Resource and Crop Management Research Monograph No. **17**

Nematodes as Production Constraints in Intensifying Cereal-based Cropping Systems of the Northern Guinea Savanna

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Preface

The Resource and Crop Management Research Monograph series is designed for the wide dissemination of results of research about the resource and crop management problems of smallholder farmers in sub-Saharan Africa, including socioeconomic and policy-related issues. The range of subject matter is intended to contribute to existing knowledge on improved agricultural principles and policies and the effect they have on the sustainability of small-scale food production systems. These monographs summarize results of studies by IITA researchers and their collaborators; they are generally more substantial in content than journal articles.

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Introduction

Intensifying cereal-based cropping systems

Land use is being intensified across the savannas of West and Central Africa as the need increases for food to feed the teeming population. Agroecological and socioeconomic conditions determine different pathways of intensification (Smith and Weber 1994). Traditional systems based on sorghum and millet with intermittent fallow periods are changing rapidly to more intensive land-use systems with reduced fallow periods. In many areas where inputs are hardly available and soil fertility is low, sorghum and millet continue to dominate the system. In other areas, availability of fertilizers, market access, and improved maize varieties may initiate a change of the production system to a maize-based system.

The northern Guinea savanna (NGS) of Nigeria has undergone dramatic changes of this type during the last two decades, especially in Kaduna and Katsina states. The zone is characterized by a growing period varying between 150 and 180 days per year. Cereals, such as maize, sorghum, and millet, constitute the major food crops with continuous cropping and the use of fertilizer.

The development of maize-based systems has benefitted the farmer and increased agricultural output substantially (Smith et al. 1994). However, large differences exist among villages and individual farms. Whereas some farmers adopted maize cropping more than 15 years ago, others started only recently to grow the crop. Thus, the zone is highly heterogeneous with respect to cropping history.

Nematodes as production constraints

Frequent cropping of the same or related species, for example, maize and sorghum, favors a buildup of pests associated with those crops and can threaten the sustainability of intensified cereal-based systems in the NGS. Soilborne pests such as nematodes, root and stem pathogens such as *Fusarium moniliforme*, and parasitic weeds such as *Striga hermonthica* can parasitize maize and sorghum. They have been found in the NGS, although their importance as yield-reducing constraints has only been well-established for *S. hermonthica* (Lagoke et al. 1991; Oikeh et al. 1991). Plant-parasitic nematodes have been reported to constitute serious impediments to intensified cereal production in various parts of the world (Lindsey and Cairns 1971; Martin et al. 1975; Reuhle 1973; Tarte 1971; Taylor 1967). Caveness (1992) contributed considerably to the identification of nematode species under different cropping systems in West Africa and reported *Pratylenchus* spp., *Helicotylenchus* spp., *Rotylenchus reniformis*, and *Tylenchorhynchus* spp. as pests of maize. Yield losses due to these nematodes have rarely been evaluated, but Egunjobi (1974) found a yield reduction of 28 to 33% from *P. brachyurus* on maize in western Nigeria.

Most of the earlier nematological research in the African savannas was restricted to the preparation of mainly faunistic lists from surveys or trials under controlled conditions. Information is scanty from on-farm situations. This study pioneers the characterization and assessment of nematode problems on farmers' fields. It was initiated as a collaborative research project between the Farming Systems Research Program of the Institute for Agricultural Research (IAR), Samaru and the Resource and Crop Management Division of IITA.

Objectives

The study was undertaken with the following objectives.

1. Identify and classify plant-parasitic nematodes associated with cereal-based systems.
2. Identify the determinants of the build up of nematode populations.
3. Identify farming systems with a high risk of cereal damage caused by nematodes.
4. Diagnose opportunities for nematode suppression in farming systems.
5. Assess farmers' perceptions of nematode problems and the implications of those perceptions for on-farm research.

II

Research Approach

Field monitoring

The study was conducted in five villages: Gwanki, Kaya, and Tsibiri in Kaduna state and Barde and Boring Dawa in Katsina state. The selection of the villages was based on an earlier study by Smith et al. (1994) who identified representative locations for the different farming systems in the area. The study area is located between 10° and 11° 30' latitude and 7° and 9° longitude at an altitude of 650 to 750 m above sea level, and has an annual precipitation of 900 to 1200 mm. Upland fields are under continuous cultivation. Animal traction is common in parts of the study area and fertilizers are used intensively on maize, sorghum, cotton, and vegetables. Cereals such as maize, sorghum, and millet dominate the cropping system in all villages; but cotton, groundnut, cowpea, or vegetables are grown in some areas depending especially on market access. Intercropping of maize and sorghum, millet and sorghum, or maize and cotton is a common practice in the area. Cowpea is often relay-cropped into maize and sorghum (table 1).

The soils in the upland fields are mostly alfisols with a sandy loam or loamy sand texture. Organic carbon, total nitrogen, and pH values tend to be low, but vary widely (table 2).

In 1990, between 10 and 15 fields per village were intensively monitored during the whole cropping season from planting to harvest. For methodology, see Weber et al. 1993. Fields were categorized into two groups according to farmers' perceptions: those with unchanged/increasing yields and those with decreasing yields, over recent years. About two thirds of the fields in each village were chosen from the second category of decreasing yields. Cropping patterns, crop phenology, pests and diseases, and crop management practices were evaluated every 3 to 4 weeks in 10 fixed evaluation points of 2 rows of 5 m length in all fields without interfering with the farmers' usual practices. The cropping history of the fields was obtained from the farmers through informal interviews.

The study was broadened in 1991 by the selection of 31 to 40 additional fields at random in each village. Nematode damage was evaluated on maize plants 4 to 6 weeks after planting in order to analyze the incidence of nematode damage in the study area. A quantification of nematode severity within fields requires a more elaborate study, especially with sampling methods which take into account the aggregated distribution of symptoms within fields.

Diagnostic trials

Out of the 56 fields monitored in 1990, 5 fields were selected in 1991 for the establishment of diagnostic trials. The objectives of these trials were to as follows.

1. Confirm nematodes as yield-reducing pests in farmers' fields, and
2. Analyze opportunities for nematode control.

Table 1. Major cropping systems and market access in the study villages of the northern Guinea savanna, 1990

Village	Major cropping system	Access to market[a]
Kaduna state:		
Barde	sorghum/maize sorghum/cowpea maize/cowpea sorghum/cotton	moderate
Borin Dawa	sorghum monocrop sorghum/cotton sorghum/maize sorghum/cowpea maize/cowpea	good
Katsina state:		
Gwanki	maize monocrop maize/vegetables maize/sorghum sorghum/groundnut maize/cowpea	good
Kaya	maize monocrop maize/sorghum soybean yam	good
Tsibiri	sorghum/millet sorghum/maize sorghum/maize/cowpea sorghum/groundnut maize/cotton maize/vegetables	moderate

Note
a Villages not more than 2 km from an all-weather road have good market access; those at 2 to 5 km distance have moderate access.

Table 2. Soil physical and chemical properties of 65 farmers' fields in the five study villages in the northern Guinea savanna

Variable	Min	Max	Mean	SD
Sand (%)	40.0	71.0	55.6	7.7
Silt (%)	18.0	42.0	30.7	6.5
Clay (%)	8.0	24	13.7	3.2
Phosphorus (ppm)	2.5	50.3	13.6	10.5
Potassium (meq/100g)	0.03	1.1	0.3	0.2
Organic carbon (%)	0.3	2.1	0.6	0.3
Total nitrogen (%)	0.03	0.1	0.06	0.02
pH (1:1 in water)	4.5	7.1	5.7	0.56
Soil depth (cm total)	24.4	80.8	57.3	12.7
Soil depth first layer (cm)	9.6	40.8	18.4	4.3

Notes
Min, Max, Mean, SD = minimum, maximum, mean and standard deviation of mean for all variables, respectively

Each field measured 20 m in length and had 32 ridged rows of about 75 cm width. This area was divided into 4 plots as follows:

Plot 1: Maize (m)/sorghum (s) intercropping at a row arrangement of 4m + 2s + 4m + 2s + 4m = 16 rows with a row spacing of 75 to 90 cm; maize variety TZB-SR was planted at a within-row spacing of 50 cm with 2 to 3 seeds/hill, farmers' sorghum variety "Farafara" was planted at a spacing of 60 to 70 cm with 10 to 15 seeds/hill. These stand densities and crop arrangements are commonly used by farmers in the area.

Plot 2: Carbofuran was incorporated at a rate of 2.5 kg a.i./ha into the planting row (band placement); maize (m)/sorghum (s) intercropping was done as in plot 1.

Plot 3: Soybean variety TGx923-2E was planted at a hill spacing of 15 to 20 cm with 3 to 4 seeds per hill, as farmers prefer this method to row drilling.

Plot 4: The plot was subdivided into 2 subplots of 8 rows each:

(a) the fodder crop *Aeschynomene histrix* was broadcast on the prepared land at a rate of 10 to 15 kg/ha without incorporation; seeds were supplied by the International Livestock Centre for Africa (ILCA), Kaduna; seeds were scarified before planting through hot water treatment for 3 minutes;

(b) farmers' cowpea variety "Ex-Bomo" was planted at the end of June at a hill spacing of 50 cm with 2 to 3 seeds per hill.

Plots 1 and 2 received fertilizer at a rate of 200 kg/ha NPK (15-15-15) at 2 weeks after planting (WAP) and calcium-ammonium nitrate (CAN 26% N) at a rate of 200 kg/ha at 5 WAP. These rates, resulting in a total of 82 kg N/ha, are below the actual amount of 80 to 120 kg N/ha being used by most farmers and below the officially recommended rate of

120 kg N/ha. Timing and method of application (hill placement) followed farmers' common practice. As the legumes in plots 3 and 4 showed P-deficiency symptoms, Single Super Phosphate® was applied at a rate of 100 kg/ha at 2 WAP as a band on plot 3 and broadcast on plot 4.

