, C-C-S = corn-corn-soybean, S-C = soybean-corn, S-C-C = soybean-corn-corn, W-S-C = wheat-soybean-corn. Data are least squares means generated by the PROC MIXED procedure of SAS.

in 1988, 1990, 1991, and 1992 (Table 2; Figs. 1 B and D–F), although tillage did not have a significant effect over all years. Yearly rotational effects on *H. glycines* Pf tended to be confounded with high variation (Fig. 1). SCN numbers were greatest for rotated plots in 1990 and 1992 but were largest in monoculture soybean in other years. The influence of planting date and/or a wheat cover crop on *H. glycines* Pf tended to be similar to a 1-yr corn-soybean rotation (Fig. 1).

Soybean yield was positively influenced by the length of the rotation interval (Fig. 2). Combined analysis over years indicated both linear and quadratic aspects of the length of rotation interval and soybean yield (Table 1). Soybean yields were similar in the 1-yr rotation vs. the 2-yr rotation in 1987–1989 and 1991. A 2-yr rotation had higher ($P < 0.10$) yields than a 1-yr rotation in 1992 and 1990 when measured by orthogonal contrasts (Table 3). A corn/wheat soybean double-cropping system was equivalent to soybean monoculture in the combined analysis. The double-cropping system outyielded the monoculture in 1988, but continuous soybean was superior in 1987 and 1992.

The declines in SCN population densities that occurred in our research following 1 or 2 yr of a nonhost crop were similar to other published reports (7,13, 14,21). Although the 2-yr rotation had lower SCN numbers than the 1-yr rotation, a single year of nonhost culture was adequate to reduce the population density to near nondetectable levels. Since wheat planting took place after 1 yr of corn, it is doubtful that any differences in SCN survival between tillage regimes or wheat vs. no wheat comparisons would be measurable. An additional confounding factor was that plots that did not receive wheat commonly had high densities of annual winter grasses. Although these grasses would not provide the biomass that a winter wheat crop would, their presence might affect nematode population densities similarly to that of a winter wheat crop.

The extreme yearly variation in nematode numbers over the course of this study cannot be accounted for by any one factor. The population tended to build up only every third year. Possible explanations include biological control and/or excessive moisture in certain years. Researchers have noted some locations where biological control of SCN appears to be active (12). A similar phenomenon occurred on at least one other location at this experiment station (D. P. Schmitt and S. R. Koenning, *unpublished data*). A second explanation may be excessive moisture that occurred during the growing season. Plots were irrigated in 1987, whereas the soils in 1989 and 1992 were extremely wet from excessive precipitation. The soil at this site is poorly drained and was waterlogged for long periods. Oxygen depletion in the soil may have resulted in soybean root death, which would have detrimental effects on *H. glycines*. A concurrent rotation was conducted about 15 km from this site (14) in an Arapaho sand with 88% sand, 9% silt, 3% clay, and 4.5% organic matter. The yearly population fluctuations, with periodic population crashes, did not occur in this better drained soil. The high moisture holding capacity of the soil in the current study may result in conditions favorable to biological antagonists of SCN.

The no-till treatments were effective in minimizing SCN buildup after 1987. Prior to 1988, there was no effect of tillage on *H. glycines* population densities (15). Research in Alabama and Tennessee suggests it may take several years before no-till affects *H. glycines* numbers (6,28), which may be the case in the current study. Soil in no-till systems becomes more compacted as time progresses (5), and this process likely takes place at different rates in different soil types. Young (29) showed that disturbance of soil cores removed from notill plots in Tennessee increased reproduction of SCN in the greenhouse compared to undisturbed cores. Compaction may result in physical changes in soil structure that may impede nematode

**Table 1.** Analyses of variance ($P > F$) for combined analysis over years (1987–1992) of soybean yield and final populations density (Pf) of *Heterodera glycines*

| | $P>F$ | | |
|---|---|---|---|
| | **Soybean yield** | **Pf (after soybean) eggs + juveniles[a]** | **Pf (after corn) eggs + juveniles** |
| Rotation (R) | 0.0011 | 0.0011 | 0.0279 |
| Tillage (T) | 0.0220 | 0.1575 | 0.0688 |
| Years (Y) | 0.0001 | 0.0001 | 0.4491 |
| R × T | 0.0001 | 0.0253 | 0.1388 |
| R × Y | 0.0001 | 0.0439 | 0.7527 |
| Y × T | 0.0046 | 0.0222 | 0.0093 |
| R × T × Y | 0.1150 | 0.3617 | 0.1943 |
| Rep*T*Sequence (R)[b] | 0.1130 | 0.0283 | 0.3547 |
| Contrasts | | | |
| R - S-S-S vs. C-W-S[c] | 0.1205 | 0.0027 | |
| R - C-S vs. C-W-S | 0.0500 | 0.0200 | |
| R-Linear[d] | 0.0001 | 0.0010 | |
| R-Quadratic | 0.0572 | 0.2896 | |

