RELATION OF FERTILIZER TREATMENTS AND CROPPING SEQUENCE TO POPULATIONS OF TWO PLANT PARASITIC NEMATODE SPECIES [RELACION ENTRE TRATAMIENTOS DE FERTILIZANTES, LA SECUENCIA DE CULTIVOS Y LAS POBLACIONES DE DOS ESPECIES DE NEMATODOS FITOPARASITOS].

R. Rodríguez-Kábana and R. J. Collins, Department of Botany and Microbiology, Auburn University, Auburn, Alabama 36830, U.S.A.

Accepted:
II. VI. 1979
Aceptado:

ABSTRACT

Soil populations of *Helicotylenchus dihystera* (Cobb) Sher and *Trichodorus christiei* Allen in a continuing three-year rotation scheme were found to vary with season. The rotation scheme consisted of summer crops of corn, soybean, and cotton. These were followed, respectively, by winter programs of wheat, fallow, and mixed common vetch and crimson clover. The rotation was superimposed on plots that received various combinations of N,P,K, minor elements and lime. Our results show that populations of *H. dihystera* and *T. christiei* are influenced by fertilization regime of the soil. Effects on the size of the population do not appear to be related to the absence of any one nutritional element, but rather to whether an essential major element is present or absent in the fertilization scheme regardless of its identity. Nutrient deficiencies resulted in virtual elimination of *H. dihystera* from plots, and reduced the size of populations of *T. christiei.* Lack of lime resulted in significant increases in numbers of *T. christiei.*

Key Words: population dynamics, pest management, Glycine max., Gossypium hirsutum, Vicia sativa, Trifolium incarnatum.

INTRODUCTION

The nematode complex of cultivated soils as affected by cropping sequence, soil properties and climatic conditions has been studied to a considerable extent, and crop rotation schemes have been developed that reduce host damage in individual host-parasite relationships. Crop rotations usually have been designed to suppress a particular plant-parasitic nematode species, but crop cover may influence the population dynamics of other plant parasitic nematodes as well. These other species may become a limiting factor in the present or subsequent crop growth.

Nematode populations in field and greenhouse soils fluctuate considerably and different species reach peak population levels at different times of the year on different crops (1, 2, 6). These population peaks may be related to soil conditions or to certain stages of plant development. Because of their diagnostic value it is important to determine when such peaks occur.

The effect of soil fertility on nematode populations in soil has not been fully explored. It is generally believed that soil conditions which favor plant growth also favor an increase in numbers of nematodes provided the crop is a suitable host (10). Reports from greenhouse experiments indicate that the presence or absence of major nutrient elements can directly influence the ability of certain plants to support parasitic nematodes (11, 14, 15, 16, 17). Limited field observations have shown that host nutrition and the balance of the fertilizer formula may have considerable effect on the number and type of nematodes in a given soil. No systematic study of this important

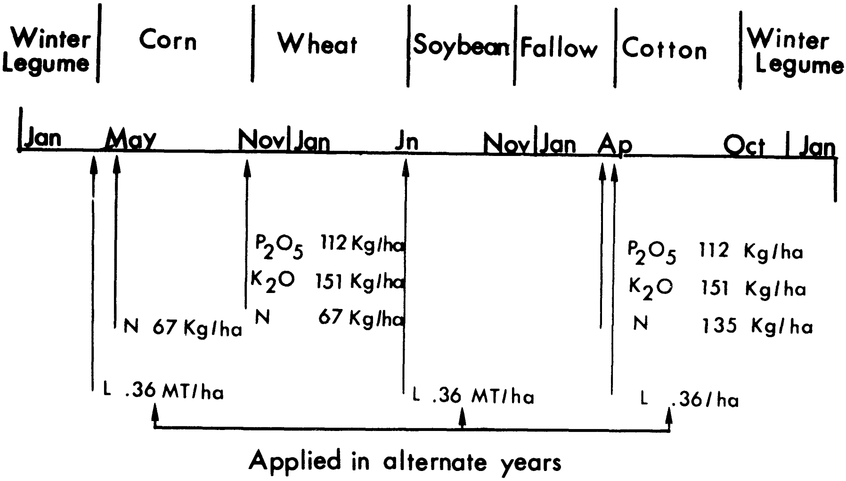

Fig. 1. Sequence of crops. quantities and times of application of fertilizers used in a two-year study of an established rotation-fertility field experiment.

aspect of nematode ecology has been undertaken.

This investigation was conducted to elucidate some of the relationships between soil fertility and cropping sequence on the population dynamics of two species of nematode, *Helicotylenchus dihystera* (Cobb) Sher and *Trichodorus christiei* Allen.

MATERIALS AND METHODS

Soil samples were collected from plots in the Cullar's rotation on the Agronomy farm of the Auburn University Experiment Station, at Auburn, Alabama. The rotation was established in 1914 and includes plots subjected to a variety of fertilization regimes, which have been maintained constant for the past 15 years. The field was essentially level with a Dothan loamy sand uniform through the plots. The field was divided into three tiers each having either corn (Fla. 200A in 1970, Funks G 4949 in 1971), soybeans (Bragg), or cotton (Auburn 56) in a three-year rotation scheme. Winter wheat (Georgia 1123) followed corn as a winter crop and a period of fallow was maintained after soybeans. A combination of common vetch and Autauga crimson clover followed cotton during the winter months and was turned under in the spring to serve as green manure. Corn and wheat were plowed under soon after harvest. Soybeans and cotton plants were chopped after harvest but were not turned under.

The tiers consisted of eleven 6-row plots (6.1x29.1 M), each with a different fertilization regime. Only 8 of these regimes in each tier were selected for study (Table 1). The sequence of crops as well as the quantities and times of application of various fertilizers used are presented in Fig. 1. The fertilization regime in the rotation in each tier was represented by four subplots (each 7 M long) from which soil samples were collected at approximately two-month intervals at critical times during the growing season beginning in March 1970.