The farmers executed all field management practices in the first 3 plots except planting and fertilization. Plot 4 was managed by the field technician, as *A. histrix* was a new crop to the farmer. All 4 plots were planted in 1992 to maize/sorghum intercrop, as in plot 1 in 1991.

Yield-loss assessment

Symptoms of nematode damage on maize were described by developing a scoring system on a 1-to-9 scale. About 80 individual plants, 20 each at score 1, 3, 5, and 7 to 9 were labeled at 5 WAP in 3 different fields according to the scoring system. Yields of individual plants were recorded at harvesttime. The data were used for the development of a yield-loss assessment method for on-farm research.

Nematode analysis

At about 6 WAP, 10 soil core samples, each of 5 cm diameter, were taken at 10 cm from the base of the plant and to a depth of 15 cm and bulked to one sample per field. Nematodes were extracted from 1.0 liter of soil using Cobb's sieving and decanting method combined with Baermann trays (Cobb 1918). Nematodes were counted after 24 hours of extraction by pipetting out 10 ml of the nematode extract into a Doncaster counting dish. Nematodes were identified to the genus level only.

Incorporation of farmers' views

Farmers' views on the nematode problems were collected in 3 different ways.

1. Informal discussions with the farmers,
2. Formal, but open-ended questionnaires, especially on the farmers' opinion about certain control technologies, and
3. Village group discussions before the start of the new season in which the past work was reviewed and future work was planned.

Data analysis

A list of variables used during the analysis is presented in table 3. Nematode populations were classified using cluster and contribution analysis based on a genotype x environment program developed by the University of Queensland, Australia (Byth and Mungomery 1981). Principal component analysis, general linear model programs, and regression analysis were run, using standard SAS programs (SAS 1985).

Table 3. Definition of variables used for the analysis

Variable	Definition
% sand	% sand in soil at 0 to 15 cm depth
% silt	% silt in soil at 0 to 15 cm depth
% clay	% clay in soil at 0 to 15 cm depth
Phosphorus	ppm P in soil analyzed as P-Bray-1
Potassium	meq K per 100 g of soil
% OC	% organic carbon content at 0 to 15 cm depth
% TN	% total nitrogen content at 0 to 15 cm depth
pH	soil pH in water
CEC	cation exchange capacity in meq/100 g of soil
Total soil depth	cm soil depth as measured by penetrometer
First layer depth	cm depth of first, cultivated soil layer as measured by penetrometer to first dense layer
Nematode density	number of nematodes per liter of soil taken with soil augers of 5 cm diameter at 0 to 15 cm depth and 10 cm from the base of plant
Across-field incidence	% of fields with nematode damage symptoms
Within-field incidence	% of plants with nematode damage symptoms
Within-field severity	% yield loss due to nematode damage estimated from within-field incidence and severity of symptoms
Time since first maize cropping	number of years since maize had first been planted in the field as a major crop
Frequency of maize cropping (M9088)	frequency of maize planting in the field during the previous 3 years from 1988 to 1990 expressed as a proportion of 1 (all 3 years)
Frequency of sorghum cropping (S9088)	frequency of sorghum planting in the field during the previous 3 years from 1988 to 1990 expressed as a proportion of 1
Frequency of non-cereal cropping (N9088)	frequency of non cereal planting in the field during the previous 3 years from 1988 to 1990 expressed as a proportion of 1
Incidence of *Andropogon*	proportion of 10 samples of 2 m interrow length in a field with presence of the weed
Incidence of *Porphyrostemma*	proportion of 10 samples of 2 m interrow length in a field with presence of the weed
Cobs/plant	number of cobs per maize plant
Panicles/plant	number of sorghum panicles per plant
Shelling %	% grain yield from total cob or panicle weight
Grain yield	grain yield in g/plant or kg/ha at 13% grain moisture
Stover yield	field dry stover weight in kg/ha

III

Results and Discussion

Incidence of nematode genera

Plant-parasitic nematodes from 18 genera were identified (table 4). Species belonging to 5 genera, *Pratylenchus*, *Aphelenchoides*, *Helicotylenchus*, *Tylenchus*, and *Ditylenchus* occurred in more than 50% of the fields. *Pratylenchus* and *Helicotylenchus* had the highest incidence with more than 90% of the fields infested. These findings support reports of Claflin (1984), Sharma (1988), Swarup and Sosa-Moss (1990), and Tiyagi et al. (1987) who reported close associations of these nematodes with maize, sorghum, and millet. *Aphelenchoides arachidis*, the groundnut testa nematode, has been reported to occur widely on cereal crops in northern Nigeria (Bos 1977), indicating that this genus may be economically important.

Although the average densities of nematode populations across fields were generally low, standard deviations were large for most genera, indicating large differences among fields. The maximum densities of *Pratylenchus* and *Aphelenchoides* were above 5000 individuals/litre of soil. Densities for *Helicotylenchus*, *Aphelenchus*, and *Ditylenchus* were above 1000 individuals/litre of soil.

The genus *Pratylenchus* is an important migratory endoparasite on cereals throughout the tropics. *Pratylenchus brachyurus*, *P. zeae*, and *P. sefaensis* have been reported from West African forest and savanna ecologies (Adesiyan et al. 1990; Caveness 1992). The most common species of *Helicotylenchus* are *H. erythrinae*, *H. nannus* (Adesiyan et al. 1990; Caveness 1992), *H. microcephalus*, *H. multicinctus*, and *H. pseudorobustus* (Caveness 1992). They are mostly ectoparasitic on plant roots and their pest status is not clear for West Africa. However, Norton et al. (1978) report a negative correlation between the density of *H. pseudorobustus* and maize yield in the United States and Bee-Rodriguez and Ayala (1977b) isolated high populations of *Helicotylenchus* from sorghum roots in Puerto Rico. The genus *Aphelenchoides* is very common in savanna soils but has not been reported in the forest zone. Its pest status in West Africa has been confirmed on groundnuts (Bos 1977), but its effect on other crops has not been studied. Bee-Rodriguez and Ayala (1977b) found moderate population densities of this nematode on sorghum roots in Puerto Rico. Little is known about the distribution and pest status of members of the genera *Ditylenchus*, *Aphelenchus*, and *Tylenchus* in tropical Africa.

Classification of nematode populations

An analysis of variance of nematodes from 18 genera across the 56 farmers' fields shows that field x nematode interactions (F x N) contribute most to the total variance (table 5). Thus, nematode genera differ in their incidence across fields. Similar observations were reported by Schmitt and Norton (1972) in the United States.

Table 4. Average density and variation of plant-parasitic nematodes from 18 genera in 56 farmers' fields in the study area in the northern Guinea savanna, 1990

Nematode genera		No.	Min[a]	Max	Mean	SD	Freq (%)
Aphelenchoides	Ap	56	0	5299.8	411.41	897.9	83.9
Pratylenchus	Pr	56	0	5299.8	383.2	929.2	94.6
Helicotylenchus	He	56	0	1900.1	199.1	299.1	92.9
Aphelenchus	Al	56	0	1600.0	56.4	217.0	46.4
Tylenchus	Ty	56	0	300.0	56.1	72.3	83.9
Ditylenchus	Di	56	0	1300.3	73.9	176.9	75.0
Tylenchorynchus	Tc	56	0	330.0	22.0	54.0	33.9
Scutellonema	Sc	56	0	650.0	30.3	93.1	48.2
Longidorus	Lo	56	0	300.0	23.0	48.0	33.9
Paralongidorus	Pl	56	0	50.0	1.1	6.8	3.6
Hoplolaimus	Ho	56	0	200.0	23.0	44.0	46.4
Paratylenchus	Pt	56	0	850.0	26.0	115.0	26.8
Paratrichodorus	Pa	56	0	190.0	6.3	28.0	7.1
Hemicriconemoides	Hc	56	0	100.0	6.1	20.4	12.5
Xiphinema	Zi	56	0	100.0	6.1	17.0	16.1
Criconemoides	Cr	56	0	100.0	2.7	13.7	7.1
Trichodorus	Tr	56	0	20.0	0.4	2.7	1.7
Hirschmanniella	Hm	56	0	130.0	4.3	20.2	3.6

Notes
No. = number of fields
Min, Max, Mean = minimum, maximum and mean density of nematodes as number of individuals per liter of soil, respectively
SD = standard deviation of mean;
Freq (%) = percent fields infested with genera (min zero)
a = below detection level

Table 5. Analysis of variance of densities of 18 nematode genera in 56 farmers' fields in the northern Guinea savanna

Source	DF	SS	% of total SS
Fields (F)	55	5255.94	9.1
Nematode genera (N)	17	19741.90	34.1
F x N	935	32925.93	56.8

Notes
DF = degrees of freedom SS = sum of squares

Nematode genera were classified using cluster analysis based on Euclidian distance (DeLacy 1981) in order to elucidate the pattern of association between nematode genera (figure 1). Three distinct groups were formed:

1. Nematodes which occur frequently in high populations and are widely distributed (group 34 containing *Aphelenchoides*, *Pratylenchus*, and *Helicotylenchus*).
2. Nematodes which often have a low incidence and occur mostly in low densities (group 29 containing 12 genera). Members of this group could be further subdivided into two groups (27 and 28). While members of group 28 occur infrequently, except for *Tylenchorynchus*, members of group 27 tend to have a higher incidence and density.
3. Nematodes which are widely distributed but occur generally at low population densities (group 31). Only *Aphelenchus* and *Ditylenchus* occurred in very high populations and in only one field each.

Based on this classification, six genera (*Aphelenchoides*, *Pratylenchus*, *Helicotylenchus*, *Aphelenchus*, *Tylenchus*, and *Ditylenchus*) were unique in their distribution and population densities across fields. Consequently, only these genera were considered for further analysis.

