Plant Health Management Research Monograph

2

Nematological Research at IITA 1969–1988

A summary of investigations conducted by Fields E. Caveness

edited by Joyce Lowe

International Institute of Tropical Agriculture

About IITA

The goal of the International Institute of Tropical Agriculture (IITA) is to increase the productivity of key food crops and to develop sustainable agricultural systems that can replace bush fallow, or slash-and-burn, cultivation in the humid and subhumid tropics. Crop improvement programs focus on cassava, maize, plantain, cowpea, soybean, and yam. Research findings are shared through international cooperation programs, which include training, information, and germplasm exchange activities.

IITA was founded in 1967. The Federal Government of Nigeria provided a land grant of 1,000 hectares at Ibadan, for a headquarters and experimental farm site, and the Rockefeller and Ford foundations provided financial support. IITA is governed by an international Board of Trustees. The staff includes around 180 scientists and professionals from about 40 countries, who work at the Ibadan campus and at selected locations in many countries of sub-Saharan Africa.

IITA is a member of a system of international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR). Established in 1971, CGIAR is an association of about 50 countries, international and regional organizations, and private foundations. The World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP).

Printed by Intec Printers Limited, Ibadan

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Fields E. Caveness

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Plant Health Management Division

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Preface

The Plant Health Management Research Monograph series aims to disseminate detailed research results obtained by IITA scientists in partnership with their colleagues in international and national research institutions. There are many interesting and relevant research results which deserve to be published in their entirety but are often not accepted in journals because they are too long. One of the aims of this series is to provide a medium of publication for such information.

The series will cover all aspects of plant health research, i.e., biological control, host plant resistance, agronomic practices, systems analysis, integrated crop and pest management, economics, policy issues, biology, ecology, and behavior of plant pests and diseases and their associated organisms.

The monographs are aimed at a wide readership, from scientists to policymakers and international development agencies. Individuals and institutions in Africa may receive single copies free of charge by writing to:

The Director
IITA Plant Health Management Division
c/o Biological Control Center for Africa
P.O. Box 08-0932
Cotonou
Republic of Benin

Original research results are available with the Root and Tuber Research Program, IITA.

The Author

Dr. Fields Caveness is a pioneer in nematological research in Africa. He first came to Nigeria in the 1950s and joined the staff of IITA in 1969. Directly or indirectly he has trained most nematologists in Nigeria and some in other countries in Africa. He retired from IITA in 1988.

His current address is: 726 North Balboa Circle, Mesa, Arizona, 88205 USA.

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I. Introduction

Nematodes (also called eelworms, threadworms, or roundworms) are abundant in the soil. The majority of them are harmless, but many species parasitize plants, including food crops (see Annex 1), causing losses in both quantity and quality. Virtually every plant has nematode parasites, and some nematodes are parasitic on many crops. This lack of specificity in a parasite can make control difficult; if one of its hosts is not available, another may be.

Losses due to nematodes are often difficult to assess, and small reductions may pass unnoticed. Yields are commonly reduced by up to 30% per year, but losses due to unmarketable produce and spoilage during storage may be much higher. The problem worsens as human population pressure increases. Shortened crop rotations, coupled with more frequent planting of food crops, favor the buildup and maintenance of large populations of nematodes in the soil.

Injury to the plant is caused by the presence and feeding of nematodes. They can cause simple mechanical damage, or damage by chemical substances; the latter may be produced by the nematodes, or by the plant itself in response to nematode attack. Some nematodes are linked with bacterial, fungal, and viral diseases of plants, e.g., yam nematode storage rot of yam tubers. Nematode damage to plants is also affected by environmental factors such as soil texture, fertility, moisture, and temperature. Under high stress, such as high temperature, low soil moisture, low soil fertility, other pathogens, or a combination of these, plant growth may be severely affected or the plant may die; under more favorable growing conditions, however, the plant may produce an economic harvest.

Field symptoms are generally nonspecific, and other possible causes for poor plant growth have to be considered. An area of reduced plant growth, usually circular, in a field crop which is otherwise growing well, is often a symptom of parasitic nematodes. The area of stunted plants generally enlarges with each new crop. On warm days, the affected plants usually wilt a few hours before moisture stress affects healthy plants. Affected plants may also be chlorotic, showing signs of nutrition deficiency caused by a reduced root system. The general reduction in plant growth causes more ground to be unshaded, and consequently weed growth is increased. The reduced canopy and root system impair the normal processes of water and nutrient uptake during the growing period, resulting in reduced yields of leaves, seeds, tubers, etc. Affected plants are sometimes forced into early senescence.

One simple symptom of nematode parasitism is that the plants are easy to uproot because of the reduced root system. Gross symptoms of damage to root tissue can appear as the familiar knots or galls (which also disrupt vascular elements); individual cells may be killed and coalesce to form lesions (in severe cases causing root pruning); new root growth may stop, giving a stubby appearance to the roots; and, especially in fleshy roots, there may be a general necrosis resulting from invasion by a secondary pathogen. If root systems are heavily attacked, especially at the seedling stage, fine feeder roots are lacking, and damage may be so severe that the plant cannot survive a period of stress.

Control is attempted by reducing the nematode populations—by affecting their ability to feed, survive, and reproduce. Some control measures limit or reduce nematode populations over various periods, in contrast to a quick kill by the use of heat or chemicals. The method used varies with the crop, and the economics of control should always be related to the price of the marketable produce. Control measures need to be modified to suit the crop involved, the facilities available, and the inputs of labor, equipment and funds that are appropriate.

Nematological research in Nigeria was given a large boost by a USAID project (620-11-110-050) in Ibadan from 1959 to 1965, at the Western Region Ministry of Agriculture and Natural Resources (Caveness 1967). A progress report indicates that the work was mainly observational—collecting data on nematode species, their distribution in the country and on different crops, and studies on nematode life histories. A few crops were tested for resistance to root-knot nematodes. Resistance was found in 31 lines of groundnut but in no cowpea lines. Control by desiccation and soil fumigation was assessed.

The main achievements of the project are listed below.

- The number of nematode species recorded in Nigeria increased from 49 to 82, based on 7000 samples collected from different parts of Nigeria. The numbers of species of plant parasitic nematodes associated with the roots of various economic plants were determined (Table 1).
- The life histories of the root-knot nematode and the reniform nematode were found to be essentially the same as those previously reported in the literature for these species.
- Soil desiccation was shown to control root-knot nematodes effectively in the top 20-25cm (8-10in) of the soil.
- Soil fumigation with D-D (300L ha^{-1}) gave a yield increase of 23% in cowpeas. However, the increase did not cover the cost of treatment.
- Oilpalm yields (2 years' data) showed no significant increase after soil fumigation.
- For maize, soil fumigation controlled the root-lesion nematode and gave a 27% increase in yield. Allowing for the cost of fumigant (but not that of labor), the value of the treated crop was 14% higher than the untreated.
- As soil fumigation presents problems, surface application of Nemagon®, followed by watering in, was tried. However, this did not control plant-parasitic nematodes.
- Under stylo (*Stylosanthes* spp) the root-lesion nematodes that attack maize were not maintained, and stylo was recommended for use in crop rotations for control of this nematode.

At the International Institute of Tropical Agriculture (IITA), nematology was originally part of the Farming Systems Program. It was transferred to the Root, Tuber and Plantain Improvement Program in 1979, as nematodes are important pests of the major root crops (cassava, sweet potato, and yams). However, work has also been done on legume crops, cereals, and a few others. Hence the nematology subprogram has involved cooperation with other programs at IITA, such as the Grain Legume Improvement Program, the Maize Research Program, the Rice Research Program, and the Resource and Crop Management Program (formerly Farming Systems Program). Nematicides may be effective, but they are expensive, and can be damaging to the environment; indeed, some have been banned in the USA, e.g., Nemagon® and Ethylene dibromide. Nematology research at IITA has, therefore, concentrated on methods that demand only low inputs from the farmer i.e., the use of resistant cultivars and appropriate cultural practices.

Table 1. Numbers of species of nematodes on crops in Nigeria.