Soil samples were collected from the root zone every 0.5 M along the two center rows of each subplot to a depth of 18 cm with a standard 2.5 cm diam soil probe. Soil was composited and the nematodes extraced with a modified Seinhorst elutriation

Table 1. Composition of the fertilization schemes in a three-year rotation with corn, soybeans, cotton and wheat.

Fertilizer Treatments[x]	Winter Legume[y]	Factor Studied
LPK	+	No commercial N
LPK	-	No N
LNPK	-	Commercial N
LNK	+	No P
LNP	+	No K
NPK	+	No lime
LNPK	+	No minor elements
LNPK & m. e.		Effect of minor elements

x L: lime applied at 0.36 MT/ha following soil test recommendations; N (kg/ha) as NH_4NO_3: 135 to cotton, 67 to corn, 67 to wheat, 135 to corn on plots with LNPK but no winter legume; P:224 kg P_2O_5/ha per three-year rotation; 302 kg K_2O/ha per three year rotation; m. e. (minor elements) kg/ha: 5.6 cupric sulfate, 11.2 manganous sulfate, 1.1 B as borax, 16.8 zinc sulfate, and 0.6 sodium molybdate. One half of the mineral fertilizer applied broadcast just prior to planting wheat and one half just prior to planting cotton.

y +: winter legume (common vetch and crimson clover) included in the three-year rotation cotton and corn; -: no winter legume.

method (18). The two center rows of each plot were harvested every season. Meteorological data were obtained from a weather station established in the same field. All data were analyzed following standard procedures for statistical analysis (19). Except where otherwise stated, indicated differences were significant to the 5% or lower level of probability.

RESULTS

Seasonal variations and crop effects. Numbers of *H. dihystera* were lowest between December and June and increased sharply as the summer crops developed (Fig. 2A-C). Highest numbers occurred in October in plots with cotton and soybean and in

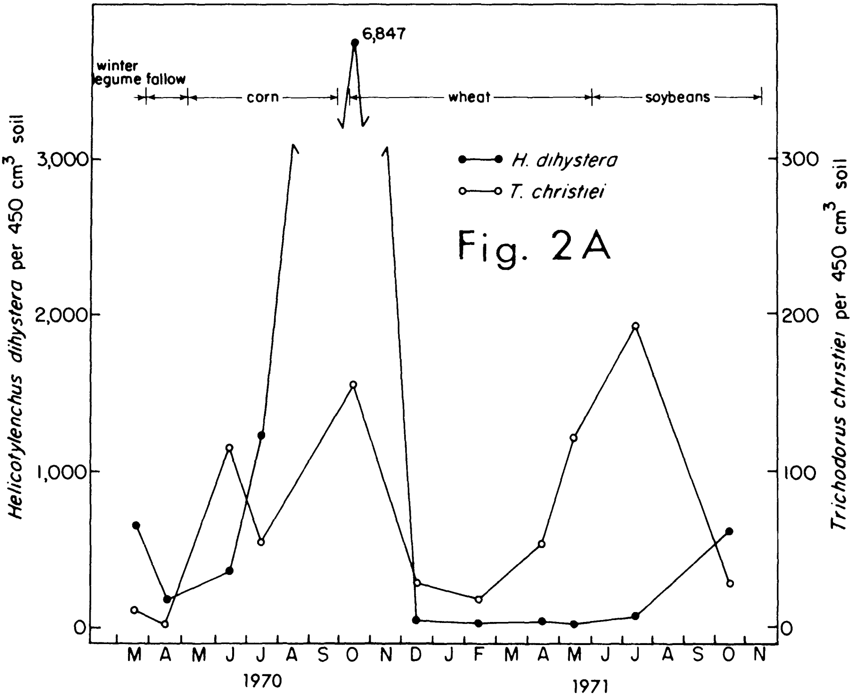
6,847
winter legume
fallow
corn
wheat
soybeans
H. dihystera
T. christiei
Helicotylenchus dihystera per 450 cm^3 soil
Trichodorus christiei per 450 cm^3 soil
0
1,000
2,000
3,000
0
100
200
300
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
1970
1971

Fig. 2A

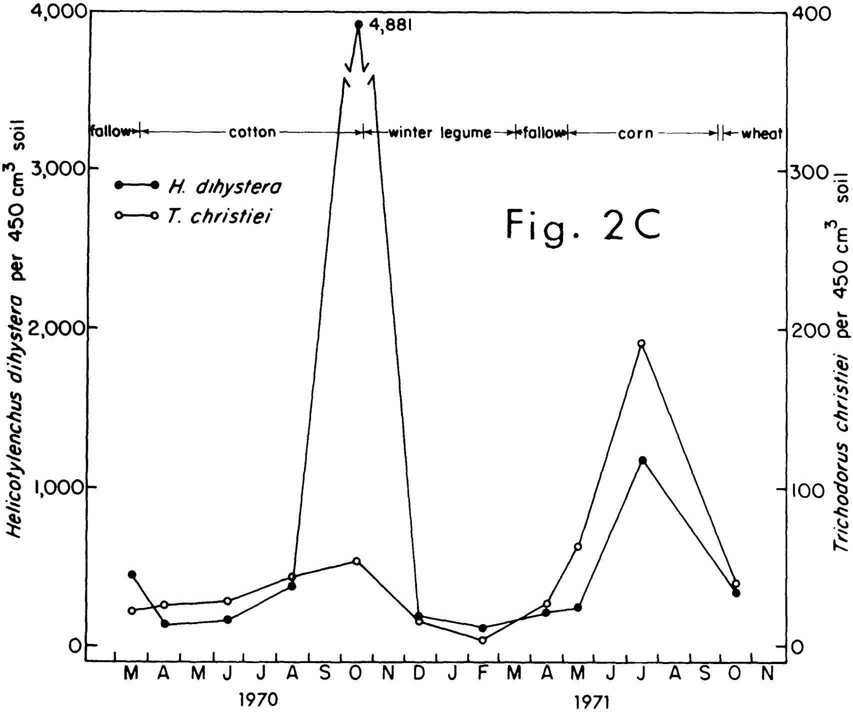
4,881
fallow
cotton
winter legume
fallow
corn
wheat
H. dihystera
T. christiei
Helicotylenchus dihystera per 450 cm^3 soil
Trichodorus christiei per 450 cm^3 soil
0
1,000
2,000
3,000
4,000
0
100
200
300
400
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
1970
1971