Associations of nematode populations and patterns of nematode distribution were further analyzed through field clustering based on the six genera. Five field groups were formed (figure 2). The reduction of the original matrix of 18 genera x 56 fields resulted in 6 genera x 5 field groups, which retained 96% of the sum of squares (SS) among nematodes, 66% of the SS among fields and 54% of the SS for N x F interaction (table 6). The genus *Aphelenchoides* contributes most to the field classification, followed by *Pratylenchus* and *Helicotylenchus*, a fact which again indicates the discretely different performance of these three genera across fields (table 7).

Table 6. Partition of variation after reduction of the original matrix of 18 nematode genera x 56 fields to 7 nematode groups and 5 field groups

No. of nematode groups	No. of field groups	Matrix reduction %	% SS retained among groups			
			Total SS	Nematode SS	Field SS	F x N SS
18	56	0	100	100	100	100
18	5	91.1	72.6	100	66.1	57.2
7	5	96.5	69.7	96.3	66.1	54.3

Determinants of nematode population densities

Linear discriminant functions were developed in a stepwise manner in order to identify factors which best differentiated the field groups (FG) formed through clustering. Soil texture, soil depth, cropping history, and weed incidence were identified as factors significantly contributing to the discrimination of field groups (table 8). The patterns of nematode densities for field groups are shown in figure 3.

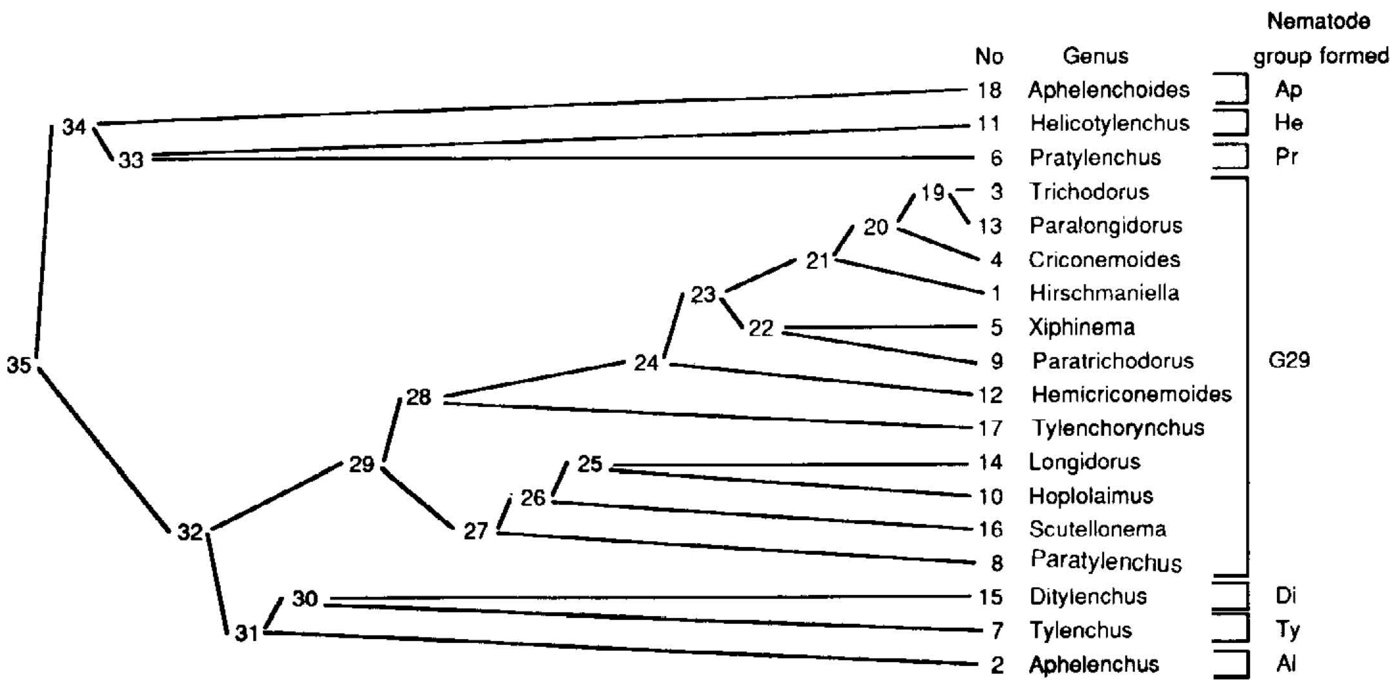

Figure 1. Dendrogram of nematode classification based on mean densities from 56 farmers' fields in the northern Guinea savanna of Nigeria in 1990; 7 nematode groups were formed, 6 of which contain only one genus while one group, G29, contains the other 12 genera

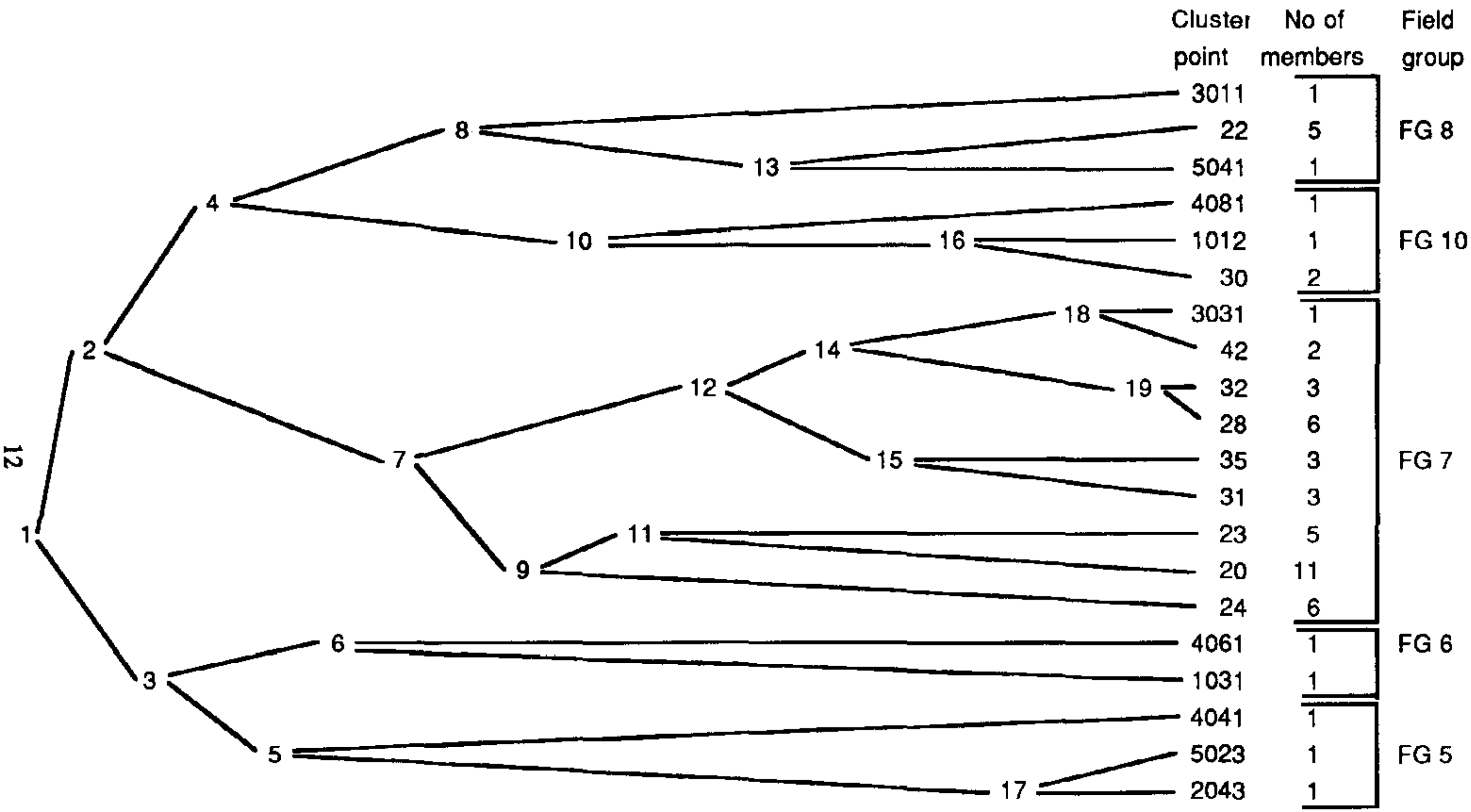

Figure 2. Dendrogram of field classification based on nematode groups shown in figure 1; 5 field groups (FG) were formed containing fields with a similar composition of nematode populations

Table 7. Contribution of main effects and interaction effects to the clustering of fields into 5 field groups and the relative contribution of the different nematode genera to the clustering based on interaction effects

Effect	Contribution to field classification (%)
Main effects	32.06
Interaction effects	67.94
Contributing genus:	Relative contribution to interaction effects
Aphelenchoides	100%
Pratylenchus	45.8
Helicotylenchus	24.3
Aphelenchus	14.7
Tylenchus	14.4
Ditylenchus	8.5

Note
Relative contribution is expressed as a percentage of the highest contribution by a genus *(Aphelenchoides)*

The model classified 76% of the fields into their original field groups formed through clustering, while 24% were wrongly classified. A clear distinction of field groups cannot be expected, as the underlying factors, such as soil texture, have a continuous rather than a discrete distribution. Additional factors not quantified in the present study, as for example, biological antagonists of nematodes in the soil, may also contribute to the development of nematode populations. In particular, FG7 is not well differentiated from FG8 and FG10 (table 9). Results from the clustering and discriminant analysis (tables 8, 10) allow a preliminary summary of the association between nematode populations and the accompanying field conditions (table 11).