Crop		West and Midwest	East	North
Common name	Scientific name			
Bamboo	*Bambusa vulgaris*	12	-	2
Banana and plantain	*Musa* spp	22	7	3
Cassava	*Manihot esculenta*	23	16	2
Citrus	*Citrus* spp	19	13	4
Cocoa	*Theobroma cacao*	26	8	-
Coconut	*Cocos nucifera*	13	6	-
Cotton	*Gossypium* sp	12	-	6
Cowpea	*Vigna unguiculata*	17	-	5
Date palm	*Phoenix dactylifera*	-	-	4
Egg plant	*Solanum melongena*	-	6	3
Groundnut	*Arachis hypogaea*	3	-	13
Guinea corn	*Sorghum* sp	7	-	11
Kola	*Cola nitida*	20	6	-
Maize	*Zea mays*	26	10	4
Mango	*Mangifera indica*	15	5	6
Oil palm	*Elaeis guineensis*	28	10	5
Okra	*Hibiscus esculentus*	4	3	8
Pawpaw	*Carica papaya*	10	4	4
Pigeonpea	*Cajanus cajan*	8	-	2
Pineapple	*Ananas comosus*	7	6	5
Potato	*Solanum tuberosum*	-	-	4
Red pepper	*Capsicum annuum*	8	2	7
Rice	*Oryza sativa*	5	4	6
Rubber	*Hevea brasiliensis*	28	4	-
Sugarcane	*Saccharum officinarum*	5	5	16
Sweet potato	*Ipomoea batatas*	7	-	2
Teak	*Tectona grandis*	14	2	-
Tobacco	*Nicotiana tabacum*	25	3	3
Tomato	*Lycopersicum esculentum*	11	10	1
White yam	*Dioscorea rotundata*	21	16	4
Bush and grass		35	22	13

II. Nematodes found in Nigeria

Root-knot nematodes

Three species have been found in Nigeria, *Meloidogyne incognita*, *M. arenaria*, and *M. javanica*. All appear to be endemic as they have been found in all areas of the country and recovered from virgin forest soils. It is doubtful whether any considerable area is free of these pests.

Root-knot nematodes are the most serious on vegetables and tobacco. In general, they cause stunting and produce characteristic galls on roots. On some plants, such as tomato, cucumber, melon, and lettuce, the galls often become large and conspicuous; but on others, such as sweet potato, lima bean, and brassica, they usually remain small and inconspicuous. Above-ground parts of plants may not show evidence of infection unless nematodes are numerous, or growing conditions become unfavorable (F.E. Caveness 1972, unpublished data). Nematodes also attack cassava, yam, cowpea, soybean, rice, and banana/plantain.

Root-lesion nematodes

Pratylenchus brachyurus and *P. sefaensis* are present in Nigeria, and attack cowpea, soybean, pigeonpea, rice, maize, sugarcane, sorghum and numerous grasses. Severe attack by root-lesion nematodes can result in circular areas of poor growth within a field. Plants may be stunted and show leaf curl during drought periods.

Reniform nematodes

Rotylenchulus reniformis occurs in all areas of Nigeria. This nematode attacks vegetables, including cowpea, but rarely causes severe stunting. Generally, there is a loss of vigor and yield. The nematode mostly lives on the root surface and does not cause the formation of galls or knots (F.E. Caveness 1972, unpublished data). It also attacks soybean and maize. *Rotylenchulus variabilis* has been found in southwestern Nigeria.

Spiral nematodes

The spiral nematodes and their relatives are a closely related group and occur frequently and in all parts of Nigeria. The yam nematode, *Scutellonema bradys*, is in this group. The true spiral nematodes, *Helicotylenchus* spp, are the most frequently encountered nematodes in soils, and about nine species are found in Nigeria. Other spiral nematodes (six species of *Scutellonema* plus *Peltamigratus nigeriensis*) are found less often, but may occur in large numbers (F.E. Caveness 1972, unpublished data).

Little is known about this group of nematodes. The yam nematode causes injury to tubers resulting in small yellow lesions turning brown to black. The lesions afford entrance for fungi, mites and other organisms, resulting in a dry rot that may destroy the whole tuber. Spiral nematodes also occur on soybean, rice, maize and banana/plantain.

Other nematodes

Burrowing nematodes *(Radopholus similis)* are found on banana/ plantain; cyst nematodes *(Heterodera* spp) on sugarcane and rice; lance nematodes *(Hoplolaimus* spp) on cowpea; and rice root nematode *(Hirschmannia oryzae)* in rice paddies. Ring nematodes *(Criconemoides* spp) have been found associated with yam, and stunt nematodes *(Tylenchorhynchus martini)* are found on maize.

There are other ectoparasitic nematodes. Many species of nematodes live in the soil, usually remaining outside the roots and feeding by piercing the tissues. Root systems of infected plants are usually poorly developed and show evidence of deterioration such as lack of small feeder roots, thickened root remnants, and conspicuously discolored areas or lesions. Rarely, small galls may occur. The following genera have been found in Nigerian soils: *Aphasmatylenchus, Caloosia, Dolichodorus, Hemicriconemoides* (sheathoid nematode), *Hemicycliophora* (sheath nematode), *Longidorus* (needle nematode), *Paratylenchus* (pin nematode), *Peltamigratus* (false spiral nematode), *Rotylenchoides, Telotylenchus, Tetylenchus, Trichodorus* (stubby root nematode), *Trichotylenchus, Trophurus, Tylenchorhynchus* (stylet nematode), *Tylenchulus* (citrus nematode) and *Xiphinema* (dagger nematode).

All the nematodes mentioned in this report are listed in Annex 2.

III. Methods of study

Counting and identification of nematodes

Nematodes are isolated from the soil using the modified Baermann funnel method (Whitehead and Hemming 1965). Caveness (1975a) developed a siphon method for concentrating the nematodes by removing excess water. The water-nematode residuum is poured into a Nalgene 500ml wash bottle and left to settle for at least 5 hours. Rubber tubing (3mm inside diameter), filled with water to form the siphon, is then slipped over the spout. With a head of 47cm, the excess water is emptied in about 6 minutes leaving a nematode concentrate of 10-45ml. Different settling times were investigated—for the single species *Pratylenchus sefaensis*, losses were under 1.5% after 5 hours, and under 0.4% after 9 hours. For mixed soil nematodes, at least 9 hours settling time was needed to give losses as low as 1.5%. Inclining the wash bottles by 3° or 8° made little difference to the numbers lost, but the volume of concentrate increased from 11 to 30ml; at a 13° inclination, hardly any nematodes were lost, but the concentrate volume was 45ml.

For the root-knot nematodes, species determination is based on morphological characters. A high magnification light microscope is necessary, and attention should be given to the perineal pattern, stylet, and head region. Eisenback et al. (1981) give illustrations of the essential characters of the four species that together account for more than 95% of root-knot nematodes from agricultural soils throughout the world.

Screening for resistant host varieties

Before the nematologist can assist in a breeding program, the species of nematodes have to be identified and their races determined where appropriate. Their prevalence and distribution need to be known, and their economic importance assessed, so that an informed assignment of priorities can be made. In this respect, microplots can be of great use. For root-knot nematodes, there are relatively few species around the world: *Meloidogyne incognita* (with four host races), *M. arenaria* (with two host races), *M. javanica*, and *M. hapla*. This means that a cultivar bred for resistance against a particular species or race would have broad utility on other continents (Caveness 1987).

Host lines (seeds, cuttings, cormels, etc., as appropriate) are planted in pots. When root growth is well developed, nematode eggs are added to each pot. Some weeks later, the roots are removed and rated for gall development. Nematode reproductive rate is estimated by an egg count from the roots of each plant. Eggs are separated from the roots using the sodium hypochlorite-agitation method (Hussey and Barker 1973) and their numbers estimated by a dilution method (Southey 1970).

Nematode cultures

As nematode cultures can be kept conveniently in pots, a greenhouse or screenhouse is satisfactory. However, in the tropics, a simple shadehouse made from local materials may suffice. Pots should be spaced to avoid cross-contamination by splashing from rain dripping though the shade cover. Roving lizards may also be a problem, unless the pots are protected by wire mesh. Large quantities of inocula of particular species (and perhaps races) are required for experimentation. The species cultured must be maintained in a pure form, and prevented from mixing with other species. It is necessary to consider each species or race separately in testing crop germplasm. Also, the plants should be planted singly in each pot. The rule is: one nematode, one plant, one pot.