[a]Analysis of Pf after soybean was conducted separately from Pf of corn because these are two separate biological processes.
[b]Sequence term estimates plot error since rotations do not occur in the same plots every year. REP*T*SEQUENCE(ROT) used as error term.
[c]Continuous soybean donoted by S-S-S, corn-wheat-soybean by C-W-S, and corn-soybean by C-S.
[d]Analysis for orthogonal polynomial contrasts was done on a subset of the data excluding the corn-wheat-soybean cropping system.

**Table 2.** Analysis of variance ($P > F$) by years with contrasts of *Heterodera glycines* egg + juvenile population densities following a soybean crop from 1987 to 1992

| | $P>F$ | | | | | |
|---|---|---|---|---|---|---|
| | **1987** | **1988** | **1989** | **1990** | **1991** | **1992** |
| Tillage[a] | 0.2881 | 0.0163 | 0.2170 | 0.0286 | 0.0537 | 0.0029 |
| Rotation | 0.0512 | 0.3788 | 0.0515 | 0.0629 | 0.0027 | 0.0508 |
| Rotation × tillage | 0.3236 | 0.4268 | 0.0395 | 0.1483 | 0.1235 | 0.0449 |
| Contrasts | | | | | | |
| S-S-S vs. C-W-S | 0.0291 | 0.0726 | 0.0343 | 0.0906 | 0.0004 | 0.1399 |
| C-W-S vs. C-S | 0.0436 | 0.4536 | 0.1295 | 0.9073 | 0.3769 | 0.0630 |
| Orthogonal polynominal contrasts[b] | | | | | | |
| Rotation linear | 0.0816 | 0.7244 | 0.0033 | 0.0865 | 0.0568 | 0.1354 |
| Rotation quadratic | 0.3930 | 0.1836 | 0.3636 | 0.0436 | 0.2257 | 0.0441 |

[a]The ANOVA for each year was for a 2 × 4 factorial with two levels of tillage (no-till vs. conventional tillage) and four rotations (0 years = soybean monoculture [S-S-S], 1 yr = corn-soybean [C-S], 1 yr short-season = corn-wheat-soybean [C-W-S], 2 yr = corn-corn-soybean [C-C-S]). Orthogonal contrasts were used tó compare soybean monoculture with short-season (C-W-S) soybean and the corn-soybean rotation (C-S) with the corn-wheat-soybean system.
[b]The analyses for each year were for a 2 × 3 factorial with two levels of tillage (no-till vs. conventional tillage) and three cropping regimes (rotations) (rotations of 0 yr = continuous soybean [S-S-S], 1 yr = corn-soybean [C-S], or 2 yr corn-corn-soybean [C-C-S]). Cropping regimes were thus analyzed as a quantitative variable for orthogonal polynomial contrasts to partition out linear and quadratic effects. This was deemed necessary since the corn-wheat-soybean differs from other systems by two variables: wheat and planting date.

movement and affect soil aeration and moisture retention characteristics. All the aforementioned factors could impact population changes of this nematode. Research conducted at this site from 1986 to 1987 showed an increase in *Helicotylenchus* spp., *Aphelenchoides, Tylenchus,* and numbers of Mononchidae and Dorylaimidae in the conventional tillage system compared to the no-till system (17). Thus, tillage practices may have variable effects on population densities of different types of nematodes. Thomas (27) found higher densities of plant-parasitic nematodes in Iowa associated with no-till, whereas other researchers in Georgia and Florida have found variable, little or no effect of tillage on densities of plant-parasitic nematodes (8,18,19,20). The effects of tillage on nematode communities may be influenced by other factors, such as climate and soil type.

Infestation levels of SCN after soybean were sometimes greater in rotated plots than in continuous soybean. Higher nematode population densities following rotation have been documented in other research, since damage to the host by an obligate parasite may result in density-dependent reproductive rates (14). Biological control agents may also be favored by monoculture.

Population densities of *H. glycines* tended to be similar in the 1-yr rotation, regardless of cropping regime (wheat or no wheat). Since different planting dates were used for these two systems, information relating effects of wheat on *H. glycines* cannot be suitably analyzed. Some researchers have hypothesized that wheat residue may have a negative impact on *H. glycines* (2,9), although other researchers attributed this to a planting date effect (13). Data from the current research cannot be used to support either hypothesis, because tillage, cropping system, and rotation were confounded in this experiment.