The classification of nematode populations into genera associations and field groups revealed some common factors, which determine the density of species, but the effects seem to be rather species-specific. Therefore, four genera with the highest incidence and the largest variation in population density were analyzed individually: *Aphelenchoides, Pratylenchus, Helicotylenchus,* and *Ditylenchus*. Single-factor correlations indicate that nematode densities are influenced by soil texture, soil depth, organic carbon/total nitrogen ratio, and the history of maize cropping (table 12). The time since maize production technologies have been introduced to the field correlates significantly with the density of *Aphelenchoides, Pratylenchus,* and *Ditylenchus,* indicating an increasing risk from these species as maize production technologies become established and intensified in an area. A quick buildup of *Pratylenchus brachyurus* after only three consecutive cycles of maize sole cropping and under maize/bean intercropping has been reported from southwestern Nigeria by Egunjobi (1974) and from Egypt by Abd-Elgawad and Saad (1989).

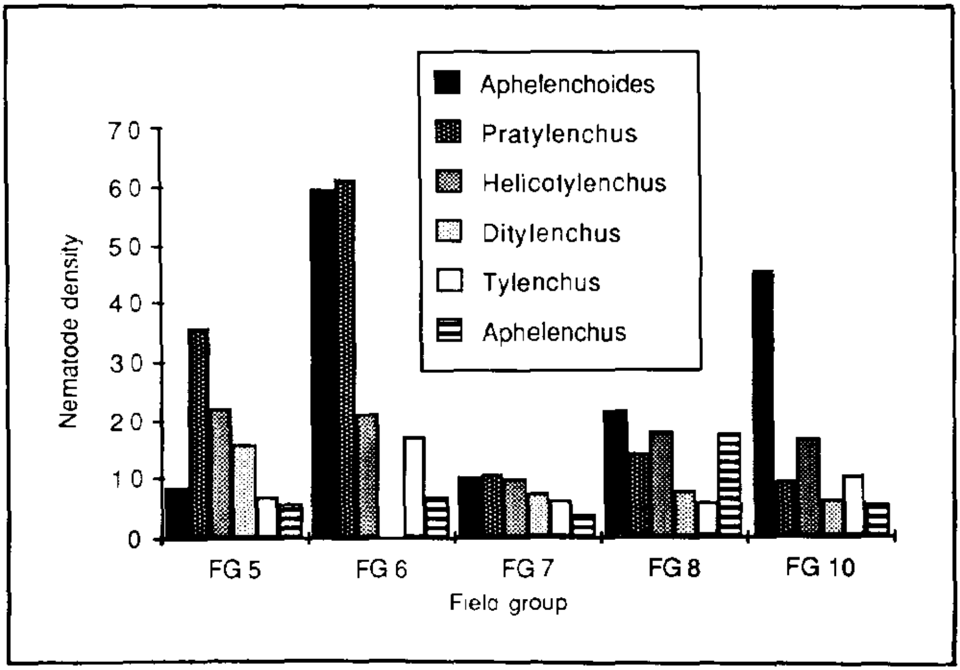

Figure 3. Mean nematode densities (square root per liter of soil) in field groups

Table 8. Fisher's linear discriminant functions, developed through stepwise discriminant analysis, differentiating field groups

Variable	Field groups				
	FG5	FG6	FG7	FG8	FG10
Constant	-32.02	-26.09	-27.97	-34.60	-40.58
Silt in soil (%)	0.406	0.594	0.651	0.717	0.683
Depth (cm)	0.599	0.497	0.498	0.562	0.573
Time since first maize cropping (years)	0.779	0.679	0.467	0.509	1.123
Frequency of sorghum cropping	0.382	1.278	5.813	6.299	1.596
Incidence of *Andropogon* sp.	-12.988	-21.600	-18.687	-19.615	-36.045
Incidence of *Porphyrostemma* sp.	15.611	5.536	2.875	1.290	14.509

Table 9. Classification of fields from original field groups (FG) formed through clustering into new field groups (NFG) according to the discriminant model

Original field group	New field group (% of fields)					
	NFG5	NFG6	NFG7	NFG8	NFG10	Total
FG5	75	25	0	0	0	100%
FG6	0	100	0	0	0	100%
FG7	3	16	52	26	3	100%
FG8	0	0	20	80	0	100%
FG 10	0	0	25	0	75	100%
Classification error	25	0	48	20	25	23.7%

Soil organic carbon/total nitrogen ratios were correlated negatively with the density of *Aphelenchoides* and *Pratylenchus*, indicating that soils with a relatively high nitrogen content in comparison with the organic matter content are more likely to support high nematode populations than soils with high organic carbon content in comparison with total nitrogen. The former conditions are more common in areas of intensive fertilization with no adequate organic matter amendments to the soil, whereas contributions of organic matter through crop residue incorporation and manuring can contribute to the maintenance of higher organic matter levels in the soil. The suppressive effect of organic soil amendments on *Pratylenchus brachyurus* under maize and on *Meloidogyne* spp. under tomatoes has been shown by Egunjobi and Larinde (1975) and Chindo and Khan (1986).

Backward elimination regression was used for the identification of multiple factor effects. Significant regression models were developed for all four genera (table 13). Again soil texture, soil depth, soil pH, cropping history, and weed incidence were the most important factor variables. Effects of soil physicochemical properties on nematodes have been reported for a long time (Wallace 1969), although the interaction of soil properties, the cropping system, and crop management practices makes general conclusions difficult.

Table 10. Comparison of nematode densities between field groups formed through clustering

Field group	n	*Aphelenchoides*			*Pratylenchus*			*Helicotylenchus*			*Ditylenchus*			*Tylenchus*			*Aphelenchus*		
		Mean		SD	Mean		SD	Mean		SD	Mean		SD	Mean		SD	Mean		SD
FG 5	6	73	b	117	1288	a	1490	495	a	702	252	a	517	53	ab	53	35	b	81
FG 6	2	3600	a	2404	3800	a	2121	450	ab	636	0	b	0	300	a	0	50	ab	71
FG 7	36	104	b	112	118	b	103	99	b	104	54	ab	51	42	b	46	16	b	31
FG 8	7	469	a	196	206	b	96	326	a	154	64	ab	106	37	b	36	309	a	577
FG 10	4	2082	a	833	94	b	46	287	ab	348	40	ab	43	103	ab	133	30	b	42

Note
Mean = number of individuals per litre of soil. Means followed by the same letter are not significantly different for $P<0.05$
SD = standard deviation of mean; significance of differences was calculated on the basis of transformed values.

Table 11. Species of moderate to high incidence in field cluster groups and factors associated with differences between these groups

Field group	Species with moderate-to-high incidence	Associated field characteristics
FG 5	*Pratylenchus* (h)*	soil depth
	Helicotylenchus (m)	history of maize cropping
	Ditylenchus (m)	weed species
FG 6	*Aphelenchoides* (h)	soil depth
	Pratylenchus (h)	history of maize cropping
	Helicotylenchus (m)	
	Tylenchus (m)	
FG 7	none	
FG 8	*Aphelenchus* (m)	soil texture
		soil depth
	Helicotylenchus (m)	frequency of sorghum cropping
FG 10	*Aphelenchoides* (h)	soil texture
		soil depth
		history of maize cropping
		weed species

Note

* h = high density, m = moderate density

Bee-Rodriguez and Ayala (1977a), for example, report higher populations of *Pratylenchus zeae* on neutral soils than on acid soils, whereas Cuarezma-Teran et al. (1984) found higher populations on acid soils. The difference may be due to crop management practices, as Abd-Elgawad and Saad (1989) report higher population increases of *Pratylenchus* spp. after fertilization with an acidifying fertilizer, ammonium sulfate, than with urea. The effect of soil depth was genus-specific in our study, as deep soils favored *Aphelenchoides* and shallow soils favored *Pratylenchus*. The weed *Andropogon gayanus* is associated with increased densities of *Ditylenchus*, whereas *Porphyrostemma chevalieri* is associated with reduced population densities of the nematode. Associations of nematodes with non crop plants or their suppression by certain plant species have been reported widely and recently summarized by Alam et al. (1990).

Table 12. Correlation between the square root of the density of 4 nematode genera and soil physicochemical properties and cropping history in 56 farmers' fields of the northern Guinea savanna

Field characteristics	*Aphelenchoides*		*Pratylenchus*		*Helicotylenchus*		*Ditylenchus*	
	r	sign	r	sign	r	sign	r	sign
Sand (%)	-0.196	n s	0.094	n s	0.044	n s	-0.005	n s
Clay (%)	0.378	xx	0.247	0	0.187	n s	-0.052	n s
Depth f (cm)[a]	0.107	n s	0.040	n s	-0.107	n s	0.003	n s
Depth t (cm)	-0.029	n s	-0.305	x	-0.258	0	0.052	n s
pH (in water)	-0.120	n s	-0.190	n s	-0.081	n s	0.186	n s
OC (%)	-0.128	n s	-0.215	n s	-0.081	n s	0.085	n s
TN (%)	-0.047	n s	-0.149	n s	-0.059	n s	0.102	n s
OC/TN (ratio)	-0.266	x	-0.278	x	-0.098	n s	-0.006	n s
CEC (meg/100g)	-0.001	n s	-0.099	n s	-0.182	n s	-0.180	n s
M9088 (ratio)[b]	0.038	n s	0.124	n s	-0.050	n s	0.101	n s
S9088 (ratio)[b]	-0.070	n s	-0.019	n s	0.008	n s	0.131	n s
N9088 (ratio)[b]	-0.009	n s	0..067	n s	0.078	n s	0.169	n s
M1st[c](years)	0.319	x	0.297	x	0.379	n s	0.333	x

Notes

r = correlation coefficient, sign = significance of r as n s (nonsignificant), 0 for $P<0.1$, x for $P<0.05$ and xx for $P<0.01$.

a Depth f = depth of first soil layer, depth t = total soil depth.

b M9088, S9088 and N90898 = frequency of maize, sorghum, and noncereal cropping in the field during the previous 3 years between 1988 and 1990, respectively.

c M1st = years since maize was first grown in the field.