A pure culture is best started from a number of specimens that have been positively identified. This broadens the genetic base of the inoculum so that it is closer to that of general field populations. If the specimens have not been identified, a single egg-mass from a root-knot female or a cyst can be applied to a suitable host plant in a pot of sterilized soil, or soil that has been pasteurized in a hot water bath. After a few weeks, successful inoculations will provide abundant material for species identification. The nematode germplasm can then be bulked, and increased and maintained on the host plants. Reinoculations to new plants should be made in good time, to ensure a constant supply of nematodes. Susceptible tomato or cucumber plants make good hosts for rapid increase of root-knot nematode eggs. For maintaining cultures over an extended period of time, pawpaw is longer-lived than most other crops of interest.

Test plants on which the parasite does not become established should be retested with a number of replicates to confirm the incompatibility. Culture purity should be routinely checked to ensure that mixing has not occurred.

Inocula of the root-knot nematode

For the root-knot nematode, inoculum is prepared by freeing the eggs from plant roots, using the sodium hypochlorite method of Hussey and Barker (1973). If a sandy soil is used as the potting medium, it is easily removed from the roots by gentle washing with water. The roots are placed in a suitable container with a tight fitting lid, e.g., a plastic jar from 500ml to 4 litres in volume. Commercial bleach is used at a concentration of 20%. A shaker is convenient and helps to standardize procedures. With a 500ml jar, which fits into the modified fingers of an automatic wrist-action shaker, 100ml of solution is shaken with the roots for a maximum of 4 minutes. The solution is poured through a coarse screen to trap the larger debris, while the nematode eggs are caught on a 500-mesh sieve. If a sieve is not available, the sodium hypochlorite solution containing the eggs can be diluted in a large volume of water (e.g., a large plastic wash tub) and the eggs allowed to settle. The surplus water is decanted and the number of eggs per litre of water calculated. The eggs can then be placed onto the soil around the test plant with a pipette, or a small vial of about 25ml. A uniform water-egg mixture should be maintained by frequent stirring.

Soil infested with the nematode, or infected roots, can be used as the inoculum source, but the inoculum level could be difficult to determine. Second-stage juveniles collected from galled roots in a mist chamber would provide infective nematodes of known age if collected routinely. Woody roots, such as those of cotton, will yield juveniles over a much longer time-span than herbaceous roots, such as those of tomato or cucumber.

Depending on plant size and kind, an inoculum of 2000-10,000 eggs per pot should be satisfactory. Seedlings at emergence would receive a quantity at the lower end of that range. (Cowpea seedlings inoculated with 5000 eggs and grown in a hot greenhouse died, while those receiving 2000 eggs grew well until the test was terminated.) Plants being propagated from slips or rhizomes should be allowed to form roots before inoculation. All plants in a particular test should receive the same number of eggs or juveniles. Screening can be done at ambient temperatures, but a soil temperature of 22-25°C will reveal incompatibility between host and parasite that might not be detected at a higher temperature. Plants with a well-known susceptible reaction should be grown as a control with each new batch of inoculum.

The ideal plant when screening for resistance is one that can withstand the shock of being uprooted when roots are inspected for galls and egg masses, and perhaps of having some roots pruned for egg count assessment, and of being replanted if the plant is considered worth saving. For crops that have a low survival rate on replanting, the double-potting method is useful, in which one pot is placed above another. The seed is planted in the upper pot and the roots given time to grow through into the soil of the lower pot. The lower roots are inoculated, and later severed for determination of infection rate and rate of nematode reproduction. Germplasm found to show resistance should be retested to confirm the results, and tested against other parasitic nematodes in the area.

Assessment of resistance

Different criteria have been proposed for assessment of resistance, e.g., the efficiency of the plant as a host (rate of nematode reproduction) and damage to the plant (harm caused by the nematode). For resistant parent material to be recommended to the plant breeder, the rate of reproduction should probably be 50 eggs or fewer per plant, unless the gene pool is very small or more resistant parent material cannot be found.

Sasser et al. (1984) proposed a scheme for classifying host suitability (Table 2). This scheme should be used with caution. A plant with a host efficiency factor of 1 would still be producing about 5000 eggs per plant if that was the inoculum level.

Table 2. A scheme for classifying host suitability *(Source:* Sasser et al. 1984).

Gall index[a] for plant damage	R factor for host efficiency[b]	Degree of resistance
≤2	≤1	resistant
≤2	>1	tolerant
>2	>1	susceptible
>2	≤1	hypersusceptible

[a] Gall index: 0 = no gall formation; 5 = heavy gall formation.

[b] Reproduction factor: $R = P_f/P_i$, where P_i = initial inoculum level, and P_f = final number of eggs.

Before using a promising plant as a resistant parent, damage caused by nematodes should be determined under field conditions. The use of replicated microplots has proved satisfactory for assessing the effects of nematodes on yields. Microplots are a good compromise between pots in the greenhouse and large plots in the field with their inherent uneven distribution of nematodes. In microplots, soil variability is reduced compared with large plots, unwanted nematodes can be eradicated with a nematicide, the desired nematode population can be introduced and increased to a high level on an efficient host plant, and the costs are less than for large field plots. In this way, promising material, which may nevertheless prove unsuitable, can be detected without undue investment of resources.

Cultural practices

Plots laid out for various IITA programs have been utilized to compare the response of nematodes to different cultural practices. These include (1) fallows, (2) rotation crops, (3) mulches, (4) intercropping, (5) cover crops, (6) alley cropping, (7) minimum tillage, (8) sanitation, and (9) trap crops. Details of the first seven of these are given in section 6 .

Other control methods

These include (1) physical control, e.g., heat, (2) chemical control, e.g., soil fumigants, (3) biological control, e.g., predatory fungi or antagonistic plants, and (4) plant quarantine regulations to prevent spread. Details of the first three of these methods are given in section VII.

IV. Observational studies

Numbers of nematodes in the soil

Nonparasitic nematode populations generally run at about 10,000 to 30,000 L^{-1} in tropical agricultural soils. Parasitic nematodes probably have an effect on crops when they exceed 500 L^{-1} of soil.

Since nematodes require moisture, they are more common in forest areas than in savanna. They are also numerous in irrigated areas in northern Nigeria.

The rotation plots of the IITA Root, Tuber, and Plantain Improvement Program were monitored for nematodes (Nematology Subprogram (NS) 1981). The weed fallows maintained root-knot, root-lesion, and spiral nematode populations through two growing seasons, although at relatively low densities (sampled in June and October). Nematode numbers remained at very low levels under different rotation crops: mucuna, leucaena, centro, and cowpea (cv TVu 1560, which is nematode-resistant).

A study of plant-parasitic nematodes at six sites in Burkina Faso, a project of the Semi-Arid Food Grains Research and Development (SAFGRAD) established the presence of root-lesion, stunt, annular, spiral, reniform, false spiral, and stubby root nematodes on maize, cowpea and yam (Table 3). Populations varied widely, but some plots showed high numbers (particularly of root-lesion, stunt, and annular nematodes) that could cause crop damage. Nonparasitic nematodes were low in number, except on the station at Kamboinse.

Nematode populations were counted in high and low yam mounds on hydromorphic soil (Table 4). Root-knot and spiral nematodes were found in all areas sampled, as well as in adjacent weed plots. Samples at harvest showed that the root-knot nematode had increased the most.

A 20ha site at Okomu-Odu (Bendel State) was monitored before the forest was cleared, and again under various treatments one year after clearance (Table 5). Nonparasitic nematodes were the most common forms (19,600 L^{-1} soil). Of the parasitic nematodes, the citrus nematode was the most numerous, with 386 L^{-1} soil, followed by the cyst nematode with 137. One year after clearance, juveniles of the root-knot nematode were the most abundant, followed by the root-lesion nematode (Table 6). However, the numbers were not damaging, except under traditional farming and under plantain, both of which treatments used vegetative planting material brought in from other areas. The other treatments were alley cropping, improved forestry, oilpalm, pasture, and cassava.