Fig. 2C

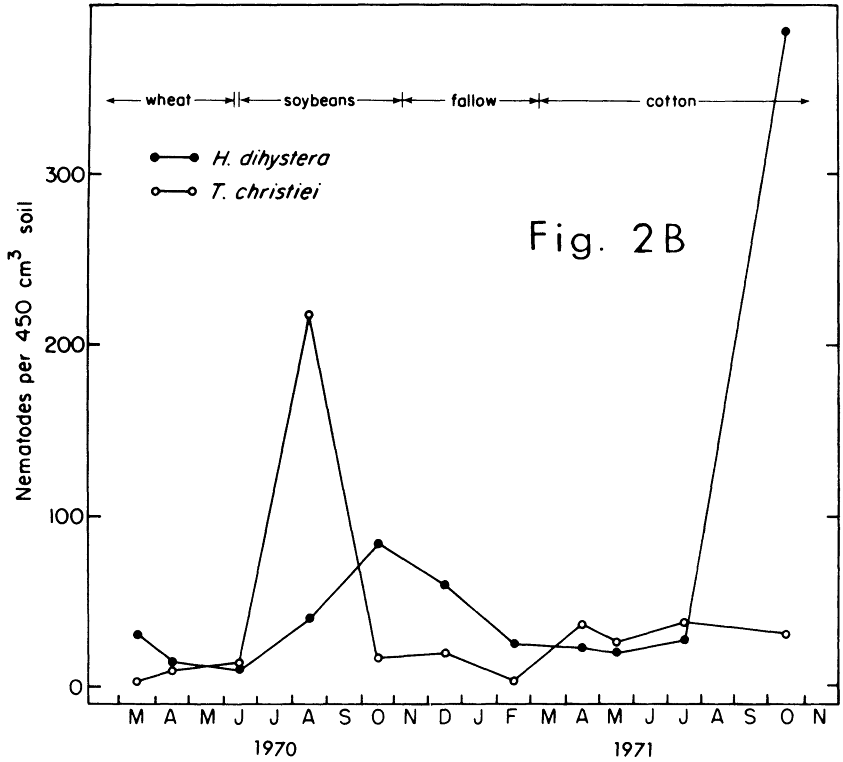

Fig. 2. Seasonal changes in numbers of *Helicotylenchus dihystera* and *T. christiei* during a two-year period in plots with corn and soybeans (A), soybeans and cotton (B) cotton and corn (C) as the major crops.

August (1971) or October (1970) in plots with corn. Corn and cotton supported the highest populations of *H. dihystera.* Winter crops did not increase populations of *H. dihystera.* The relation between changes in soil temperature (Fig. 3A) and numbers of the nematode (Fig. 2A-C) was not significant (Table 2) for any of the treatments representing complete fertilization schemes. Changes in numbers of *H. dihystera* also were unrelated to precipitation (Fig. 3B).

With one exception (Corn 1970), highest populations of *T. christiei* occurred from late June to the end of August for soybean and corn (Fig. 2); cotton supported lowest numbers of the nematode and no clear population peaks were detected in plots planted to this crop. Growth of wheat resulted in increased populations of *T. christiei*; a distinct peak was observed in May 1971, but not in the preceding year. A weak but significant correlation between numbers of this nematode species in plots receiving LNPK and a winter legume and changes in soil termperature was detected (Table 2). Changes in numbers in response to rainfall patterns were not significant.

Effect of fertilization regimes. Numbers of *H. dihystera* were invariably highest in plots receiving complete fertilization; the lack of any major element in the fertilization regime, or the lack of the winter legume resulted in either elimination of the species

Table 3. Linear correlation coefficients (r) established between populations of *Helicotylenchus dihystera* in plots with different fertilization regimes in a two-year study of a long term rotation with corn, soybean, and cotton as the major crops.

Fertilization Regime	LPK+[x]	NPK+	LNK+	LNPK+	LNPK+ & Minor elements
LPK + [x]	1.00 [y]				
NPK +	0.16	1.00			
LNK +	0.01	0.22	1.00		
LNPK +	0.38	0.25	0.01	1.00	
LNPK + & Minor elements	0.32	0.21	0.00	0.97	1.00

[x] L = Lime; + or - denote presence or absence of a winter legume, respectively, in the fertilization regime.

[y] The number of pairs to calculate each coefficient was 33; r values greater than 0.35 are significant at P = 0.05.

Table 2. Linear correlation coefficients (r) between changes in soil temperatures at 10 cm depth and changes in numbers of *Trichodorus christiei* and *Helicotylenchus dihystera* in plots receiving complete fertilization regimes.

Fertilization Regime	*T. christiei* Soil temperature		*H. dihystera* Soil temperature	
	Maximal	Minimal	Maximal	Minimal
LNPK + [x]	0.36 [y]	0.43	0.33	0.27
LNPK + & Minor elements	0.30	0.34	0.02	0.11

[x] L = Lime; + or - denote presence or absence of winter legume in the fertilization regime.

[y] Number of pairs to calculate the coefficient = 33; r values greater than 0.35 are significant at P=0.05.