Table 13. Regression analysis of the effect of soil physical and chemical characteristics and cropping history on the population densities of six nematode genera in 56 farmers' fields in the northern Guinea savanna

Parameter	Parameter estimate	F-value	Prob > F
a: Regression analysis for *Aphelenchoides*		n = 49	R^2 = 57.1
Intercept	3572.68	2.836	0.007
Clay content (%)	-712.982	4.240	0.001
Clay content squared (%)	29.452	5.270	0.001
Soil depth (cm)	0.144	1.459	0.151
Time since first maize cropping (years)	49.520	3.163	0.003
b: Regression analysis for *Pratylenchus*		n = 49	R^2 =45.0
Intercept	5540.75	3.409	0.001
Clay content (%)	- 714.673	3.620	0.001
Clay content squared (%)	26.942	4.100	0.001
Depth of first cultivated soil layer (cm)	-116.404	1.847	0.071
Soil depth (cm)	21.189	2.575	0.014
Time since first maize cropping squared (years)	2.136	3.346	0.002
c: Regression analysis for *Helicotylenchus*		n = 49	R^2 =58.0
Intercept	220.39	0.928	0.358
Sand content squared (%)	0.090	4.024	0.001
Clay content squared (%)	1.460	2.470	0.018
Soil pH	- 10.732	2.214	0.032
Time since first maize cropping (years)	- 67.360	3.919	0.001
Time since first maize cropping squared (years)	3.382	5.675	0.001
d: Regression analysis for *Aphelenchus*		n = 54	R^2 =17.7
Intercept	4555.67	9.330	0.002
Sand content (%)	- 144.777	3.190	0.004
Sand content squared (%)	1.195	2.910	0.006
Depth of first cultivated soil layer (cm)	- 11.837	2.320	0.134

Table 13. continued....

Parameter	Parameter estimate	F-value	Prob > F
e: Regression analysis for *Tylenchus*		n = 49	R^2 =32.3
Intercept	256.74	1.999	0.052
Clay content (%)	- 37.456	2.259	0.029
Cay content squared (%)	1.486	2.697	0.010
Frequency of sorghum cropping in last 3 years squared	- 63.663	2.697	0.010
Time since first maize cropping (years)	10.143	1.987	0.053
Time since first maize cropping squared (years)	- 0.326	1.839	0.073
f: Regression analysis for *Ditylenchus*		n = 48	R^2 =88.0
Intercept	- 294.34	1.452	0.154
Soil pH (square root)	148.60	1.754	0.086
Incidence of *Andropogon gayanus* in field	1376.877	16.680	0.001
Incidence of *Porphyrostemma chevalieri* in the field	- 206.375	3.597	0.001

Yield-loss assessment

Symptoms of nematode damage are difficult to differentiate from those caused by other stresses such as low soil fertility, water logging, or *Striga* attack. As the damaging organism is microscopic, farmers are not aware of the problem and do not differentiate nematode infestation from soil fertility problems and *Striga*. The recovery of plants, at least in color, through increased nitrogen fertilization, gives farmers the impression that there is a soil fertility problem. The stunted growth, changed root morphology, and leaf-discoloration resemble early symptoms of *Striga* attack, and can make farmers associate the problem with an unemerged *Striga*.

However, a differentiation of symptoms is necessary for on-farm work, even in cases where the services of a nematology laboratory are not available. Additionally, information about the incidence of the problem has to be complemented with information on the severity and potential yield loss. Therefore, symptoms of nematode damage as visible on individual plants were described in farmers' fields and the presence of high nematode populations on the roots of such plants was confirmed in the laboratory. A methodology was developed for scoring nematode damage on individual plants on a 1-to-9 scale (table 14). The severity of symptoms in terms of yield loss was assessed in 3 different fields by labelling individual plants with different symptom expression at 5 WAP and measuring their grain yield at harvest. The yield of individual plants was highly correlated with symptom expression at 5 WAP and highly significant regression equations were developed for all 3 fields analyzed (tables 15, 16). Symptoms were similar in these fields but only the laboratory analysis indicated that the population composition of nematodes in these fields was very different (table 17). The data from field K1 at Kaya suggest, additionally, that *Ditylenchus*, the most important genus in this field, may cause severe symptoms and yield losses at relatively low population densities. These results can be confirmed only by conducting trials under controlled conditions with just one species in each trial. A quadratic model of the form:

$$y = a + bx + cx^2 \qquad (1)$$

fitted best the data in all fields, where x is the score for the damage symptoms on the plant. The function

$$y = 147.98 - 39.288x + 2.747x^2 \qquad (2)$$

described best the data across all fields.

Equation (2) simulates well the yield of plants with different symptoms (figure 4). Yield losses can be calculated by comparing yields for scores 3, 5, and 7 from equation (2) with the yield of undamaged plants which score 1. Yield differences can then be expressed as a percentage yield of healthy plants as follows:

score	approximate yield loss
1	0
3	50
5	80
7	95

The incidence and severity of nematode damage in farmers' fields can be estimated from the percentages of plants (p) with nil (p1), light (p3), moderate (p5), and severe (p7) symptoms of nematode damage at 5 WAP. The incidence of nematode damage indicates the percentage of plants showing any symptom of nematode damage between scores 3 to 7 and can be calculated according to equation (3).

$$\text{incidence} = p3 + p5 + p7 \qquad (3)$$

The severity of nematode damage is the sum of percentages of plants for each score 3 to 7 weighted by the approximate yield loss for each score. The severity permits an estimate of the percentage yield loss caused by nematodes in the field.

$$\text{severity} = p3*0.5 + p5*0.8 + p7*0.95 \qquad (4)$$

Equations (3) and (4) were used to estimate the incidence and severity of nematode problems in different farming systems of the study area. A total of 185 fields was randomly selected and evaluated at about 5 WAP for the incidence of plants with symptoms of nematode damage. An average of 72% of the fields showed symptoms. Fields were subsequently grouped according to field history into 3 categories:

1. fields with at least 2 years of sorghum and not more than one year of maize during the last 3 years (sorghum-based cropping system),
2. fields with at least 2 years of maize and not more than one year of sorghum during the last 3 years (maize-based cropping system), and
3. fields that had been planted at least twice with maize and sorghum during the last 3 years (cereal intercropping system).

Table 14. Scoring system for evaluating symptoms of nematode damage on maize

Symptoms: Roots are significantly reduced in length and many fibrous roots emerge. The above-ground symptoms are less specific, they resemble those of a poorly fertilized plant. Yellowish discoloration of the plant and stunted growth become most clearly pronounced during the vegetative elongation of the plant at 4 to 6 WAP. The patchy, aggregated distribution of affected plants in an otherwise well-performing fieldcrop is typical for nematode attack.

Evaluation: A 1-to-9 scoring system can be used to evaluate the severity of nematode attack in a field. As the symptoms are not very specific, the roots of 3 to 5 affected and nonaffected plants should be pulled out and taken to the laboratory for confirmation. The severity of symptom expression is correlated with yield loss:

Score 1:	no symptoms of damage
Score 3:	slight discoloration of leaves to light green
Score 5:	moderate discoloration of leaves to light green and yellow, reduced plant height and stem diameter, root system moderately stunted and fibrous
Score 7:	heavy discoloration of leaves to light green and yellow, stunted growth, root system stunted, proliferation of fibrous roots
Score 9:	stunted growth, no ear formation, complete leaf yellowing causing premature death of the plant

Note
For practical field evaluations, score 7 and 9 can be joined together resulting in none (1), slight (3), moderate (5), and severe (7–9) symptoms.

The frequency of affected fields was higher in intensified maize-based systems than in systems with an increasing frequency of sorghum cropping. Within-field incidence was generally low, but it was significantly higher in intensified maize-based systems. The severity reached up to 24% in these fields (table 18).

The analysis of the incidence of plants affected by the *pokkah-boeng* disease, caused by the fungal pathogen *Fusarium moniliforme (Giberella fujikuroi)*, suggests some kind of association between this fungus and the nematodes.

Table 15. Yield of individual plants, which were labeled at 5 WAP in three farmers' fields for above-ground symptoms of nematode damage

Field code	Symptoms score	Number of plants	Grain yield Mean	(g/plant) SD
Barde C1	1	15	116.1	33.27
	3	14	45.6	30.51
	5	–	–	–
	7	13	16.4	26.41
Barde C2	1	13	105.6	36.44
	3	12	69.9	22.73
	5	–	–	–
	7	11	3.3	5.25
Kaya K1	1	14	111.7	30.85
	3	13	51.7	17.12
	5	15	19.5	23.91
	7	14	3.0	6.11

Note
SD = standard deviation of mean

Table 16. Regression analysis of the relationship between grain yield (y) at harvest and nematode damage symptoms (x) at 5 WAP

Field code	Regression equation	R^2	Prob>F
Barde C1	$y = 165.23 - 53.816x + 4.651x^2$	0.67	0.001
Barde C2	$y = 124.06 - 18.687x + 0.206x^2$	0.74	0.001
Kaya K1	$y = 147.86 - 39.489x + 2.696x^2$	0.80	0.001
All	$y = 147.98 - 39.288x + 2.747x^2$	0.73	0.001

Note
y = yield in grams per plant at 15% moisture; x = nematode damage score at a scale of 1–9 on the maize plant at 5 WAP.

