Correlations of Field Populations of Nematodes with Crop Growth Responses for Determining Relative Involvement of Species

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Abstract: Treated and nontreated field plots were assayed, and the population density of each plant-parasitic nematode present was compared with crop growth and yield and with the population densities of other nematode species in the same plots. The strongest correlations between nematode population densities and growth responses occurred when soil assays for nematodes were made 55-73 days after planting. *Belonolaimus longicaudatus* was the most damaging parasite on peanut, *Arachis hypogaea*, as evidenced by high negative correlations between population densities and plant growth responses. *Criconemoides ornatus, Meloidogyne hapla, Helicotylenchus dihystera, Trichodorus christiei, Tylenchorhynchus claytoni,* and *Pratylenchus brachyurus* were involved to varying degrees, depending on previous crop and initial densities of these nematodes. *Hoplolaimus galeatus* and *Xiphinema americanum* did not appear to affect crop response. The negative correlation of *Trichodorus christiei* to yield of soybean, *Glycine max,* was higher than that of *Belonolaimus longicaudatus,* although both contributed to yield losses. Similar correlation analyses showed that apparent antagonistic or synergistic population-density relationships among nematodes under field conditions depend on the time of sampling and the composition of the nematode community under study.

Species of plant-parasitic nematodes, their population densities, and their potential for damaging crops, vary considerably from field to field. The kinds present and population densities in soil are greatly influenced by past cropping history and various environmental factors such as soil type, moisture, and temperature. Assays of soil samples from fallow fields or from the rhizosphere of plants showing nematode damage usually reveal two-to-nine genera of plant-parasitic nematodes. Occasionally, one species may be dominant, but in most cases a mixture of several genera and species appear to be attacking the host crop and contributing to the overall disease complex. Unfortunately, there have been only limited investigations of the interactions among nematodes in such polyspecific communities, and most of these

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were done in the laboratory or greenhouse (3, 4, 5, 15). The extensive research on population dynamics of nematodes is summarized in two recent reviews (6, 14). Relations between nematode population density and plant damage also have been studied for certain nematode-host combinations (2, 7, 8, 13, 14, 16).

Our investigations were conducted to test the use of correlation studies of nematode population densities and crop responses under field conditions for delineating the importance of the prevalent nematode species relative to crop production, and to identify interactions among nematode species in polyspecific communities. This approach, if successful, could yield valuable data on the role of individual species in causing poor growth. With an appropriate design, fields of various crops on commercial farms could be used to study the relationships of naturally occurring species to crop damage. Information obtained over a period of years could provide a valuable base for predicting probable damage to crops grown in the presence of certain nematodes and/or combinations of nematode species. Also, it would provide much needed information for the development of effective nematode management practices such as rotation, use of resistant and/or tolerant cultivars, and nematicides.

MATERIALS AND METHODS

Selection of test fields: Fields infested with from five-to-nine different parasitic nematode genera were used in these studies. Population densities of certain species were high enough to cause considerable damage to planted crops if control measures were not applied. Soil type for the various tests was deep Norfolk sandy loam.

Experimental field design: Randomized complete block designs with five-to-ten replications were used. Each plot consisted of two rows 15.24 m long of varying widths (0.9 to 1.05 m), depending on the crop. Two nontreated border rows were planted between each two-row treatment plot, and one border row on either side of the test field. When replication blocks were in the lengthwise direction of the rows, blocks were separated by a 3-m alleyway; when replication blocks were across the field, each block was separated by two border rows.

Crops: Crops used in these studies were peanut (*Arachis hypogaea* L., 'NC-2' and 'Florigiant') and soybean [*Glycine max* (L.) Merr., 'Bragg']. Cultural practices, including weed, insect, and disease control were those normally employed by the grower.

Soil treatments: Several nematicides were used at varying dosage levels to provide a range of population densities between treated and nontreated plots. Applications were made just prior to, or at time of, planting and consisted of row treatments only. Fumigants were injected 15 cm deep under a flat row premarked by the grower with an empty planter. Nonfumigant granular and liquid nematicides were applied in a 35-cm wide band over the row and immediately incorporated into the soil to a depth of 6-10 cm with a rototiller. Crops were planted the day of treatment or 2-3 days later.

Assays for nematode populations: Nematode populations were determined prior to treatment, and from one-to-three times following treatment. The method of nematode extraction was that of Byrd et al. (1).