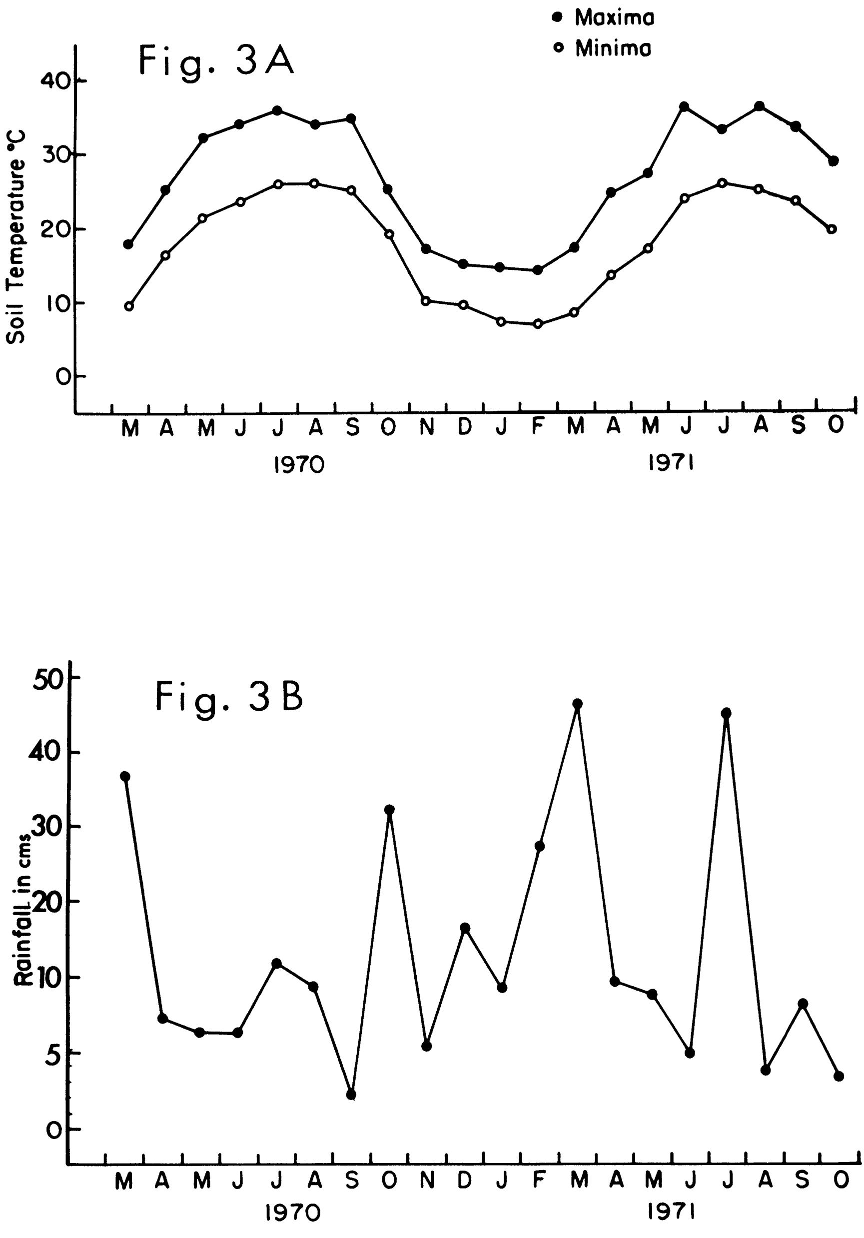

Fig. 3. Changes in soil temperature at 10 cm depth(A), and rainfall (B) in the field.

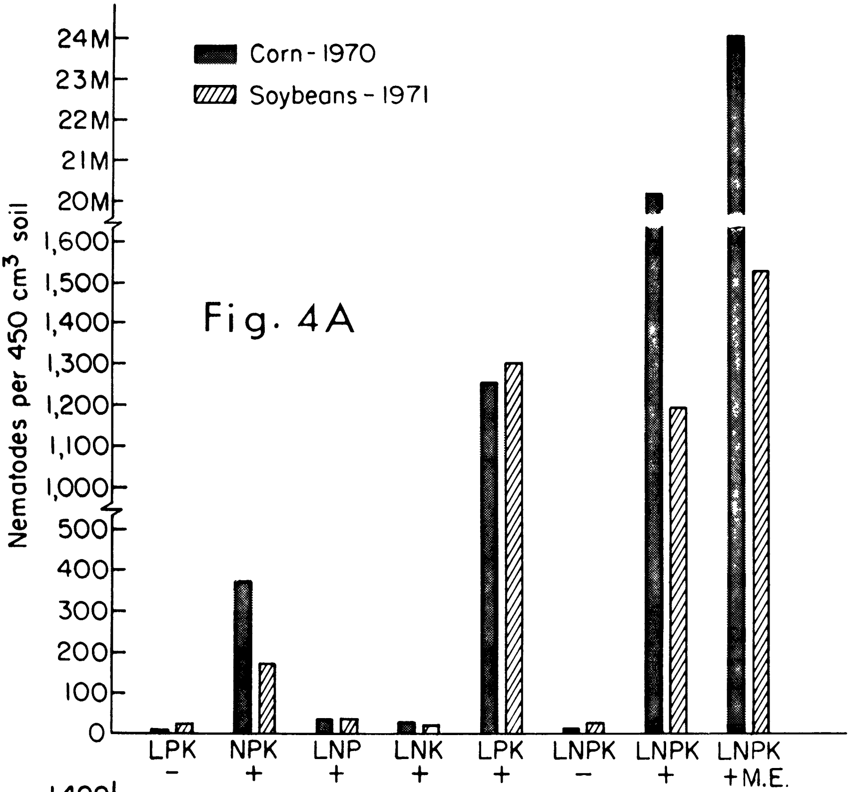
Corn - 1970
Soybeans - 1971
Nematodes per 450 cm^3 soil
24M
23M
22M
21M
20M
1,600
1,500
1,400
1,300
1,200
1,100
1,000
500
400
300
200
100
0
LPK −
NPK +
LNP +
LNK +
LPK +
LNPK −
LNPK +
LNPK +M.E.