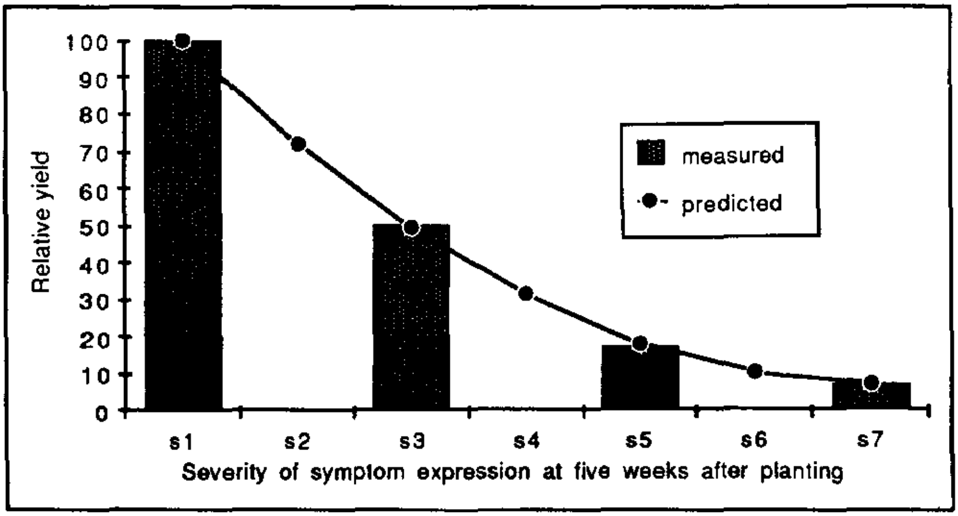

Figure 4. Relative yield of maize as affected by severity of nematode infestation; measured values are compared with simulated values from equation (2)

Table 17. Nematode populations (number of individuals per liter of soil) in farmers' fields, where yield losses were assessed according to symptom expression in 1991

Nematode genera	Field			
	Barde C1	Barde C2	Kaya K1	Gwanki A1
Aphelenchoides	5300	550	10	140
Pratylenchus	5300	70	20	140
Helicotylenchus	900	400	90	500
Aphelenchus	0	0	10	1600
Tylenchus	300	70	60	40
Ditylenchus	0	10	149	40

The incidence of *pokkah-boeng* is correlated with the incidence of nematode symptoms across all fields (correlation coefficient $r=0.30$ with significance $P<0.1$). ***Fusarium moniliforme*** is known as a seedborne pathogen, which additionally can survive on crop residues in the field. Its attack on the plant can be favored by nematodes which cause root lesions and these serve as entry points for the fungus. Such effects on maize have also been suggested by Nath et al. (1974) for *Hoplolaimus indicus* and *Fusarium moniliforme* in India, and by Bee-Rodriguez and Ayala (1977a) for *Pratylenchus zeae* and *Fusarium moniliforme* on sorghum in Puerto Rico.

Table 18. Incidence and severity of symptoms of nematode damage in 185 farmers' fields according to the prevalent cropping system

Production system	n	% across-field incidence[a]	Within-field incidence[b]				Within-field severity[c]			
			Min	Max	Mean	SD	Min	Max	Mean	SD
Sorghum-based system	59	67.8	0	10.6	1.4 b	2.3	0	7.7	1.0 b	1.6
Maize-based system	77	80.5	0	2.98	2.5 a	4.1	0	24.2	1.8 a	3.2
Cereal-intercropping system	49	69.4	0	5.4	0.9 b	1.3	0	3.4	0.7 b	0.9

Notes

Means were compared for arcsin-values; means followed by the same letter are not significantly different for $P<0.05$.

a % fields showing symptoms.

b % plants within fields showing symptoms.

c incidence weighted for severity for estimating % yield loss caused by nematodes.

Evaluation of control options

The negative effect of nematodes on cereal performance was confirmed through diagnostic trials in 1991. Four fields with different compositions of nematode populations (see table 17) but severe symptoms of nematode attack were used for these trials. Treatment of maize and sorghum with carbofuran reduced significantly in both crops the incidence of plants with nematode symptoms (table 19) and maize yields were increased by 141%. Sorghum showed more vigorous growth and an increase of 33% in biomass, but grain yield did not change significantly (table 20). This confirms reports by Chindo and Ayayi (unpublished) that many sorghum varieties are tolerant to nematodes commonly occurring in the savanna.

Table 19. Incidence of maize and sorghum plants with light, moderate, and severe symptoms of nematode damage in untreated and carbofuran treated plots in 4 fields, northern Guinea savanna, in 1991

Variable	No.	Untreated		Treated	
		Mean	SD	Mean	SD
For maize					
% plants score 3	24	8.1	8.7	3.3	0.67
% plants score 5	24	13.7	11.5	1.6	0.27
% plants score 7	24	14.4	15.2	3.3	0.81
For sorghum					
% plants score 3	16	22.8	25.8	29.6	36.8
% plants score 5	16	9.4	18.7	0.0	–
% plants score 7	16	9.3	14.6	0.0	–

Note

No. = number of evaluations   Mean = % of plants with score   SD = standard deviation of mean

Plots treated and untreated in 1991 had similar yields in follow-up trials in 1992 (tables 21 and 22). This suggests that the nematicide treatment for one year had no lasting effect of reducing the nematode problem. The rapid rate of reproduction of nematodes with 2 to 4 generations in one year and the lack of a persistant effect from the nematicide beyond about 4 weeks after application allow the pest population to recover rapidly. Di-Sanzo (1973) reports additionally a change of behavior of nematodes in soil treated with carbofuran.

Table 20. Grain yield of maize and sorghum in untreated and carbofuran-treated plots in 4 farmers' fields infested with nematodes. Maize and sorghum were planted in a 2:1 ratio in the field in 1991

Parameter	Untreated		Treated		LSD (0.05)
	Mean	SD	Mean	SD	
For maize					
Cobs (No./plant)	0.88	0.22	0.99	0.11	0.11
Grain (kg/ha)	1186.1	536.8	2859.8	697.6	402.6
Stover (kg/ha)	5259.5	2645.8	8667.1	1721.5	1264.1
For sorghum					
Panicles (No./hill)	1.91	0.547	2.38	0.78	0.546
Grain (kg/ha)	465.8	251.7	568.45	366.5	132.8
Stover (kg/ha)	9693.5	4031.3	12909.8	2043.0	1991.4

Note

LSD = least significant difference between means for $P<0.05$

Pratylenchus penetrans and *Tylenchorhynchus claytoni* did not move towards plant roots in treated soils. They avoided the pesticide, systemic in the plant roots, whereas they readily penetrated roots in untreated soil. Thus, populations were temporarily reduced because of starvation but recovered quickly afterwards.

In 1991, the rotation of cereals with soybean increased maize yields by 48% and sorghum yields by 47%. Rotation of cereals with *Aeschynomene histrix* in 1991 increased maize yields by 83% and sorghum yields by 18% while rotation with cowpea had no significant effect on maize or sorghum yields. The severity of symptom expression was accordingly reduced on maize (figure 5). However, the contribution of the legumes to increases of grain yield through nematode control cannot be differentiated from their effect on grain yield through nitrogen contributions. The suppressive effect of crop rotations on nematode populations has been widely reported (Curl 1963) and continues to be the most important control strategy in crop production. However, the design of suppressive cropping systems is complicated by the fact that their effectiveness depends considerably on the composition of the nematode species in the soil.

Farmers' perceptions

Nematodes are not known to farmers in the study area because of their microscopic size. There is no word in the local language (Hausa) for these organisms. However, farmers know the symptoms: the term *wuta-wuta*, which means "fire-fire", is used for describing the symptoms of stunted growth, plant yellowing, and leaf death. The term *wuta-wuta* is a general description for such problems in a field, independent of the causal factors.

Table 21. Effect of previous year's (1991) treatments on cobs/plant, shelling percentage, and grain yield of subsequent component maize in a 2:1 mixture ratio with sorghum in 1992

Treatment	Cobs (no./plant)			Shelling (%)			Grain yield/plant (g)			Grain yield/ha (kg)		
	Mean		SD	Mean		SD	Mean		SD	Mean		SD
Maize/sorghum 1991	0.97	a	0.22	64.9	b	8.1	72.0	b	23.9	1733	c	351
Carbofuran 1991	0.83	b	0.15	63.0	b	11.6	66.1	b	14.0	2080	c	633
Soybean 1991	0.99	a	0.18	66.7	a	7.5	87.1	a	19.4	2561	b	565
Aeschynomene 1991	0.93	a	0.10	71.4	a	2.1	93.8	a	22.8	3174	a	634
Cowpea 1991	0.93	a	0.29	60.4	b	11.2	63.0	b	22.8	2000	c	219

Notes
Means followed by the same letter in a column are not significantly different at $P < 0.05$
Shelling percentage was transformed to arcsin and component yields were compared using hill density as a covariant

Table 22. Effect of previous year's treatments on panicles/hill, shelling percentage, and grain yield of subsequent component sorghum in a 1:2 mixture ratio with maize

Treatment	Panicles/hill			Shelling %			Grain yield/hill (g)			Grain yield/ha (kg)		
	Mean		SD	Mean		SD	Mean		SD	Kg/ha		SD
Maize/sorghum 1991	2.55	a	0.40	65.4	c	9.9	58.7	b	28.3	1205	b	780
Carbuforan 1991	2.42	a	0.44	69.0	bc	9.0	62.4	b	31.5	1174	b	656
Soybean 1991	2.84	a	1.09	80.7	a	5.2	87.1	a	16.4	1777	a	365
Aeschynomene 1991	2.44	a	0.57	71.8	b	1.2	69.2	ab	25.1	1422	ab	392
Cowpea 1991	2.76	a	0.40	76.7	b	6.8	70.3	ab	27.6	1451	ab	411

Note
Means followed by the same letters in a column are not significantly different at $P<0.05$;
Shelling percentage was transformed to arcsin and component yields were compared using hill density as a covariant