A maize plot in Block C-17 (IITA) was sampled for plant-parasitic nematodes in the soil (Table 7). There was an abundance of root-lesion nematodes for which maize is one of the host plants. Areas of either generally good or generally poor growth showed no significant differences in root-lesion nematode numbers. The highest number of root-lesion nematodes was recovered from a plot of tall, green maize (tag 36), which reflects tolerance of maize under irrigation and a good food supply for the nematodes. No root-knot nematodes were found, but they are poor competitors against root-lesion nematodes.

The maize plots in Block C-7 (IITA) were sampled for plant-parasitic nematodes (Table 8). All the plots contained the root-lesion nematode, and spiral and root-knot nematodes were encountered at very low densities. The numbers appeared to vary mainly according to location.

Table 3. **Survey of plant-parasitic nematodes (no. L^{-1} soil) at IITA/SAFGRAD sites in Burkina Faso, 1983 (*Source*: IITA 1983).**

Nematode[a]	Kamboinse	Saria (O)[b]	Saria (N)[b]	Pobre	Farako (S)[c]	Farako (T)[c]
Non-plant-parasitic	17,811	4438	2948	3005	3484	3410
Root-lesion	3,221	189	118	219	272	173
Stunt	2,347	467	186	246	4	-
Annular	7	724	158	-	-	-
Spiral	266	38	56	4	20	86
Reniform	134	-	-	38	-	203
False spiral	10	-	-	1	-	6
Stubby root	-	28	20	-	-	-
Total plant-parasitic	5,985	1446	538	508	296	468

[a] Root-lesion nematode = *Pratylenchus sefaensis*, *P. zeae*; stunt nematode = *Tylenchorhynchus nudus*, *Tylenchorhynchus* spp; annular nematode = *Tetylenchus annulatus*; spiral nematode = *Helicotylenchus pseudorobustus*, *Helicotylenchus* spp; reniform nematode = *Rotylenchulus reniformis*; false spiral nematode = *Scutellonema clathricaudatum*; stubby root nematode = *Trichodorus* spp.

[b] 0 = no nematicide applied; N = nematicide applied. [c] S = station; T = farm trials.

Table 4. **Plant-parasitic nematodes (no. L^{-1} soil) associated with white yam cultivation in high and low mounds on hydromorphic soil (*Source*: NS 1984).**

Nematode[a]	Sampling	High mounds			Low	Weeds	
	time	East	Center	West	mounds	Up valley	Down valley
Non-parasitic	preplant	4008	3340	4,035	4380	6,750	3328
	harvest	5718	7049	12,264	5994	11,212	4620
Root-knot	preplant	1	0.6	16	21	102	23
	harvest	48	9	559	-	4	-
Spiral	preplant	9	19	3	17	7	224
	harvest	11	-	17	-	4	707
Root-lesion	preplant	-	-	-	7	-	-
	harvest	-	-	-	-	88	-
Stylet	preplant	-	-	-	-	-	-
	harvest	-	-	-	-	328	-
Sheath	preplant	-	-	-	2	0.6	-
	harvest	-	-	-	-	-	-

[a] Root-knot nematode = *Meloidogyne* sp; spiral nematodes = *Helicotylenchus pseudorobustus*, *H. erythrinae*; root-lesion nematodes = *Pratylenchus sefaensis*, *P. brachyurus*; stylet nematode = *Tylenchorhynchus martini*; sheath nematode = *Hemicycliophora sp.*

Table 5. Nematodes (no. L^{-1} soil) under forest at Okomu-Odu, Bendel State, 1984 (*Source*: NS 1984).

Nematode	No	Nematode	No
citrus	386	rotoid	4
cyst	137	ring	2
pin	71	root-lesion	1
gracil	61	sheath	0.8
stylet	6	stubby root	0.8
spiral	5	dagger	0.2

Table 6. Plant-parasitic nematodes (no. L^{-1} soil) recovered from deforested plots at Okomu-Odu, November 1985 (*Source*: NS 1985).

Treatment	Non-parasitic	Parasitic[a]								
		CR	CY	DA	RL	RD	SP	SB	SY	RK
Forest control	4721	152	8	-	-	5	-	2	-	-
Traditional farming	9635	-	70	-	576	774	1	-	-	49
Alley cropping	7058	-		-	2	-	8	-	-	18
Improved forestry	3240	-	2	-	2	2	7	-	5	-
Oil palm	6786	-	-	2	-		5	-	-	19
Pasture	5139	3	-	-	-	2	2	-	-	5
Plantain	6175	-	-	-	3451	14	530	-	-	4928
Cassava	6999	-	-	-	-	-	2	-	-	7

[a] CR (citrus) = *Tylenchulus semipenetrans;* CY (cyst) = *Heterodera* spp; DA (dagger) = *Xiphinema nigeriense;* RD (rotoid) = *Rotylenchoides intermedius;* RL (root-lesion) = *Pratylenchus* spp; RK (root-knot) = *Meloidogyne* sp; SP (spiral) = *Helicotylenchus erythrinae, H. multicinctus, Helicotylenchus* spp; SB (stubby) = *Trichodorus* sp; SY (stylet) = *Tylenchorhynchus* sp.

Soil samples from alley cropping trials on farmers' fields near Ibadan were examined for plant-parasitic nematodes (Table 9). Of 16 samples, only one had damaging numbers of plant-parasitic nematodes.

The Hydromorphic Cropping System study of the Farm Management Market Garden, located in the Block A hydromorphic area (IITA), was sampled for the presence of plant-parasitic nematodes. Each treatment was a crop of rice, followed by one of five different crops, green manure, or fallow (Table 10). At the end of one year's cultivation, spiral and root-lesion nematodes were found in low numbers. Nonparasitic nematode populations were at relatively low levels.

The Irrigated Intensive Cropping Systems study in the same area was also sampled for the presence of plant-parasitic nematodes (Table 11). Each treatment was a rotation of three crops: two crops of rice followed by a crop of sweet potato, soybean, cowpea, green manure, vegetable, or mungbean. At the end of one year's cultivation, spiral, stunt, and reniform nematodes occurred in very low to trace numbers. Nonparasitic nematodes were at relatively low population levels.

Table 7. **Nematodes (no. L^{-1} soil) recovered from soil around the roots of maize in Block C-17, IITA, Ibadan, 15 May 1986 (*Source*: NS 1986).**

Sample site	Plot	Non-parasitic	Parasitic[a] Root-lesion	Spiral	Reniform
In-row	tag 36	5,661	13,653	-	-
	tag 84	3,330	5,994	-	-
	tag 187	13,986	5,661	-	-
	tag 327+	14,985	3,996	-	-
	tag 439	5,661	5,994	-	-
	mean	8,725	7,060	-	-
Between rows	tag 36+	5,328	666	83	-
	tag 84-	6,660	583	83	-
	tag 187+	8,325	749		
	tag 328-	2,498	83		
	tag 439+	3,996	5,661	-	83
	mean	5,361	1,548	33	17

[a] Root-lesion = *Pratylenchus sefaensis, P. brachyurus;* spiral = *Helicotylenchus pseudorobustus;* reniform = *Rotylenchulus reniformis.*

At the Onne high rainfall substation, near Port Harcourt, the following nematodes were found associated with crops: root-knot, root-lesion, burrowing, and banana spiral. In addition, cyst, dagger, lance, and sheath nematodes were found. Root-knot and cyst nematodes were found in soil under secondary forest (NS 1987/88).

Which species are associated with which crops?

Scientific names of the plants discussed in this section are given in Annex 2.

Root and tuber crops

Cassava. Root-knot nematodes, *Meloidogyne incognita* race 2 and *M. javanica*, are found associated with cassava. In an experiment in which two cultivars (Tme 30555 and Tme 30572) were inoculated with eggs of these root-knot nematodes, *M. javanica* was the more aggressive parasite on both cultivars when juvenile populations were high or very high (>1800 juveniles L^{-1}) (NS 1981).