Fig. 4A

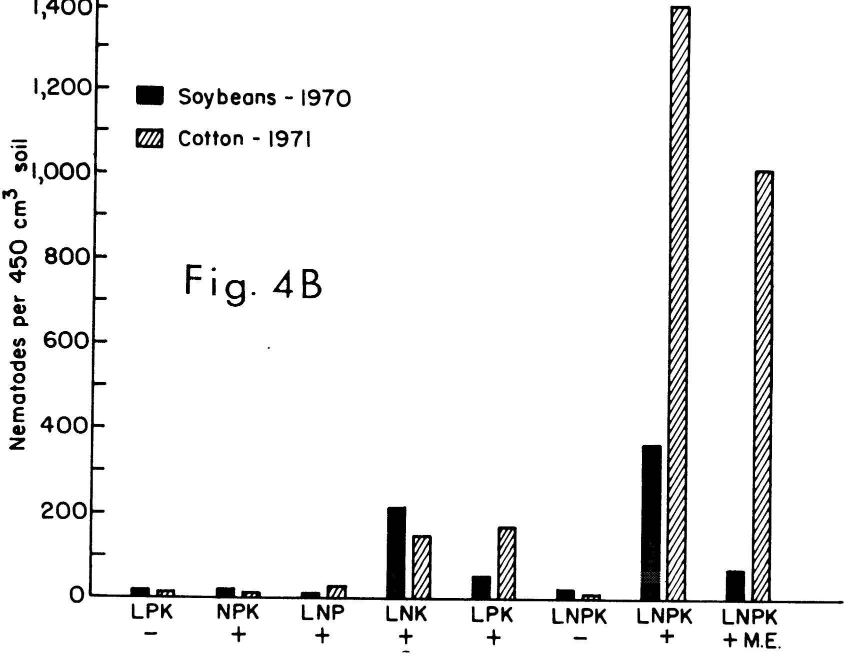
Soybeans - 1970
Cotton - 1971
Nematodes per 450 cm^3 soil
1,400
1,200
1,000
800
600
400
200
0
LPK −
NPK +
LNP +
LNK +
LPK +
LNPK −
LNPK +
LNPK + M.E.

Fig. 4B

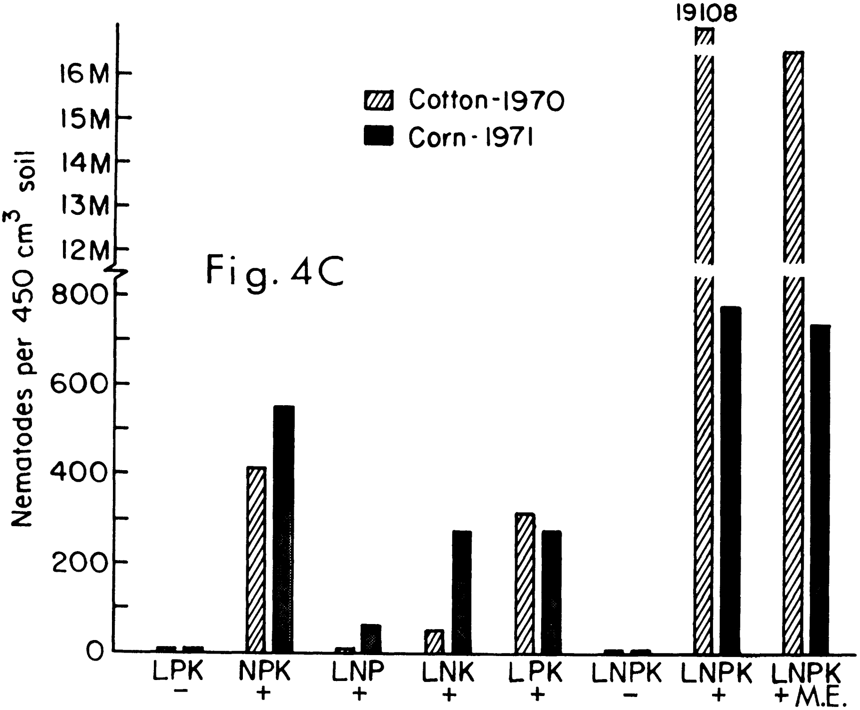

Fig. 4. Population peaks for *Helicotylenchus dihysteria* in plots with various fertilization regimes [L: lime; + : winter legume; - : no winter legume; M.E. : minor elements].

from the soil or reduction to very small numbers (Fig. 4A-C). The degree of reduction in numbers of *H. dihystera* in deficient plots was not related to the kind of element missing. Seasonal changes in populations in plots receiving all major elements and winter leagumes were highly correlated (Table 3); however, when N was supplied solely by mean of green manuring, seasonal changes in these plots were either not related or were weakly related (r=0.38) to changes in plots that received LNPK and winter legume. When winter legume was omitted and LNPK were added, *H. dihystera* was almost eliminated from the soil.

All plots, regardless of fertilization regime, sustained significant numbers of *T. christiei*. Highest peak populations occurred in plots deficient in lime (Fig. 5). Most differences in peak populations between all other treatments were not very pronounced and no pattern of response to fertilizer regime was detected. Changes in populations among treatments were significantly correlated (Table 4). Correlation coefficents obtained among treatments with complete fertilization regimes were of higher value than those between treatments in which major elements were missing. With few exceptions, slope values of the linear regression equations relating population changes among treatments were closest to 1.00 for comparisons among treatments with complete fertilization regimes (Table 5). Slopes of equations relating populations in completely fertilized plots to populations in plots deficient in any major