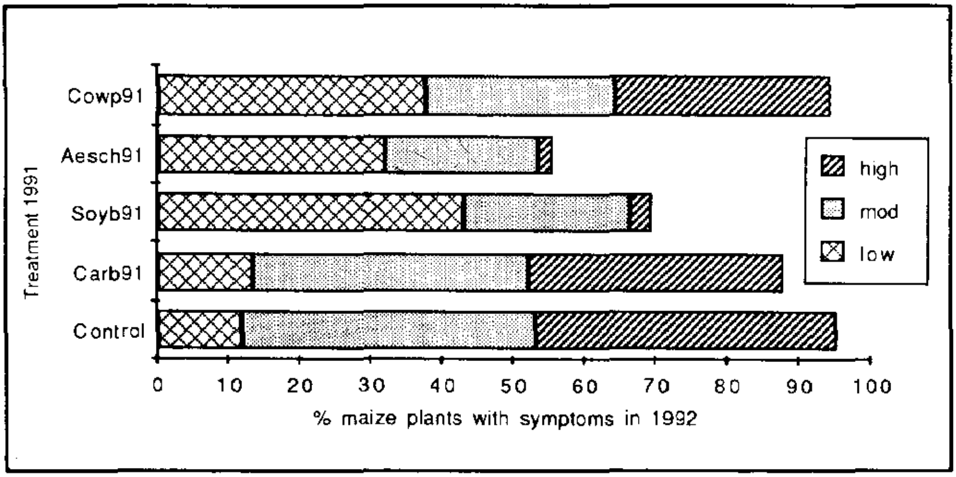

Figure 5. Percentage plants in 1992 with low, moderate and high expression of nematode damage on maize crop planted after cowpea, *Aeschynomene histrix*, soybean, maize treated with carbofuran, and untreated maize (control) in previous year, 1991

Our field research showed that these symptoms may be caused by *Striga hermonthica*, nematodes, or micronutrient deficiencies. Farmers' concern about the symptoms on the plant rather than about the organism coincides with our findings, that the symptoms of *wuta-wuta* from nematodes correlate well with the yield loss. Further discussions with farmers accompanied by photographs of fields with nematode damage enabled farmers to recognize and differentiate the *wuta-wuta* problem caused by nematodes from the others. The aggregated distribution of symptoms of nematode damage in large patches in the field was mentioned by farmers as a distinctive characteristic of this kind of *wuta-wuta*.

About 86% of the farmers mentioned *wuta-wuta* (nematode symptoms) as a rather new problem in their fields, which they had observed increasingly during the last 5 years. Maize was mentioned by 78% of the farmers as the only or the most affected crop. Groundnut was mentioned as another crop. Most farmers (57%) have no remedy for curing the plant disorder. The application of an increasing amount of fertilizer was mentioned by 43% of the farmers as reducing the symptoms.

IV

Implications for the Sustainability of Cereal-based Cropping Systems

Identification of risk systems

The analysis identifies land-use intensity and the predominant cropping system as the primary determinants for nematode population build up in the savanna. Their effects, however, appeared to be genus-specific. Soil physicochemical properties and the predominant weed community tend to modify the population densities. The subsequent paragraphs summarize and conceptualize the information, which was presented in earlier chapters, and refer especially to information contained in tables 8, 11, 13, and 18.

The interrelationship of primary and modifying determinants as expressed in the discriminant and multiple regression analyses results in the identification of systems at risk of nematode infestation (table 23). For instance, intensified maize-based systems with a low frequency of noncereal crops stand a risk of *Aphelenchoides* infestation if they are located on sandy loam or sandy clay loam with a clay content of about 20%. These production systems may additionally have problems with high populations of *Pratylenchus*, especially if they are located on shallow soils with a soil depth of less than 50 cm. Systems dominated by maize in association with sorghum with a low-to-moderate frequency of noncereal components may support moderate population densities of *Aphelenchoides* and *Pratylenchus* under the same soil conditions as mentioned above. *Helicotylenchus* may build up to high densities, especially in sandy clay loam with low silt content. Moderate densities of Helicotylenchus can still be expected in sandy clay loam under sorghum-based cropping systems with frequent intercropping of noncereal crops. Genera such as *Ditylenchus* may increase in population density, depending on the intercropped noncereals or the predominant weed community in the system. Although fields with high population densities of *Aphelenchus* and *Tylenchus* were identified in our study, the cases were few and a clear association of these genera with agroecological factors could not be ascertained.

In the past, the study of single populations of nematodes in sterilized soil provided much information on the effects on growth of specific environmental parameters. More recently, the study of nematode communities has intensified with the aim of understanding the relationship of species or groups of species to one another and to the environment. The impact of a nematode community on a population of host plants is the result of all interactions, known and unknown, internal and external, of that community with the environment, including those with the host plant. The occurrence, size, density, and species composition need to be explained. Nematode populations are influenced by physical and chemical aspects of the environment, the ecology of the host plant, and edaphic factors, but cause/effect relationships are difficult to delineate (Norton 1979). A comparison of nematode populations from different ecologies by Yeates (1981) indicates that abundance and diversity are correlated across different ecologies but not within ecologies.

Table 23. Comparison of the risk of nematode buildup under increasing intensification from sorghum-based systems with fallow rotation to intensive maize-based systems

	Primary determinants of nematode populations: land-use intensity and cropping system Increasing land-use intensity with increasing dominance of cereals towards predominance of maize			
Nematode genera	Cereal-based system, less intensive, with fallow periods	Sorghum-based with noncereal crops, short or no fallow	Systems dominated by maize in association with sorghum	Maize-based systems with low frequency of noncereals
Pratylenchus	low	low	moderate-to-high + sandy loams +shallow depth	high + sandy loams +shallow depth
Aphelenchoides	low-to-moderate + weed community	high +groundnut cropping +sandy loams +deep soils	high +sandy loams +deep soils	moderate-to-high +sandy loams +deep soils
Helicotylenchus	low	moderate-to-high +sandy clay loams +acidic soils	high +sandy clay loams +acidic soils	low-to-moderate +frequency of sorghum intercropping
Ditylenchus	moderate +weed community +alkaline soils	moderate +non cereal hosts +weed community +alkaline soils	low-to-moderate +weed community	low-to-moderate +weed community

Note

Risk of nematode damage as determined by primary factors is indicated as low, moderate, or high; major modifying factors of risk are marked +

Risk and the primary determinants and modifying factors were assessed for each genus according to correlation, regression, and discriminant analysis in tables 12, 13, and 8, respectively

The present study confirms the lack of correlation between abundance and diversity for intensified agricultural production systems of the NGS. Differences in land-use intensity and cropping practices were identified as more important within the ecology for explaining differences in population densities among fields. These primary determinants affected nematode genera in different ways, and thus changed the genera-composition of the population.

The dependance of nematode population densities on the frequency of encounter with its host plants in space (crop density, cropping pattern) and time (crop rotation, land-use intensity) has been shown to be the primary factor for many species in determining their population dynamics (Seinhorst 1970; Barker and Olthof 1976; Freckman and Caswell 1985). Population densities normally fluctuate around equilibrium densities, determined by the primary determinants. However, equilibrium densities may be disturbed and populations may increase exponentially to high densities if favorable external conditions and/or host-plant conditions promote high rates of increase (Seinhorst 1970). Changes of equilibrium densities, and the promotion of high rates of increase of certain species can be a threat to the sustainability of agricultural crop production. Six genera were identified in the present study as reaching very high densities in some fields and yield losses from nematodes were confirmed through subsequent trials. The analysis of factors determining nematode population dynamics is therefore of extreme importance in predicting the sustainability of crop production in the savannas, where land-use intensity and cropping systems are dynamically changing all over Africa.

Besides the above-mentioned primary determinants, additional factors have modifying effects on nematode population densities. Soil depth, soil texture, soil pH, soil organic matter (Norton 1979; Seinhorst 1970) and the composition of plant communities (Seinhorst 1970; Alam et al. 1990) influence soil nematode populations. *Pratylenchus brachyurus* has, for example, been shown by Endo (1959) to have higher rates of increase on sandy loams than on sands, and this coincides with our findings for *Pratylenchus* spp. However, many of these interactions are species-specific. *P. zeae* has been reported to be most common on sandy soils, whereas *P. hexincisus* is more common on medium-to-heavy textured soils (Norton 1979).

As bacterial feeders, fungivores, omnivores, plant feeders, and predators, nematodes contribute considerably to nutrient dynamics in soils as part of the overall soil biota (Freckman and Caswell 1985). The present study focused on the plant-parasitic genera, which are of direct agricultural importance. Their populations, however, are influenced by the overall soil biota. Nematodes are prey to certain fungi, bacteria, rickettsia, protozoa, and other nematodes (Freckman and Caswell 1985), which in turn are influenced by the soil environment. The suppressive effect of increased soil organic matter content or organic soil amendments seems to be at least partly due to an increase of antagonists, especially nematode-trapping fungi, under these conditions (Norton 1979; Freckman and Caswell 1985). The negative correlation between organic carbon/total nitrogen ratios with population densities of *Aphelenchoides* and *Pratylenchus* in the present study indicates also the suppressive effect of adequate organic matter content in the soil for these two genera. Direct biological interactions of the plant-parasitic nematodes with antagonists in the soil were not analyzed in our study, and need further detailed research.