Data on crop response: A scale of 0-5, with 5 representing the maximum, was used for recording plant growth. Top growth responses for the four tests (3 with peanut and 1 with soybean) were taken as follows: peanut (1967), 127 days after planting; peanut (1968), 73 days after planting; peanut (1969), 60, 90, and 120 days after planting. Growth response data for soybean (1971) were taken 60 days after planting. Yields, as well as commerical grades for peanuts, were taken at harvest and values per hectare were determined from the unit grade price and total yields.

Statistical analyses: Correlation analyses were done for response variables and numbers of the various nematode species to determine the relative importance of various species. Competitive and complementary relationships among nematodes were also analyzed by these correlation techniques. Preliminary results, as well as results of analyses of variance of treatment effects of the nematicides, have been published (9, 10, 11, 12).

RESULTS

Results of the four separate experiments (3 with peanut and 1 with soybean) are presented by crop and year. Because the chemicals and rates varied from experiment to experiment, it was not possible to conduct a combined analysis of results for all four tests. Also nematode species and population densities in test sites varied. However, because of strong treatment effects during the season, initial counts could not be used as covariates in the analyses of variance of yield and growth variables.

Peanut after peanut–1967: The field selected had been planted to peanut for several years prior to initiation of these studies and was heavily infested with sting (*Belonolaimus longicaudatus* Rau), root-knot (*Meloidogyne hapla* Chitwood), and ring (*Criconemoides ornatus* Raski) nematodes. A light infestation of lesion [*Pratylenchus brachyurus* (Godfrey) Filipj. & Schuur.-Stekh.] and stubby root (*Trichodorus christiei* Allen) nematodes occurred, but these did not increase appreciably during the growing season.

Simple correlation coefficients showing relationships among peanut yield, growth index (127 days after planting), nematode counts, and time of sampling are presented in a matrix (Table 1). Populations of sting nematodes 55 days after planting were more highly correlated with growth index and yield than were populations after 85 or 136 days. For example, a high negative correlation (r = −.80) was found between sting nematode populations and growth index 55 days after planting, and an even higher negative correlation (r = −.82) between sting nematode populations and yield. The correlation between yield and sting nematode populations 85 days after planting was highly significant (r = −.59), but that between nematode population and growth index was not (r = −.40). The correlation between yield and sting nematode populations 136 days after planting was significant (r = −.51), but to a lesser degree. There was no significant correlation between sting nematode population and growth index 136 days after planting. A very high positive correlation was indicated between growth index and yield (r = .94). The correlation between yield and the ring nematode (*C. ornatus*) populations 136 days after planting was not significant. Correlation analyses between root-knot nematode (*M. hapla*) populations 136 days

TABLE 1. Matrix of simple correlation coefficients showing relationships among yield and growth index of peanut, and nematode counts at three times of sampling.

Variables	Peanut growth index[1]	*Belonolaimus longicaudatus* 55 days	*Belonolaimus longicaudatus* 85 days	*Belonolaimus longicaudatus* 136 days	*Meloidogyne hapla* 136 days	*Criconemoides ornatus* 136 days
Peanut yield	.94**[2]	−.82**	−.59**	−.51**	.48*	.23 NS
Peanut growth index	...	−.80**	−.40*	−.32 NS	.44*	.30 NS
B. longicaudatus:						
55 days	...	...	.54**	.33 NS	.54**	−.35 NS
85 days	...	...	...	.73**	−.52**	−.35 NS
136 days	...	...	...	...	−.42*	−.25 NS
M. hapla:					...	.74**

[1]Growth readings were made 127 days after planting.
[2]Values of r required for significance: r (P = 0.05) = .39, r (P = 0.01) = .50. (NS = not significant).

TABLE 2. Matrix of simple correlation coefficients showing relationships among peanut growth, yield and nematode counts[1] (based on 44 treatment mean pairs).

Variables	Peanut growth index	Peanut yield	*Belonolaimus longicaudatus*	*Criconemoides ornatus*	*Meloidogyne hapla*
Peanut yield	.88**[2]				
B. longicaudatus	−.74**	−.80**			
C. ornatus	−.64**	−.65**	.75**		
M. hapla	−.45**	−.53**	.44**	.70**	...
Helicotylenchus dihystera	−.40**	−.50**	.45**	NS	.34*
Trichodorus christiei	−.39**	−.39**	NS	NS	.31*
Pratylenchus brachyurus	−.33*	−.36*	NS	NS	.44**

[1]Growth index and nematode assays made 73 days after planting.
[2]Values of r required for significance: r (P = 0.05) = .29, r (P = 0.01) = .38. (NS = not significant).

after planting and peanut yield indicated that the low numbers of *M. hapla* were not contributing to crop damage.