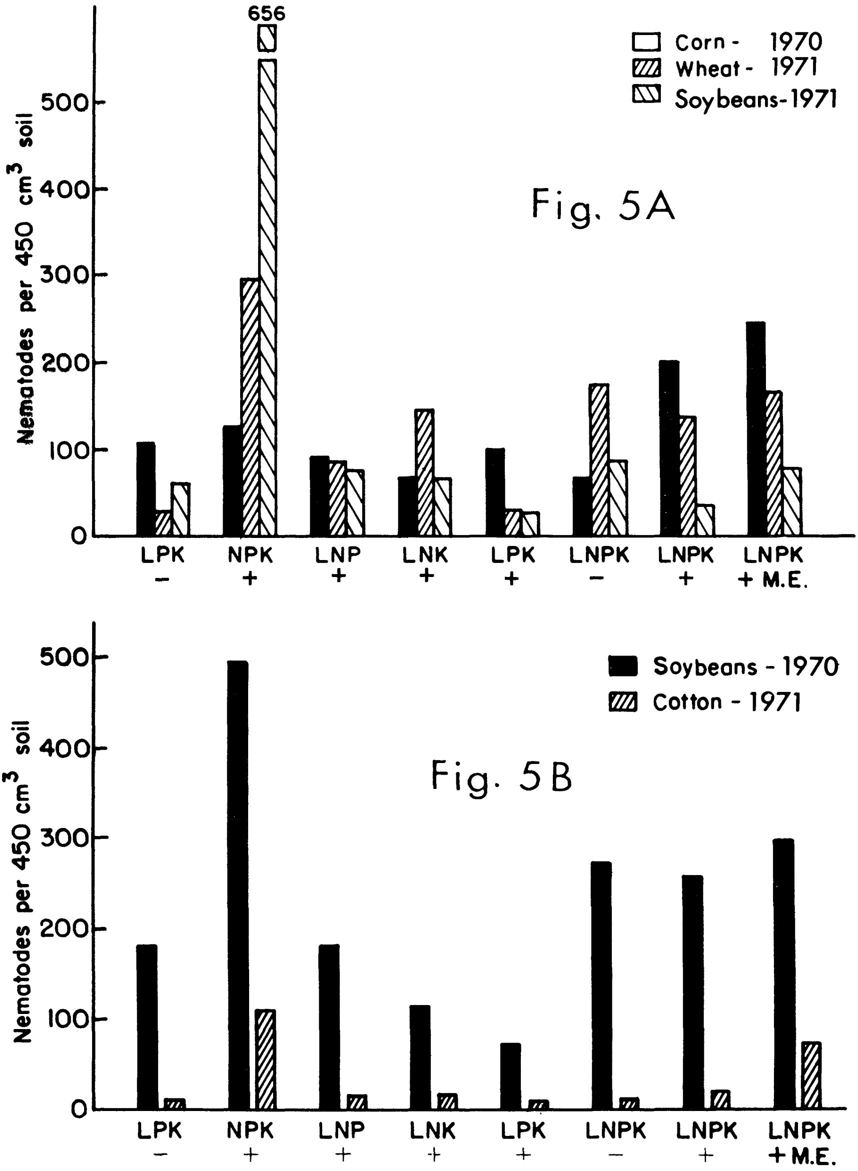

Fig. 5. Population peaks for *Trichodorus christiei* in plots with various fertilization regimes and crops [L : lime; + : winter legume, - : no winter legume; M.E. minor elements].

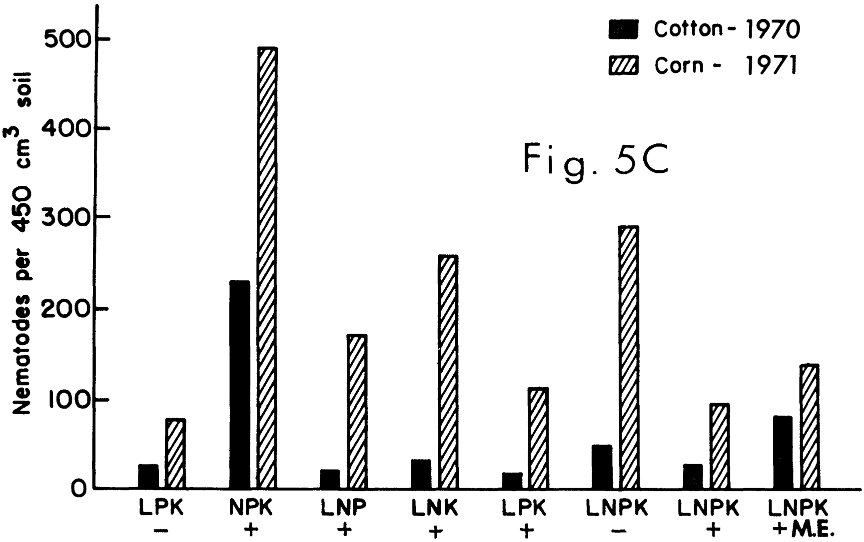

Fig. 5C

Table 4. Linear correlation coefficients (r) established between populations of Trichodorus christiei in plots with different fertilization regimes in a study of a long term rotation with corn, soybean, and cotton as the major crops.

Fertilization Regime	LPK-[x]	NPK+	LNP+	LNK+	LPK+	LNPK-	LNPK+	LNPK+ & m.e.
LPK-x	1.00							
NPK+	0.61	1.00						
LNP+	0.82	0.77	1.00					
LNK+	0.49	0.66	0.76	1.00				
LPK+	0.58	0.54	0.74	0.61	1.00			
LNPK-	0.55	0.74	0.78	0.74	0.78	1.00		
LNPK+	0.57	0.53	0.63	0.49	0.77	0.83	1.00	
LNPK+ & Minor elements	0.56	0.62	0.66	0.49	0.80	0.86	0.96	1.00

[x] L = Lime; + or - denote the presence or absence of winter legume in the fertilization regime.

[y] The number of pairs used to calculate each coefficient was 33; r values greater than 0.35 are significant at P=0.05

Table 5. Slope values of linear equations relating changes in populations of Trichodorus christiei from plots with varying fertilization regimes in a study during two seasons of a long term rotation with corn, soybeans, and cotton as the major crops.