Growth of cassava was investigated in microplots under two moisture regimes, nonirrigated and irrigated weekly during the dry season. The design was a randomized complete block, with 40 replications of each treatment. The cassava was planted in June into soil infested with root-knot nematode (*M. incognita* race 2) and reniform nematode (*Rotylenchulus reniformis*). Nematode populations were measured the following May, and were not significantly different under the two regimes. The cassava was harvested in August, and there was no significant difference between treatments for either top weight or storage root weight (NS 1988).

Cocoyam. Root-knot, root-lesion, and spiral nematodes have been reported on tannia. However, in one IITA trial, the root-knot nematode almost died out under tannia (Caveness et al. 1981).

Sweet potato. Root-knot nematodes, *M. incognita* and *M. javanica,* commonly attack feeder roots, and often disfigure storage roots.

Yam. Yam is attacked by the yam nematode and root-knot nematode, and also involved in a tuber decay complex. For the yam nematode, in descending order of resistance to attack, yam species are ranked *Dioscorea alata, D. rotundata,* and D. *cayenensis* (Caveness 1982). Cultivated *D. rotundata* had root-knot, spiral, root-lesion, reniform, and ring nematodes associated with it, but all were well below the damage threshold level (Table 12). However, numerous tubers showed cracking and disfigurement, symptoms of infection by the yam nematode, although the latter was not found in any soil samples or tubers.

Table 8. Plant-parasitic nematodes from soil and roots in Block C-7 maize plot, IITA, Ibadan, 17 June 1986 *(Source:* NS 1986).

Breeding line	Field no.	Soil nematodes[a]			Root nematodes [b]
		Root-lesion[c]	Spiral[d]	Root-knot[e]	Root-lesion[c]
K 8601	102	32,967	-	-	4
	101	8,658	-	-	2
TZi 10	1044	23,643	-	-	22
	2030	7,326	83	-	4
	3059	5,661	-	-	1
TZi 9	1006	19,331	-	-	9
	2002	4,995	-	-	4
	3057	3,996	-	-	1
KU 1414	3041	19,314	-	-	12
	2073	5,661	167	-	2
	1051	3,330	-	83	13
Ant C	1013	14,985	-	-	17
	3098	6,327	-	-	2
	2066	1,082	-	-	2
MOZOW	2058	12,321	-	-	25
	3005	6,660	-	-	2
	1091	667	-	-	1
TZi 30	3051	8,991	83	-	5
	1029	1,748	167	-	1
	2116	583	167	-	1

[a] No. L^{-1} soil. [b] No. g^{-1} root. [c] Root-lesion = *Pratylenchus sefaensis.* [d] Spiral = *Helicotylenchus pseudorobustus.* [e] Root-knot = *Meloidogyne* sp juveniles.

Table 9. **Soil nematodes (no. L^{-1} soil) in 16 samples of soil from farmer alley cropping trials, Ibadan *(Source:* NS 1986).**

Nonparasitic	Parasitic[a]		
	Spiral	Root-lesion	Root-knot
9,000	60	-	
6,000	40	-	40
6,500	60	-	60
10,000	-	-	1,500
4,750			
4,750	220	-	220
14,000			
9,000	-	-	60
10,000	180		
8,250	120	-	60
4,500	-	-	-
8,000	-	-	-
11,000	80		
6,000	40	-	40
1,500		40	-
3,750	40		-

[a] Spiral = *Helicotylenchus pseudorobustus;* root-lesion = *Pratylenchus sefaensis;* root-knot = *Meloidogyne* sp juveniles.

Table 10. **Soil nematodes associated with a crop rotation trial in the Block A hydromorphic area, IITA (no. L^{-1} soil, based on thirty $100cm^3$ samples per treatment) *(Source*: NS 1987/88).**

Rotation	Non-parasitic	Parasitic[a]	
		Spiral	Root-lesion
Rice - sweet potato	3397	8	14
Rice - vegetable	6435	46	8
Rice - green manure	3463	94	8
Rice - cowpea	2864	10	152
Rice - soybean	4138	18	10
Rice - sweet corn	3513	36	380
Rice - fallow	2922	12	82

[a] Spiral = *Helicotylenchus pseudorobustus;* root-lesion = *Pratylenchus sefaensis;* ring nematode, *Criconemoides* sp, occurred in trace amounts.

Table 11. Soil nematode population densities from the Intensive Cropping Systems study (irrigated) in the Block A hydromorphic area, IITA (no. L^{-1} soil, based on six $100 cm^3$ samples per plot for each of five replications) (*Source*: NS 1987).

Crop rotation	Non-parasitic	Parasitic[a]		
		Spiral	Stunt	Reniform
Rice - rice - sweet potato	3172	-	2	-
Rice - rice - soybean	3688	-	30	2
Rice - rice - cowpea	2939	2	-	-
Rice - rice - green manure	2240	22	-	-
Rice - rice - vegetable	3147	-	-	-
Rice - rice - mungbean	2897	4	39	-

[a] Spiral = *Helicotylenchus pseudorobustus*; stunt = *Tylenchorhynchus nudus*; reniform = *Rotylenchulus reniformis*.

Table 12. Plant-parasitic nematodes associated with white yam, advanced yield trial in block B-22, IITA, 1982 growing season (no. L^{-1} soil, based on 342 samples each of $100 cm^3$ of soil in each sampling period) (*Source*: NS 1982)

Time of sampling	Root-knot[a]	Spiral	Root-lesion	Reniform	Ring	Total
May	2.7	157	159	14	0.1	333
August	0.3	136	69	11	0.5	167
October	1.7	112	28	11	0.3	153

[a] Root-knot = *Meloidogyne* sp juveniles; spiral = *Helicotylenchus pseudorobustus;* root-lesion = *Pratylenchus sefaensis, P. brachyurus;* reniform = *Rotylenchulus reniformis;* ring = *Criconemoides* sp.

Legume crops

Cowpea. Cowpea is attacked by all root-knot nematode species known in Nigeria, and in all regions where cowpea is grown. *Meloidogyne incognita* and *M. javanica* are the most common (Caveness 1978). Reniform, root-lesion, and lance nematodes also occur. Altogether, 20 species have been reported on cowpea in Nigeria (Caveness and Ogunfowora 1985). Root-knot nematodes also predispose cowpea to infection by fungi and bacteria.

Lima bean. Spiral, root-lesion, and root-knot nematodes have been reported associated with lima bean (Badra and Caveness 1984).

Soybean. Soybean is heavily attacked by the four root-knot species found in the tropics. Cyst nematode and reniform nematode are also serious pests (Caveness 1982). It has been reported to be affected by spiral, root-lesion, and root-knot nematodes, causing chlorosis and stunting (NS 1986). Severely affected plants were a total loss.

Winged bean. Root-knot nematodes have been reported as associated with winged bean in Papua New Guinea (Duncan et al. 1979)

Cereal crops

Maize. High population levels of root-lesion, spiral, sting, reniform, and stunt nematodes have been reported on maize. At IITA, populations of one million root-lesion nematodes per plant have been observed (Caveness 1982). Root-knot nematodes were also observed, and trace numbers of dagger, ring, and yam nematodes (Caveness 1979b). Populations of nematodes increased with the amount of nitrogen fertilizer applied (Caveness 1982).

Rice. High populations of root-knot, root-lesion, and spiral nematodes have been found on upland rice at IITA. In one paddy, the sugarcane cyst nematode (a parasite of rice) was found in great numbers (Caveness 1982). Wet-niche nematodes have been monitored for a number of years at IITA (NS 1981, 1982, 1986, 1988):

- 1981: No plant-parasitic nematodes were recovered from 205 samples examined from the lakeshore and rice paddies at IITA. The sugarcane cyst nematode was found associated with rice roots in Block CH.

- 1982: The rice-root nematode was found for the first time at two locations (the lakeshore near the nursery and Block CH rice paddy). The sugarcane cyst nematode was again found in Block CH.

- 1986: In a more recently established paddy (EH), all categories of nematodes occurred in low numbers. Spiral and root-knot nematodes were the plant-parasitic nematodes found.

- 1987: All nematodes, including nonparasitic forms, were present in very low numbers. Spiral, root-knot, root-lesion, and reniform nematodes were found, but would not have been a limiting factor in rice production.