Peanut after peanut–1968: The following year, another test was conducted in the same field. The presence of the following nematode species in the test plots of peanut made it possible to compare their relative involvement, and to study interactions within the nematode population complex: *B. longicaudatus; M. hapla; C. ornatus; T. christiei;* spiral, *Helicotylenchus dihystera* (Cobb) Sher; *P. brachyurus;* lance, *Hoplolaimus galeatus* (Cobb) Thorne; stunt, *Tylenchorhynchus claytoni* Steiner; and dagger, *Xiphinema americanum* Cobb.

A matrix of simple correlation coefficients was developed which showed highly significant relationships among peanut yield, growth index, and nematode counts made 73 days after planting (Table 2). Correlations with yield and growth variables were determined individually for each nematode species. Also correlations between various pairs of nematode species were determined. In general, yield was inversely related to nematode count, with the strength of this inverse correlation being of the order: (yield vs. sting) > (yield vs. ring) > (yield vs. root-knot). Weak to nonsignificant relationships were detected between the crop growth responses (growth index or yield) and counts of spiral, stubby-root, and lesion nematodes. Although they had significant negative correlations with growth index and yield, they did not account for much variation in yield. Lance, stunt, and dagger nematodes were not significantly related to growth or yield.

There were highly positive correlations between population densities of certain nematode species. These correlations were strongest between ring and sting (r = .75**), and between ring and root knot (r = .70**).

Peanut after corn–1969: The following year the test plots were conducted in another field on the same farm. Corn was the previous crop and nematode assays prior to planting revealed the presence of eight different species. These included: *B. longicaudatus, M. hapla, C. ornatus, T. christiei, H. dihystera, P. brachyurus, T. claytoni,* and *X. americanum.*

Plant growth and nematode populations were measured 60, 90, and 120 days after planting. Nematode populations were also determined before treatment. Correlations among crop response variables and numbers and kinds of nematodes varied. Growth, yield, and crop value were inversely related to population densities of certain nematodes 60, 90, and 120 days after planting; the strength of these correlations with stunt, sting, and spiral nematodes being much greater than the correlations with lesion, ring, and root-knot nematodes (Table 3).

Positive correlations were found between growth and yield (r = .86**, .89**, and .88**); and growth and crop value (r = .59**, .55**, and .41**) at 60, 90, and 120 days, respectively. Dagger and stubby-root populations were not significantly related to growth, yield or crop value. Positive correlations among nematode populations not shown in the table were: root-knot with dagger 60(**), 90(**), and 120(*) days after planting, with sting 60(**), with stunt 60(*), and with ring 60(*); lesion with stunt 60(**), 90(**), 120(**), with spiral 60(**), 90(**), 120(**) and with sting 60(**) and 120(**); stunt with ring 60(**), 90(**), 120(**); spiral with ring 60(**), 90(**), 120(**); ring with sting 60(**) and 120(**); stubby-root with dagger 60(*), and with sting 60(*) and 90(*) nematodes. There were no negative correlations in nematode associations in this test.

Soybean after corn–1971: Test plots for soybean following corn were infested predominantly with stubby-root and sting nematodes. Only a few root-knot, spiral, stunt, and lesion nematodes were detected in the pretreatment assays and these did not increase significantly during the growing season. Populations of the stubby-root and sting nematodes, however, increased rapidly in control plots during the 60 day period following treatment. Consequently, correlations were studied only among densities of these two species, growth index (60 days after planting), and yield (Table 4).

Positive correlations were found between growth index and yield (r = .93**). A significant negative correlation (r = −.40*) occurred between the population density of *T. christiei* and growth index, as well as yield (r = −.51**). *B. longicaudatus* also was negatively correlated with yield only (r = −.37*).