Fertilization	Fertilization Regime (Y)[y]							
Regime (X)[y]	LPK-[x]	NPK+	LNP+	LNK+	LPK+	LNPK-	LNPK+	LNPK+ & m.e.
LPK-[x]	1.00[z]	7.01	1.42	2.74	0.45	4.00	3.31	4.18
NPK+		1.00	0.21	0.21	0.10	0.38	0.23	0.88
LNP+			1.00	0.89	0.50	1.48	1.01	3.07
LNK+				1.00	0.35	1.20	2.83	3.55
LPK+					1.00	3.64	3.16	3.81
LNPK-						1.00	1.03	1.24
LNPK+							1.00	1.30
LNPK+ & minor elements								1.00

[x] L = Lime; + or - denote the presence or absence of winter legume in the fertilization scheme, respectively.

[y] Y refers to independent variables and X to dependent variable.

[z] Number of pairs used to calculate each slope value was 33.

element (or with legume N only) had values close to 1.00 or higher, the sole exception being comparisons with lime deficient plots for which slope values were significantly below 1.00.

Relations between H. dihystera and T. christiei.

Changes in populations of *H. dihystera* and *T. christiei* were significantly correlated in plots where both species occurred in significant numbers (Table 6).

Yields

Yield data for corn and cotton (Table 7) indicate that the most fertile plots were those that received all major elements and lime, and those that received N in the form of a winter legume plus the other elements. While this also was true of soybeans, plots that received no N (mineral or from green manure) also gave high yields. Wheat yields were best in plots that received the major elements plus lime with or without green manure, and in plots that received no K.

DISCUSSION

Seasonal population changes observed for the two nematode species in this study

Table 6. Correlation coefficients (r) and slopes (m) of linear equations relating changes in populations of *Trichodorus christiei* (Y) to those observed for *Helicotylenchus dihystera* (X) in response to different fertilization regimes in a long term rotation which included corn, soybeans, and cotton as the major crops.

	Fertilization Regime				
	LNK+[x]	LPK+	NPK+	LNPK+	LNPK+ & minor elements
r	0.417	0.415	0.071	0.391	0.577
m	0.580	7.998	0.138	26.195	32.210

[x] L = Lime; + refers to the presence of winter legume in the fertilization scheme.

[y] r and m values calculated from 33 pairs; r values greater than 0.350 are significant at P=0.05; Y considered as independent variable and X as the dependent variable.

generally agree with those reported in cotton by Minton (12) for these species as well as other species in Alabama which evidenced maxima in late fall or early winter and minimal populations in late spring. Population changes were not related directly to rainfall or soil temperature. Our results also are in agreement with those of Ferris and Bernard (5) for *Helicotylenchus* sp which was found to increase in numbers during the growing season of soybeans and reached a peak near the end of the period. Increments in numbers of nematodes with development of the crop are likely related in part *(T. christiei)* to changes in soil temperature, but probably more closely related to development of the root system providing for feeding sites. The traditional recommendation to farmers in Alabama has been to sample soils for nematode analysis in late winter prior to planting. Our data indicate that sampling for these nematode species should be conducted during late summer (corn) or the fall (soybeans and cotton) to coincide with population peaks.

Data on the suitability of crops as hosts for *T. christiei* agree with what is known about this nematode (7). Corn and wheat sustained the highest numbers. Population peaks observed early during development of soybeans probably represent "carry-over" populations from wheat, particularly since numbers of this nematode in soybeans declined rapidly after mid-season. Data on the relative suitability of corn, cotton or soybeans as hosts for *H. dihystera* are lacking. Kinloch (8) found that a field population of *H. dihystera* increased exponentially on soybeans following a stationary period on winter wheat. Our data confirm these findings. Orbin (13) found that soybeans sustained populations of *H. dihystera* to levels of 700-800 per 450 cm^3 soil in a field in south Alabama. He also found that peak populations for the nematode occurred in the fall. Our results confirm these findings and indicate that corn and

Table 7. Yields of crops from a two-year study on the effects of fertilization schemes on populations of *Helicotylenchus dihystera* and *Trichodorus christiei*.

Fertilization Scheme	Yield (Kg/ha)							
	Corn[y]		Soybeans		Cotton		Wheat	
	1970	1971	1970	1971	1970	1971	1970	1971
LPK+	1573	7026	1440	2130	3210	2219	424	450
LPK-	242	928	1662	1866	2123	1735	430	241
LNPK-	1573	6953	1494	1932	2830	2423	1701	1694
LNK+	155	4222	751	642	2507	1402	605	928
LNP+	87	5164	1494	720	1317	359	1667	1432
NPK+	504	6078	588	174	2282	1061	356	363
LNPK+	1741	7685	1573	2574	3247	2079	961	1479
LNPK+ & minor elements	1862	7806	1416	2364	2833	2071	995	1560

[x] L represents Lime, and + or - refer to the presence or absence of winter legume in the three year rotation between cotton and corn.

[y] Corn yields for 1970 were depressed because of severe incidence of corn blight (*Helminthosporium maydis*).

cotton are more suitable hosts than soybeans for *H. dihystera*. It is possible that the magnitude of the peak population in soybeans may vary according to variety. Orbin (13) showed in a greenhouse study with 15 soybean cultivars that there were significant differences in suitability of the cultivars as host for *H. dihystera*.

Our results for *H. dihystera* generally support the view that high numbers of nematodes are related to soil fertility. However, this cannot always be assumed since some complete fertilization regimes (LNPK with no winter legume) resulted in virtual elimination of the nematode. Results also suggest that reduction in numbers of the nematode in response to deficiencies is not related to any particular element. This finding is at variance with some reports on the effects of plant nutrients on nematode development and size of populations. Increases or decreases in numbers of several nematode species have been linked to the presence or absence of one or more specific elements (3, 4, 9, 11). It is difficult to compare our results with previous works on nutrition which have, for the most part, been performed under laboratory or greenhouse conditions, or in the field for only short periods. Our results represent long-term effects of fertilization.