Soybean yields were positively affected by rotation and the strong linear relationship between years of rotation and yield point to the superiority of a 2-yr nonhost interval between soybean crops. Data from individual years, however, suggest that a 2-yr rotation (2 yr of corn) of full-season soybean yielded significantly, but marginally, better than a 1-yr corn-soybean rotation in only 2 yr out of the six. A 1-yr corn-soybean rotation may be more appropriate than a 2-yr rotation for this soil type under current economic conditions for corn and soybean production. Data from earlier rotation studies conducted in the 1960s by other researchers indicated the need for extended rotations when this nematode was present (21,23). Several factors may explain the acceptable yields with shorter rotation intervals used in the current research: 1) biological antagonists of *H. glycines* may be more prevalent and

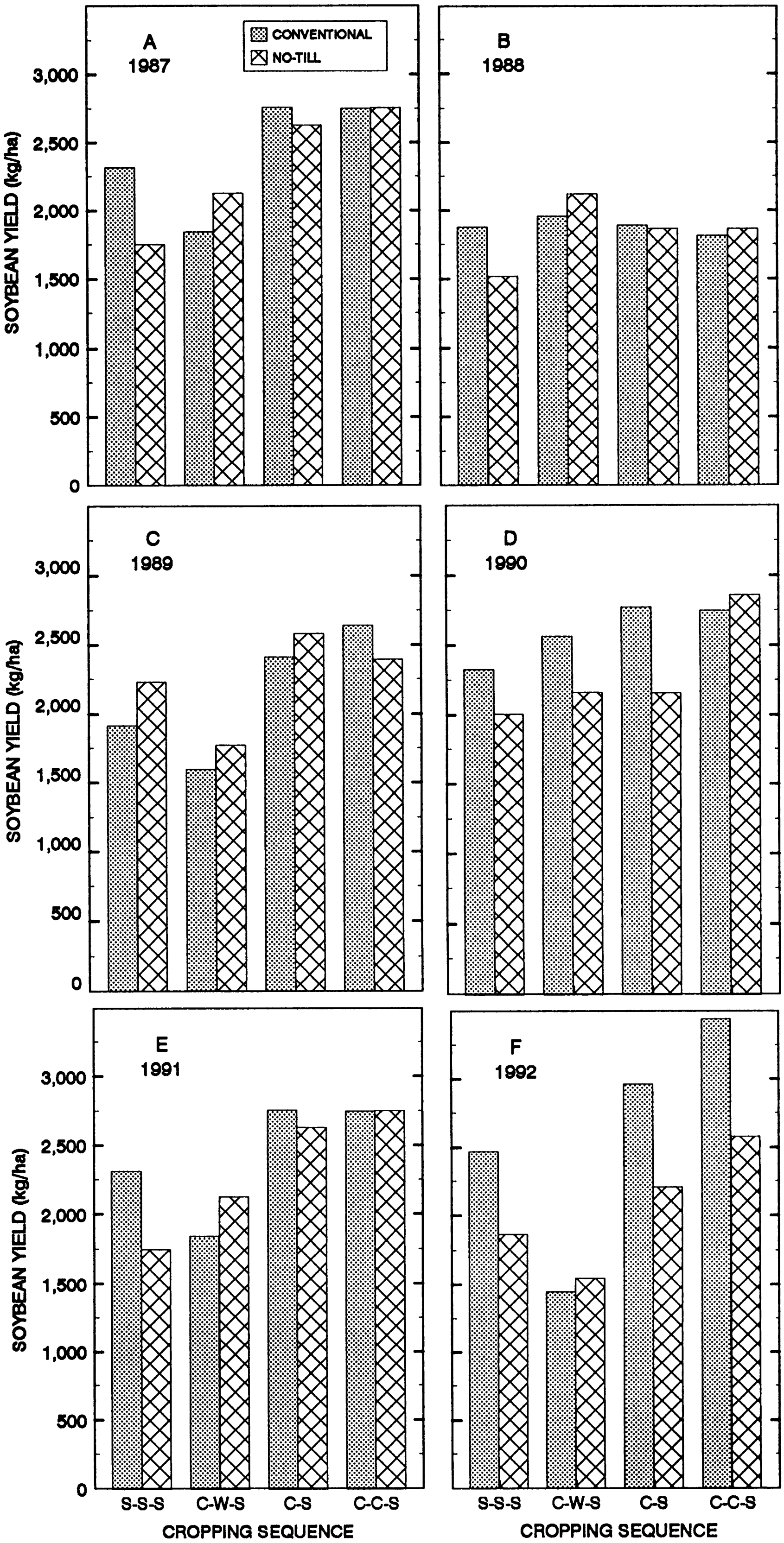


**Fig. 2.** Soybean yield (kg/ha) as influenced by tillage regime (no-till vs. conventional till) in a field infested with *Heterodera glycines* with various cropping patterns: S-S-S = soybean monoculture, C-W-S = corn-wheat-soybean (soybean planted after wheat harvest in June), C-S = corn-soybean (May-planted soybean), and C-C-S = corn-corn-soybean. Data are least squares means from the PROC MIXED procedure of SAS.