Other crops

Banana and plantain. These are hosts to several nematodes, especially burrowing, spiral, and root-knot (Caveness 1982). At IITA, a more serious pest to plantain was found to be the banana spiral nematode (*Helicotylenchus multicinctus*); it was tolerant to drought and survived the dry season in untreated soils (Badra and Caveness 1983). At Onne high rainfall substation, near Port Harcourt, the root-knot nematode was associated with 84% of the lines examined, and the banana spiral nematode with 27%, but at low population levels. The lance nematode occurred with 19% of the lines, at low levels also. The burrowing nematode was found in small numbers associated with four lines. Its presence is serious, as it is a major pest of plantain and banana in the tropics, but it has been found in Nigeria only once before (NS 1987/88).

Crop losses caused by nematodes

Root and tuber crops

Cassava. Losses throughout the tropics are estimated at 6%, equivalent to 6 million tons (Caveness 1982). A study was made of two cassava cultivars (TMe 30555 and TMe 30572) inoculated with root-knot nematodes (Caveness 1982). One month before planting, all microplots were treated with D-D mixture to eradicate all nematodes. Three weeks after cassava cuttings were planted, each plot was inoculated with 10,000 eggs of *M. incognita* race 2 or *M. javanica*. The cassava was harvested 15 months later. Soil sampling showed wide variation in populations of juvenile nematodes; six categories were distinguished, from "none" to "very high." In a study of storage root weight, "none" was taken as the control (100%); light parasitism by root-knot nematodes increased storage root weight slightly ("very low" 106%, "low" 104%); "medium" parasitism (600-1300 juvenile L^{-1} soil) decreased it to 83%; "high" parasitism (1800-2500 juveniles) decreased it to 50%; and "very high" parasitism (2800-5150 juveniles) reduced it to 2%. Stalk weight was similarly affected, but stalk height was not much reduced.

Cassava seedlings were also evaluated in greenhouse trials (Caveness 1982). Heavy infestations on some lines reduced plant height by as much as 52%, and caused a storage root loss of 87%.

Distribution and intensity of root-knot nematode infestation were studied in cassava plots on 26 farms near Ibadan and five cassava plots at IITA (Table 13). Root-knot nematodes were present in all the farm plots, and in four of the five plots at IITA. However, the percentage of plants infected and the severity of the disease were significantly lower at IITA, presumably because of strict adherence to a crop rotation program. Cassava grown in rotation suffered no yield loss, but ratooned cassava (for increase of planting stock) had a hypothetical yield reduction of 3%. On-farm cassava had an average decrease in yield per farm of 8%.

Cocoyam. In an experiment by Caveness et al. (1981) tannia was planted on land which had previously carried a cowpea crop and residual populations of root-knot nematode juveniles (*M. incognita* race 2) were measured. Corms were harvested after 14 months (Table 14). A visual estimate of vigor was also made. Where the initial population had been 5000 L^{-1}, corm weight was significantly ($P<0.05$) reduced. However, petiole length, lamina length, and number of suckers per plant were not significantly different. At harvest, the nematode population density for all treatments except the control was only 14 L^{-1}, indicating that the root-knot nematode could not maintain itself under tannia.

Sweet potato. A mean loss of 15% of yield of sweet potato has been reported for the tropics (Caveness 1982).

Yam. When a nonfumigant nematicide was used to control root-knot and root-lesion nematodes in yams, tuber yield was increased by 42-49%, and storage rot reduced by 14% (Caveness 1982).

Legume crops

Cowpea. Where root-knot nematodes are a problem, overall losses in the tropics are about 26% (Caveness 1982). In one study at Moor Plantation, Ibadan, grain yields were reduced on average by 59%; and control of the reniform nematode by soil fumigation increased yields by 23%. In pot experiments with root-knot nematodes, Olowe (1981) reported yield reductions of 25 and 94% for inoculation with 1000 and 80,000 second-stage juveniles kg^{-1} soil, respectively.

Soybean. Worldwide losses from root-knot nematodes are estimated at 11% (Caveness 1982). At IITA, two improved varieties showed poor growth due to stunted plants and chlorotic leaves. Spiral, root-lesion, and root-knot nematodes were recovered in quantity from the soil around plant roots. Various attributes of growth and yield—root weight, top weight, seed weight, weight per seed, top height, pods per plant, seeds per pod and seeds per plant—were all seriously affected (NS 1986). Grain yield losses are given in Table 15.

Winged bean. Four lines of winged bean were exposed to infestation of root-knot nematode (*M. incognita* race 2) and reniform nematode (*R. reniformis*) in concrete microplots and grown for 120 days during the dry season (Caveness 1980). Seed yield and number of seeds per plant showed decreases under both nematode species (Table 16).

Cereal crops

Maize. A grain loss of 20% due to nematodes has been reported in Panama. Control of root-lesion nematode in Zimbabwe resulted in a yield increase of 33%. When root-lesion nematodes were controlled by soil fumigation in a field trial at Agege Research Station, Nigeria, maize showed a yield increase of 27%. However, in a trial at IITA, fumigation of the soil gave no significant increase in yield (Table 44). Other investigations at IITA and University of Ibadan showed that high populations of the root-lesion nematode could cause economic losses. Nematode problems were more severe under maize monoculture than in mixed cropping with grain legumes (Caveness 1982).

Table 13. Survey of local farm and IITA cassava plots for root-knot nematodes (*Meloidogyne* spp), 1983 (*Source*: IITA 1983).

	26 farms	IITA increase plots	IITA plots under rotation
Plots with root-knot (%)	100	100	80
Infested plants (% of all examined)	80	46	2
Infested plants below threshold (%)[a]	73	70	100
Infested plants above threshold (%)[a]	27	30	0
Percentage of plants suffering hypothetical yield loss of:			
1 to 25%	17	24	0
26 to 50%	4	3	0
51 to 75%	2	3	0
76 to 100%	4	0	0
Mean yield loss per plant (%)	31	20	0
Mean yield loss per farm (%)	8	3	0

[a] A previous study indicated the threshold for yield reduction to be 544 nematodes L^{-1} soil.

Table 14. **The effects of root-knot nematode *(Meloidogyne incognita* race 2) on yields of tannia *(Xanthosoma mafaffa)* *(Source:* Caveness et al. 1981).**

Initial population (juveniles L^{-1})	Mean corm weight[a] (kg)	Visual estimate of vigor (%)
0	4.0	100
800	3.5	76
1500	3.2	75
2500	4.2	86
5000	1.8	50

[a] The values for 5000 nematodes L^{-1} is significantly different ($P = 0.05$) from the remaining values in the column.

Table 15. **Percentage losses in grain yield for soybean showing various degrees of stunting and chlorosis due to nematodes *(Source:* NS 1986).**

Stunting and chlorosis	Var. 1	Var. 2
Severe	100	100
Moderate	86	81
Light	48	71
None	0	0

Table 16. **Percentage changes after 120 days of various growth attributes of winged bean infested with two species of nematode *(Source:* Caveness 1980).**

	Root-knot nematode	Reniform nematode
Aggregate seed yield	-11	-4
Dry weight of top	-10	+21
No. seeds per plant	-13	-14
Weight per seed	+4	+12
No. pods per plant	-4	0

Rice. The world-wide loss caused by the root-knot nematode alone is given as 25%, and paddy rice losses due to nematodes have been reported at 25% (Caveness 1982). A study at Moor Plantation, Ibadan, showed that root-knot and cyst nematodes caused a reduction of 52% in plant growth. At IITA, a yield loss of 25% was prevented by soil fumigation, which controlled the spiral nematode (Caveness 1982).

Other crops

Banana and plantain. At IITA, a trial on chemical control of root-knot and spiral nematodes showed that oxamyl increased plantain yield by 99% and carbofuran increased it by 62% (Table 17).

Celosia. Growth was significantly retarded in soil infested with root-knot nematode. At harvest, all plants grown in infested soil were significantly reduced in height and weight, compared with plants grown in soil fumigated with D-D mixture at 400L ha^{-1} (Table 18).

Table 17. The effect of plant-parasitic nematode control by nematicides on plantain growth and marketable fruits (means of eight replications of one tree each) (*Source:* Caveness and Badra 1980).