Results for *T. christiei* contrast with those for *H. dihystera* in that the population of *T. christiei* was not drastically reduced by deficiency in any element. Indeed, in plots deficient in lime (low pH) numbers of the parasite increased. Correlation coefficients relating changes in population between the various fertilization regimes were without exception highly significant, indicating that the effect of fertility was such that population changes with time in all plots were "in-phase". i.e., maxima and minima occurred at the same time regardless of fertility level. Slope values of linear equations relating changes in numbers of *T. christiei* among fertility treatments were near 1.00 for comparisons between plots that were under complete fertilization regimes (LNPK and winter legume) indicating that changes in population were "in-phase" but also were of the same magnitude. In contrast, with only one exception, slope values for equations relating plots that received LNPK and a winter legume with those that were lacking either N, K, or P, or that received N in the form of a winter legume, were greater than 1.00, indicating that the effect of the deficiences was one of restricting the size of the population. The relations suggest that the effect of low fertility on *T. christiei* is a reduction in the size of the population, but that seasonal changes in deficient plots are "in-phase" with those in high fertility plots.

The stimulatory effect of a lack of lime on populations of *T. christiei* is surprising and to our knowledge has not been reported before. It is impossible to determine with these results whether this effect is a reflection of lack of calcium on the hosts or the low soil pH in these plots (4.8-5.2).

CONCLUSIONS

Our results show that populations of *H. dihystera* and *T. christiei* are influenced by fertilization regime of the soil. Effects of nutrient deficiencies on populations of *H. dihystera* are drastic and result in virtual elimination of the species from deficient plots. Corresponding effects of deficiencies in N, P, or K on populations of *T. christiei* lead to a reduction in population size but not as drastically as for *H. dihystera.* The lack of lime resulted in significant increases in numbers of *T. christiei.* Effects of fertilization regimes on populations of *H. dihystera* and *T. christiei* were on the size of populations and not on seasonal changes; where both species occurred in significant numbers population maxima and minima occurred in deficient plots at the same time as in completely fertilized plots.

RESUMEN

En un estudio sobre una rotación trienial de cultivos las poblaciones del suelo de *Helicotylenchus dihystera* (Cobb) Sher y de *Trichodorus christiei* Allen fluctuaron de acuerdo con los cambios de estación. La rotación fue de maíz, soya, y algodón, como cultivos estivales y trigo cada tres años como cultivo de invierno. En uno de los otros dos inviernos las parcelas se sembraron con una combinación de trébol caramesí *(Trifolium incarnatum)* y de arveja *(Vicia sativa)* y en el invierno restante se dejó el campo en baldío. La rotación fue superpuesta sobre parcelas que recibieron varias combinaciones de N, P, K, elementos menores, y cal. Las densidades de población de *H. dihystera* o de *T. christiei* no resultaron relacionadas con la ausencia del esquema de fertilización de ningún elemento nutritivo en particular. El tamaño de las poblaciones dependió más bien de la presencia o de la deficiencia de cualquier elemento esencial sin importar cuál. Los efectos de la deficiencia de nutrientes sobre las poblaciones de *H. dihystera* fueron drásticos resultando en la eliminación virtuál de la especie de parcelas con fertilización deficiente. Los efectos de deficiencias en N, P, o K, correspondientes a las poblaciones de *T. christiei* fueron de reducciones en el tamaño de las poblaciones. La falta de cal resultó en un aumento significativo en el número de *T. christiei.*

Claves: dinámica de población, factores edáficos, Glycine max, Zea mays, nematodos ectoparásitos, manejo de plagas.

LITERATURE CITED

1. Barker, K. R., C. J. Nusbaum, and L. A. Nelson. 1969. J. Nematol. 1: 232-239; *2.* Barker, K. R. 1968. Nematologica 14: 2-3; *3.* Bird, A. F. 1960. Nematologica 5: 78-85; *4.* Davide, R. G., and A. C. Triantaphyllou. 1967. Nematologica 13: 111-117; *5.* Ferris, V. R., and R. L. Bernard. 1971. J. Nematol. 3: 119-122; *6.* Ferris, V. R., and R. L. Bernard. 1961. Plant Dis. Reptr. 45: 788-793; *7.* Jenkins, W. R., and D. P. Taylor. 1967. Plant Nematology. Reinhold Publishing Corp., New York, 270 pp; *8.* Kinloch, R. A., M. C. Lutrick, and W. K. Robertson. 1971. Proc. Fla. Soil. and Crop. Sci. Soc. 31: 262-263; *9.* Kirkpatrick, J. D., W. F. Mai, K. G. Parker, and E. D. Fisher. 1964. Phytopathology 54: 706-712; *10.* Krusberg, L. R. 1967. Phytopathology 57: 643-655; *11.* MacDonald, D. H. 1969. J. Nematol. 1: 296-297; *12.* Minton, E. B. 1964. Diss. Abstr. 25: 1478-1479; *13.* Orbin, D. P. 1970. Investigations on the biology and pathology of the spiral nematode, *Helicotylenchus dihystera,* on soybeans. M. S. Thesis, Auburn Univ., Auburn, 97 pp; *14.* Oteifa, B. A. 1955. Plant Dis. Reptr. 39: 902-903; *15.* Oteifa, B. A. 1952. Helm. Soc. Wash. Proc. 19: 99-104; *16.* Oteifa, B. A., and A. D. Khalil. 1961. Plant Dis. Reptr. 45: 932; *17.* Oteifa, B. A. 1951. J. Wash. Acad. Sci. 41: 393-395; *18.* Seinhorst, J. W. 1962. Nematologica 8: 117-128; *19.* Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York, 481 pp.