**Table 3.** Analysis of variance ($P > F$) of soybean yields for years 1987–1992 of tillage and rotation study at Plymouth, North Carolina

| | P>F | | | | | |
|---|---|---|---|---|---|---|
| | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| Tillage[a] | 0.6834 | 0.6929 | 0.3150 | 0.0132 | 0.2499 | 0.0014 |
| Rotations | 0.0001 | 0.1823 | 0.0001 | 0.0059 | 0.0001 | 0.0086 |
| Tillage × Rotation | 0.2413 | 0.3481 | 0.2516 | 0.1797 | 0.0165 | 0.2185 |
| Contrasts | | | | | | |
| S-S-S vs. C-W-S | 0.0106 | 0.0323 | 0.0126 | 0.2353 | 0.6891 | 0.0114 |
| C-W-S vs. C-S | 0.0010 | 0.1775 | 0.0001 | 0.0638 | 0.0001 | 0.0001 |
| S-S-S vs. C-S | 0.0005 | 0.2377 | 0.0069 | 0.0760 | 0.0001 | 0.0934 |
| S-S-S vs. C-C-S | 0.0041 | 0.3514 | 0.0051 | 0.0007 | 0.0001 | 0.0021 |
| C-S vs. C-C-S | 0.3828 | 0.7956 | 0.8990 | 0.0476 | 0.6291 | 0.0944 |
| Orthogonal polynominal contrasts[b] | | | | | | |
| Rotation linear | 0.0031 | 0.3541 | 0.0092 | 0.0012 | 0.0001 | 0.0024 |
| Rotation quadratic | 0.0065 | 0.4053 | 0.1342 | 0.8914 | 0.0147 | 0.9972 |

[a] The ANOVA for each year was for a 2 × 4 factorial with two levels of tillage (no-till vs. conventional tillage) and four rotations (0 years = soybean monoculture [S-S-S], 1 yr = corn-soybean [C-S], 1 yr short-season = corn-wheat-soybean [C-W-S], 2 yr = corn-corn-soybean [C-C-S]). Orthogonal contrasts were used to compare soybean monoculture with short-season (C-W-S) soybean and the corn-soybean rotation (C-S) with the corn-wheat-soybean system.

[b] The analyses for each year were for a 2 × 3 factorial with two levels of tillage (no-till vs. conventional tillage) and three cropping regimes (rotations) (rotations of 0 yr = continuous soybean [S-S-S], 1 yr = corn-soybean [C-S], or 2 yr corn-corn-soybean [C-C-S]). Cropping regimes were thus analyzed as a quantitative variable for orthogonal polynomial contrasts to partition out linear and quadratic effects. This was deemed necessary since the corn-wheat-soybean differs from other systems by two variables: wheat and planting date.

effective in reducing numbers of this nematode than in previous studies; 2) current cultivars may possess higher levels of tolerance; and 3) populations of *H. glycines* may be less virulent now than 30 yr ago.

The corn-wheat-soybean rotation was generally equivalent to soybean monoculture in terms of soybean yield when averaged over the 6 yr. There was, however, considerably more variation in soybean yield on a yearly basis in the double-cropping system. This effect is largely in response to planting date. Late plantings tend to be more subject to drought stress since the soybean pod filling period is shortened. Late plantings, however, will occasionally outyield full-season soybean since the pod filling period is shifted to a time that may be more favorable for soybean yield. There was a trend toward highest soybean yields in no-till early in the study (1987–1989), but this trend was reversed in the last 3 yr of the study (1990–1992), with highest yields in the conventional tillage system, although neither trend was statistically significant. The advantage of no-till early in the study could be attributed to the suppression of *H. glycines* densities in this system, but this causal relationship cannot be proven. Lower yields in the no-tillage system in the latter half of the study were probably a result of poor weed control (data not included). Weed control could be improved by altering the row spacing, but the practice of drilling soybean had not become an established practice in our area in 1985 when the study was established.

This research shows that tillage regime has a significant impact on the population dynamics of *H. glycines*. More research is warranted to explain mechanisms that affect suppression of *H. glycines* in no-tillage production systems. The current work and other studies show that a 1-yr rotation may be sufficient to reduce soybean yield losses caused by SCN if longer rotational intervals present an economic hardship to growers. The large yearly fluctuations in population densities of *H. glycines* in this study also warrant more research.


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