Treatment	Height increase[a] (cm)	Sucker ht (cm)	Circumference increase[a] (cm)	No. fingers[b] (no. $bunch^{-1}$)	Bunch wt[b] (kg)
Oxamyl 10G	145	118	15	30 a	15.5 a
Carbofuran 10G	133	102	13	26 b	12.6 b
Oxamyl liquid	115	75	12	25 b	10.4 c
Nil (control)	112	68	10	20 c	7.8 d

[a] Height or circumference increase represents the difference in the measurements taken at the beginning of the trial and at harvest.

[b] Values within a column followed by the same letter are not significantly different ($P = 0.01$).

Table 18. Growth of *Celosia argentea* in fumigated soil and in soil infested with root-knot nematode (Caveness and Wilson 1977) *Source*: Caveness and Wilson (1977).

Treatment	Plant ht (cm)	Top wt (g $plant^{-1}$)	Root wt (g $plant^{-1}$)	Root-knot index
Fumigated soil	102	270	50	0.0
Infested soil	38	47	10	2.9

[a] Root-knot index: 0 = no gall formation; 4 = heavy gall formation.

V. Resistant host varieties

The food crops that are studied at IITA have been screened for nematode resistance, but success has been limited. Scientific names of these crops are given in Annex 2.

Root and tuber crops

Cassava. Seed from IITA yield trials was bulked, and tested in pots in the greenhouse to determine resistance or susceptibility to root-knot nematodes. All 190 seedlings tested were highly susceptible to *M. incognita* race 2. A root-knot index for gall development (5 = maximum galling) averaged 4.6 (Caveness 1978).

Cocoyam. All 21 lines of cocoyam tested showed high resistance to root-knot nematodes *(M. incognita* race 2 and *M. javanica)* and the reniform nematode *(R. reniformis)* (NS 1982). Cocoyam is no longer part of the IITA mandate.

Sweet potato. At IITA, 414 lines of sweet potato were screened in greenhouse tests; 55 lines were found to be resistant to root-knot nematodes *(M. incognita* race 2 and *M. javanica)* (IITA 1982). Sweet potato is no longer part of the IITA mandate.

Yam. Three species of yam (as 2-month-old seedlings) were greenhouse tested, for resistance to root-knot nematode. *Dioscorea dumetorum* was highly resistant, but *D. praehensilis* and *D. rotundata* were highly susceptible, with heavy galling of roots and tubers (Caveness 1979a).

Cultivar Abi of the white yam *(D. rotundata)* showed light galling from root-knot nematodes *(M. incognita* race 2 and *M. javanica)* and also some reproduction of reniform and root-lesion nematodes. No attack was reported on the other lines tested: TDr 819, TDr 820, TDr 821, TDr 830, TDrs/4001-C226, RI 8-60-300, and RM 7-3-168 (NS 1982).

Legume crops

Cowpea. At IITA, 421 lines of cowpea were tested in the greenhouse for resistance to root-knot nematode. Four lines were resistant, and 28 were moderately resistant (Caveness 1982). A later study confirmed good resistance in five lines of cowpea (Zannou 1981). The line TVu 1190E was identified as a single plant from an original collection, TVu 1190, from eastern Kenya. It was labelled VITA-3, since it is resistant to leafhoppers and several diseases, as well as to the root-knot nematode (Singh 1980).

A further 116 lines were screened for resistance to the root-knot nematode, *M. incognita* race 2. One hundred lines were highly susceptible (Annex 3) while 16 lines were moderately resistant (Table 19).

Lima bean. Ten lines of lima bean showed moderate resistance to the root-knot nematode *M. incognita* race 2, but another 277 lines were susceptible or highly susceptible (Caveness 1978).

Seven lines were screened for resistance to root-knot nematode in the screenhouse (NS 1986). Moderate resistance was shown by four lines (White ventura V, Small bush, Morris, and Lee), but the test was regarded as suspect, and needs repeating. Lima bean is no longer included in the grain legume program at IITA.

Soybean. None of the soybean germplasm tested at IITA has shown the high degree of resistance to root-knot nematodes necessary for use in a breeding program (Caveness 1982).

Table 19. Moderately resistant cowpea lines as determined by greenhouse screening trials using the root-knot nematode, *Meloidogyne incognita* race 2 (*Source*: NS 1985).

Cowpea line	Root-knot index[a]	Egg count ('000 $plant^{-1}$)	R value[a]
IT81D-1151	3.0	2	0.8
IT83D-213	0.0	1	0.7
IT83D-344-1	4.6	3	0.9
IT83D-375	0.0	1	0.9
IT83S-513-2	3.0	1	0.6
IT83S-555-4	0.0	1	0.4
IT83S-672-10	0.0	1	0.9
IT83S-680-9	0.0	1	0.9
IT83S-692-1	0.0	1	0.9
IT83S-724-10	3.8	1	0.3
IT83S-728-5	4.2	1	0.4
IT83S-861	0.0	1	0.6
IT83S-875	0.0	3	0.9
IT83S-911	0.0	1	0.9
IT83S-945	0.0	1	0.9
IT83S-951	0.0	2	0.8

[a] Root-knot index: 0 = no gall formation; 5 = heavy gall formation.
[b] $R = P_f/P_i$, where R is the rate of reproduction, P_i is the initial population (number of eggs in the inoculum) and P_f is the final egg count.

Winged bean. All lines of winged bean tested by Duncan et al. (1979) were susceptible or highly susceptible to the two root-knot nematodes *M. incognita* race 2 and *M. javanica*. The former appears to be the more aggressive pathogen on winged bean. The root systems of all inoculated plants were badly damaged and storage root formation was restricted in a 180-day trial. Winged bean is no longer included in the grain legume program at IITA.

Cereal crops

Maize. Selected maize breeding lines were inspected for the presence of root-lesion nematodes with the aim of identifying germplasm that could be used in a breeding program for nematode resistance (Table 20). Root-lesion nematodes were recovered in moderate numbers from soil around maize roots, and in smaller numbers from maize roots themselves.

However, there were no significant (P =0.05) differences in the populations for either the roots or associated soil, indicating that no maize line had an inherent resistance.

Table 20. Root-lesion nematode[a] numbers in soil and roots of maize, Block C, IITA, 1987 (*Source*: NS 1988).

Maize	Nematodes in roots (no. g^{-1})	Nematodes in soil (no. L^{-1})
IK.83 TZSR-W-1	32	7,248
EKO.83 TXSR-Y-1	8	8,658
EV.8443-SR	56	6,577
EV.8429-SR	88	7,659
KAMB(1)83 TZUT-W	155	4,829
ACR.84 TZESR-W	104	8,991
IK.84 POOL 16	197	3,663
DMR-ESR-W	52	12,737
8322-13	52	7,659
8428-19	52	6,910
8425-8	55	11,655
8505-12	87	3,996

[a] Root-lesion nematodes = *Pratylenchus sefaensis* and *P. brachyurus* (1% or less).

VI. Cultural practices

Fallows

Population densities of nematodes have been found to decline by 85% within two months of clearing bush and forest cover, with some species disappearing altogether (Caveness 1972). Subsequently, at each cropping the populations increased, although they declined slightly during the fallow period between crops. The species that increased were mainly root-lesion, root-knot, and spiral nematodes. The root-lesion nematode was rarely found prior to cropping, but became the dominant species (96%) after four plantings of maize.

Under the traditional farming system of shifting cultivation, various nematode species are able to survive, albeit in small numbers. Modern farming practices favor certain species, while other species decline (Caveness 1982).

Monitoring of weed fallow plots at IITA showed all plant-parasitic nematode populations to be at innocuous levels at the end of the crop year (IITA 1983). Elephant grass, often recommended as a rotation crop for increasing soil organic matter content, maintained populations of root-knot, root-lesion, and stunt nematodes.

Leucaena fallow. At sites previously planted to cowpea, rice or maize, 3000-24,000 parasitic nematodes L^{-1} soil were found before fallow. After 3-12 years under a leucaena (*Leucaena leucocephala)* fallow, the numbers of plant-parasitic nematodes were drastically reduced (Table 21). When the fallow was replaced by alley cropping, the parasitic nematodes remained very low, compared with a crop of maize alone (Table 22). This suggests that cropping systems based on a planted leucaena fallow could have the added benefit of controlling nematodes.