DISCUSSION

These studies show that considerable information about the individual effects of nematode species on crop performance can be determined from field experiments. This is done through detailed population studies of the species involved and correlation of this information with measured crop responses, such as growth, yield, and market quality. Soil assays for correlating kinds and densities of nematodes with crop response were more meaningful when taken 55-73 days after planting than at later times. This length of time after planting is sufficient for the populations in nontreated plots to increase substantially, while those of treated plots (because of reduced initial numbers) remain relatively low. However, if soil assays are taken later, there is a tendency for the populations in nontreated plots to level off or decline, presumably because of the lack of sufficient food. This results in smaller differences in populations between treated and nontreated plots, and nematode assays made at this time show weak or nonsignificant negative or positive correlations with plant growth. It is well known that nematode damage to susceptible annual plants results primarily from high populations at the time the plants are getting established (7, 8, 13). The damage caused by late-season buildup is small compared with damage from high initial infestations (2).

Previous cropping history greatly influences the kinds and population densities of nematodes in a given field (6). The mid-season relationships or balances among nematode kinds and numbers were influenced by host suitability to the prevailing species, chemical treatments applied, and also to some extent by the population densities present at time of planting. In fields where only one species occurred in high numbers (*B. longicaudatus*, Table 1), a very high negative correlation for density vs. growth index and yield usually was obtained; however, in situations where several nematode species occurred (Table 2), densities of all of these

TABLE 3. Matrix of simple correlation coefficients showing relationships among peanut growth, yield, value/cwt (hundred weight), and nematode counts and between nematode species (*Tylenchorhynchus claytoni; Belonolaimus longicaudatus*, and *Helicotylenchus dihystera*).

Variables[1]	Growth index	Yield	Value/cwt	*T. claytoni*	*B. longicaudatus*
Peanut yield	.86**				
	.89**	...			
	.88**				
Value/cwt	.59**	.53**			
	.55**	.53**	...		
	.41**	.53**			
T. claytoni	−.35**	−.38**	−.24**		
	−.47**	−.49**	−.33**	...	
	−.45**	−.45**	−.36**		
B. longicaudatus	−.39**	−.41**	−.24**	.58**	
	−.34**	−.40**	−.15*	.40**	...
	−.48**	−.55**	−.43**	.61**	
H. dihystera	−.30**	−.30**	−.21**	.46**	.37**
	−.42**	−.41**	−.24**	.62**	.28**
	−.28**	−.35**	−.13NS	.33**	.38**

[1]Growth responses and nematode counts were taken 60, 90, and 120 days after planting, and correlation coefficients are presented in this order. Asterisks, * and **, indicate significance at $P = 0.05$ and $P = 0.01$, respectively. Values of r required for significance: r ($P = 0.05$) = .15; r ($P = 0.01$) = .19.

TABLE 4. Matrix of simple correlation coefficients showing relationships among soybean growth, yield, and nematode counts[1].

Variables	Soybean growth index	Soybean yield	*Belonolaimus longicaudatus*
Soybean yield	.92**[2]	...	
B. longicaudatus	−.27NS	−.37*	...
Trichodorus christiei	−.40*	−.51**	.35*

[1]Growth readings and nematode assays made 60 days after planting.
[2]Values of r required for significance:r ($P = 0.05$) = .32, r ($P = 0.01$) = .42. (NS = not significant).

were negatively correlated with yield, but at a lower level. Competition between nematode species undoubtedly would alter the results that one might obtain in elucidating the role of a given species on a crop from field to field or from year to year.

Growth indices and yields were always highly positively correlated. Densities of certain nematode species 55-73 days after planting, however, were negatively correlated with both growth index and yield. These correlations strongly support the conclusion that increased growth is due to nematode control during that period, and that the effects of early season control are carried over into yield results.

Positive correlations of densities of one nematode species with another on the same host probably are primarily due to relatively low initial populations successfully reproducing compatibly on a common susceptible host. In cases where negative correlations were found, the suppression of one or more nematode species with the simultaneous increase of another was probably related to the effects of the more competitive species on the root system, rendering it less suitable for certain other species. Some of the correlations for which no feasible explanation is available could be due to chance. Greenhouse investigations on interactions have shown most nematodes to be antagonistic to other species, but this varies with host, nematode species, and sequence of inoculation (3, 4, 5). Although some variables cannot be controlled in the field, useful information can be obtained on the effects of density and time on competition among various kinds of nematodes.

The approach described herein of using altered field populations of diverse species offers considerable promise in securing immediate qualitative and quantitative data on nematode-host relationships. However, more precise experiments with single nematode species under various conditions also are needed to obtain the information ultimately needed to provide a basis for determining the most efficient management of nematode pests of plants and construction of population models (6, 8, 13, 14).

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