Research needs

The study area has experienced intensification of cereal cropping within the past decade. Similar trends are developing in other parts of West and Central Africa. The results of the study show that, as maize becomes predominant in the system, problems of plant-parasitic nematodes can increase to become major production constraints. This raises serious questions about the sustainability of intensified maize-dominated systems. The following research needs have been identified:

1. The host-parasite relationship has not been studied for most genera occurring in high densities in the study area. *Pratylenchus* is a known cereal-parasitic nematode (Egunjobi 1974; Caveness 1992), while the pest-status of *Helicotylenchus* and *Aphelenchoides* has not been clarified, although associations with cereals in the tropics have been reported (Bee-Rodriguez and Ayala 1977b; Caveness 1992). Therefore, an assessment of the pest-status of these genera and their population dynamics on the predominant crops in the savanna requires immediate attention. Consideration should also be given to other genera of relatively low population densities but of high damage potential such as *Aphelenchus*, *Tylenchus*, and *Ditylenchus*.
2. The yield-loss assessment method described in this monograph needs further refinement. Genera-specific yield losses should be assessed and the quantification of nematode damage within fields needs sampling methods appropriate to the aggregated distribution of the pest in the field.
3. Associations between nematodes and other pathogens, for example *Fusarium moniliforme*, have been reported in the literature, and seem to be present in the study area. Such interactions can provide additional threats to intensified cereal-based systems. These interactions need further studies.
4. Existing and new varieties of cereals should be screened to establish their response to each nematode genus of major economic importance as part of an overall integrated system of nematode management. The screening should avoid the development and release of highly susceptible cultivars and should explore the potential for resistance.
5. The development of nematode-suppressive cropping systems requires medium- to long-term trials on the population dynamics of nematodes and crop damage under different cropping systems. Opportunities should be explored to use some of the existing crops, varieties, and even new crop options, such as fodder crops in the savannas, as trap crops for nematodes. The adoptability of such crops in rotation may increase, if they are suppressive to nematodes and substantially increase the yield of the subsequent cereal crop.
6. Opportunities for biological control of nematodes may be limited, but the creation of a soil environment which favors nematode antagonists against plant-parasitic nematodes contributes to low equilibrium densities of the pest. This requires research on the population dynamics of nematode communities and their antagonists in agoecosystems.
7. Control options should be developed with a clear systems perspective. The use of nematicides is economically and toxicologically too risky. Given the high location-specificity of cropping systems and crop varieties across West and Central Africa, nematode-suppressive cropping systems can best be developed at the local level.

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References

Abd-Elgawad, M.M., and F.F. Saad. 1989. Nematode dynamics on common bean as affected by intercropping with maize. Beiträge zur tropischen Landwirtschaft und Veterinärmedizin 27:443-448.

Adesiyan, S.O., F.E. Caveness, M.O. Adeniji, and B. Fawole. 1990. Nematode Pests of Tropical Crops. Heinemann, Ibadan, Nigeria.

Alam, M.M., M.A. Siddiqui, and A. Ahmad. 1990. Antagonistic plants. Pages 41-50 *in* Nematode Bio-Control, edited by S. Jairajpuri, M.M. Alam, and I. Alam. CBS Publishers, Delhi, India.

Barker K.R., and T.H.A. Olthof. 1976. Relationships between nematode population densities and crop responses. Annual Review of Phytopathology 14:327-353.

Bee-Rodriguez, D., and A. Ayala. 1977a. Interaction of *Pratylenchus zeae* with four soil fungi on sorghum. Journal of Agriculture of the University of Puerto Rico 61:501-506.

Bee-Rodriguez, D., and A. Ayala. 1977b. Nematodes associated with sorghum in Puerto Rico. Nematropica 7:16-20.

Bos, W.S. 1977. *Aphelenchoides arachidis* n.sp. (Nematoda: Aphelenchoidea), an endoparasite of the testa of groundnuts in Nigeria. Journal of Plant Diseases and Protection 84 (2): 55-99.

Byth, D.E., and V.E. Mungomery (eds.). 1981. Interpretation of plant response and adaptation to agricultural environments. Australian Institute of Agricultural Science, University of Queensland, St. Lucia, Australia.

Caveness, F.E. 1992. Nematological Research at IITA 1969-1988, edited by J. Lowe. Plant Health Management Monograph No. 2. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Chindo, P.S., and F.A. Khan. 1986. Effect of soil organic amendment with poultry manure on the damage caused by the root-knot nematode, *Meloidogyne incognita,* on tomato. International Nematology Network Newsletter 3:30-33.

Claflin, L.E. 1984. Plant-parasitic nematodes affecting sorghum. *In* Sorghum root and stalk rots, a critical review: Proceedings of the Consultative Group discussion on research needs and strategies for control of sorghum root and stalk rot disease, 27 Nov-2 Dec 1984 ICRISAT. Bellagio, Italy; Patancheru, A P 502324, India.

Cobb, N.A. 1918. Estimating the nema population of the soil. Circular of the Agricultural Technology Bureau for Plant Identification, United States Department of Agriculture 1:47.

Cuarezma-Teran, J.A., L.E Trevathan, and S.C. Bost. 1984. Nematodes associated with sorghum in Mississippi. Plant Disease 68:1083-1085.

Curl, E.A. 1963. Control of plant diseases by crop rotation. The Botanical Review 29:413-479.

DeLacy, I.H. 1981. Cluster analysis for the interpretation of genotype by environment interaction. Pages 272-292 *in* Interpretation of plant response and adaptation to agricultural environments, edited by D.E. Byth and V.E. Mungomery. Australian Institute of Agricultural Science, University of Queensland, St. Lucia, Australia.

Di Sanzo, C.P. 1973. Nematode response to carbofuran. Journal of Nematology 5:22-25.

Egunjobi, O.A. 1974. Nematodes and maize growth in Nigeria. I. Population dynamics of *P. brachyurus* in and around the roots of maize and its effects on maize production at Ibadan. Nematologica 20: 181-186.

Egunjobi, O.A., and M.A. Larinde. 1975. Nematodes and maize growth in Nigeria. II. Effect of some amendments on population of *Pratylenchus brachyurus* and on the growth and production of maize (*Zea mays* L.). Nematologica Mediterraneae 3: 65-73.

Endo, B.Y. 1959. Responses of root-lesion nematodes, *Pratylenchus brachyurus* and *P. zeae*, to various plant and soil types. Phytopathology 49:417-421.

Freckman, D.W., and E.P. Caswell. 1985. The ecology of nematodes in agroecosystems. Annual Review of Phytopathology 23:275-296.

Gokte, N., V.K. Mathur, A. Lal, and Rajan. 1992. On the occurrence of *Aphelenchoides besseyi* and some free-living nematode species in *Stylosanthes hamata* seeds. Nematologica Mediterraneae 20:63.

Lagoke, S.T.O., V. Parkinson, and R.M. Agunbiade. 1991. Parasitic weeds and control methods in Africa. Pages 3-14 *in* Combating Striga in Africa, edited by S.K. Kim. Proceedings, International Workshop organized by IITA, ICRISAT, and IDRC, 22-24 August 1988. IITA Ibadan, Nigeria.

Lindsey, D.L., and E.D. Cairns. 1971. Pathogenicity of the lesion nematode *Pratylenchus brachyurus* on six soyabean cultivars. Journal of Nematology 3: 226-230.

Martin, G.C., J. I. Way, and A.M. Armstrong. 1975. Soil fumigation and the control of *Pratylenchus* spp. and other plant-parasitic nematodes affecting maize production in Rhodesia. Paper presented at the 32nd Conference of the Nematological Society of South Africa, Stellenbosch, South Africa.

Nath, R.P., M.G. Haider, and S.S. Prasad. 1974. Combined effect of *Hoplolaimus indicus* and *Fusarium moniliforme* on maize plants. Indian Journal of Nematology 4:90-93.

Norton, D.C. 1979. Relationship of physical and chemical factors to populations of plant-parasitic nematodes. Annual Review of Phytopathology 17:279-299.

Norton, D.C., L.R. Frederick, P.E. Ponchillia, and J.W. Nyhan. 1971. Correlation of nematodes and soil properties in soybean fields. Journal of Nematology 3: 154-163.

Norton, D.C., J. Tollefson, P. Hinz, and S.H. Thomas. 1978. Corn yield increases relative to nonfumigant chemical control of nematodes. Journal of Nematology 10:160-165.

Reuhle, J.L. 1973. Influence of plant-parasitic nematodes on long pine seedlings. Journal of Nematology 5: 7-9.

SAS, 1985. Statistical Analysis System User's Guide. SAS Institute Inc., Cary, NC. USA.

Schmitt, D.P., and D.C. Norton. 1972. Relationships of plant-parasitic nematodes to sites in Native Iowa Prairies. Journal of Nematology 4: 200-206.

Sharma, S.B. 1988. Nematode diseases of groundnut, pigeon pea, chickpea, sorghum, and pearl millet. Progress report on international data collection on nematode diseases of ICRISAT's mandate crops, 1987-88. 39 pp.

Smith, J., A.D. Barau, A. Goldman, and J.H. Mareck. 1994. The role of technology in agricultural intensification: the evolution of maize production in the Northern Guinea Savanna of Nigeria. Economic Development and Cultural Change 42: 537-554.

Smith, J., and G.K. Weber. 1994. Strategic research in heterogeneous mandate areas: an example from the West African Savanna. Pages 545–565 *in* Agricultural technology: policy issues for the international community, edited by J.R. Anderson. CAB International, Wallingford, UK.

Seinhorst, J.W. 1970. Dynamics of populations of plant parasitic nematodes. Annual Review of Phytopathology 8:131-156.

Swarup, G., and C. Sosa-Moss. 1990. Nematode parasites of cereals. Pages 109-136 *in* Plant-parasitic Nematodes in Sub-tropical and Tropical Agriculture, edited by M. Luc, R.A. Sikora, and J. Bridge, CAB International.

Tarte, R. 1971. The relationship between preplant populations of *Pratylenchus zeae* and growth and yield of corn. Journal of Nematology 3: 330-331.

Taylor, A.L. 1967. Principles of measurement of crop losses in nematodes. Pages 225-237 *in* Papers presented at the FAO Symposium on crop losses, Rome, Italy, 2-6 October 1967.

Tiyagi, S.A., Mehar Bano, and S. Anver. 1987. Populations build up of phytonematodes associated with pearl millet. International Nematology Network Newsletter 4(4): 19-20.

Wallace, H.R. 1969. The influence of nematode numbers and soil particle size, nutrients, and temperature on the reproduction of *Meloidogyne incognita*. Nematologica 15: 55-64.

Weber, G., K. Elemo, A. Awad, P. Chindo, V. Chude, A. Adeoti, and S. Oikeh. 1993: Monitoring of constraints in intensifying maize-based systems. Research Guide, International Institute of Tropical Agriculture, Ibadan. pp. 27.

Yeates, G.W. 1981. Nematode populations in relation to soil environmental factors: a review. Pedobiologia 22:312-338.

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