Mucuna fallow. Five blocks, previously under cassava, cowpea or soybean, were put under mucuna (*Mucuna utilis)* fallow at the beginning of the rains. Soil samples were collected in July, October and November. Nonparasitic nematode populations were moderate, and did not change much (Table 23). The spiral nematode was the only parasitic species to increase to moderate levels under mucuna (Table 24). The root-lesion nematode was maintained at a low level, root-knot juveniles were not found after the July sampling and false spiral and reniform nematodes were found only in trace numbers. Screenhouse pot tests showed that the root-knot nematode was maintained on mucuna at a very low level, but at high levels on cowpea and weeds (Tables 25 and 26).

Weed fallow. Under a weed fallow after seven cropping seasons of maize, the root-lesion nematode was reduced (Tables 38 and 40).

Rotation crops

Following six continuous crops of maize (3 years), the use of pigeonpea, soybean, or cowpea as a rotation crop greatly reduced the soil population of root-lesion nematode. The root-knot nematode was also reduced (more so under the tilled regime), but the spiral nematode tended to increase under the tilled regime and decrease under no tillage (Tables 38 and 40).

When potential rotation crops were grown for six months in nematode-infested soil following *Celosia argentea*, the total parasitic nematode population was reduced to approximately 10-30% (Table 27). After six months, root-knot nematodes (*M. incognita* juveniles) were reduced to negligible numbers under all the legumes except *Arachis prostrata* and *Psophocarpus palustris*, and under all the grasses, other crops, and clean weeding, but were maintained under *Celosia argentea*. The spiral nematode (*H. pseudorobustus*) was reduced under *Arachis hypogaea*, *A. prostrata*, *Psophocarpus palustris*, *Pueraria phaseoloides*, *Stylosanthes gracilis*, *Vigna unguiculata*, *Digitaria decumbens*, and *Amaranthus hybridus*, but maintained under the others. The root-lesion nematode (*P. sefaensis*) was initially at low levels; these remained similar (or were slightly reduced) under all the crops except *Crotalaria juncea*, where it significantly increased (Wilson and Caveness 1980).

Table 21. Plant-parasitic nematode populations under a soil regeneration fallow of *Leucaena leucocephala* (no. L^{-1} soil, based on thirty $100cm^2$ soil samples) (*Source*: NS 1984).

Leucaena site	Years of fallow	Nonparasitic	Parasitic[a]		
			Spiral	Root-lesion	Root-knot
BN-lake	12	12,500	47	-	-
B-2	8	1,318	26	-	-
B-3	8	2,458	3	-	-
B-5	4	3,625	3	-	-
D-8	3	5,420	0.4	-	-
D-11	3	4,990		12	0.4
D-14-6	3	4,775	1.2	0.8	0.4
D-14-9	3	4,853	0.4	29	-

[a] Spiral = *Helicotylenchus pseudorobustus*, *H. erythrinae*; root-lesion = *Pratylenchus sefaensis*, *P. brachyurus*; root-knot = *Meloidogyne* spp.

Table 22. Plant-parasitic nematodes (no. L^{-1} soil) under a *Leucaena leucocephala*-based alley cropping system (*Source*: IITA 1984).

Treatment	Nonparasitic	Parasitic		
		Spiral	Root-lesion	Root-knot
Leucaena ratooned	9000	123	4	127
Leucaena-maize alley cropped	7120	186	49	235
Maize only	8438	1170	4551	5721

Tannia reduced soil populations of root-knot nematode juveniles (*M. incognita* race 2), and this crop could therefore be used in rotations for control of this nematode (Caveness et al. 1981).

Table 23. Non-parasitic nematodes (no. L^{-1} soil) recovered from soil under a mucuna mulch on three dates (*Source*: IITA 1984).

Plot	Jul	Oct	Nov
EE-16	3,763	4,296	2,375
EE-17	2,514	2,964	7,493
EE-18	2,647	6,727	6,577
EE-24	7,826	7,426[a]	25,308[a]
EC-1	12,521	5,828	3,164
ES-8	4,729	6,377	12,737
Mean	5,667	5,238	6,469

[a] Cowpea replaced mucuna, and value was not used in calculation of the mean.

Table 24. Parasitic nematodes (no. L^{-1} soil recovered from soil under a muncuna mulch on three sampling dates (*Source*: NS 1988).

Plot	Spiral nematodes			Root-lesion nematodes			Root-knot juveniles		
	Jul	Oct	Nov	Jul	Oct	Nov	Jul	Oct	Nov
EEC-16	22	165	319	1	11	0	1	0	0
EE-17	13	178	619	0	1	0	0	0	0
EE-18	15	104	373	2	15	0	0	0	0
EE-24	7	18[a]	937[a]	11	18[a]	937[a]	7	94[a]	728[a]
EE-1	51	265	120	478	118	0	7	0	0
ES-1	14	62	161	16	114	132	0	0	0
Mean	20	155	318	85	52	26	2	0	0

Note: Trace numbers of false spiral (*Scutellonema clathricaudatum*) and reniform (*Rotylenchulus reniformis)* were found, in addition to those for which data are presented.

[a] Cowpea replaced mucuna, and value was not used in calculating the mean.

Table 25. Juvenile root-knot nematodes (no. L^{-1} soil) in a screenhouse pot test (*Source* NS 1988).

Treatment	Jun 1986	Nov 1986	Mar 1987
Mucuna	400	11	0
Cowpea	250	16	11
Weeds	93	53	18

Table 26. Root-knot nematode root gall index and average number of eggs per pot in a screenhouse pot test (*Source*: NS 1988).

Treatment	Root-Knot index[a]	Eggs (no. pot^{-1})
Mucuna	0.0	50
Cowpea	5.0	12,500
Weeds	0.0	16,400

[a] Root-knot index: 0 = no gall formation; 5 = heavy gall formation.

Table 27. Plant-parasitic nematode soil populations before and after six months' growth of selected rotation crops (*Source*: Wilson and Caveness 1980).

Plant species	Root-knot[a]		Spiral[b]		Root-lesion[c]		All parasites[d]	
	B	A	B	A	B	A	B	A
Legumes								
Arachis hypogaea [e]	21	0	243	28	0	0	264	28
Centrosema pubescens [e]	51	0	332	127	2	0	385	127
Desmodium triflorum[e]	220	0	410	120	5	1	635	121
Indigofera subulata[e]	82	0	323	125	50	60	455	185
Pueraria phaseoloides[e]	180	0	239	24	110	27	520	51
Leucaena leucocephala[f]	549	0.1	340	118	20	8	909	126
Stylosanthes gracilis[f]	687	0.4	287	36	2	5	976	41
Crotalaria juncea[f]	498	0.5	259	199	4	412	761	611
Vigna unguiculata TVu1190[e]	96	10	242	42	9	32	347	84
Arachis prostrata[e]	301	132	425	26	10	6	736	164
Psophocarpus palustris[e]	345	199	263	12	0	38	608	249
Grasses								
Cynodon nlemfuensis IB-8[f]	533	0	229	188	11	11	773	199
Digitaria decumbens[f]	658	0	344	88	11	5	1013	93
Paspalum notatum[f]	359	0.6	247	164	0	3	606	168
Miscellaneous								
Amaranthus hybridus[f]	440	3	289	76	4	5	733	84
Tagetes patula [f]	413	4	420	130	4	7	937	141
Controls								
Celosia argentea large plots[e]	263	198	375	215	60	34	698	447
Celosia argentea small plots[f]	593	442	358	312	2	2	953	756
Clean weeded[f]	538	0.5	331	173	2	1	871	174

Note: B = sampling before rotation crops planted; A = sampling after six months's growth of rotation crops.

a Root-knot = *Meloidogyne incognita* juveniles only.

b Spiral = *Helicotylenchus pseudorobustus*.

c Root-lesion = *Pratylenchus sefaensis*.

d All parasites, including trace numbers of *Scutellonema clathricaudatum, Xiphinema ifacolum, Rotylenchulus reniformis and Criconemoides* sp.

e Based on four replications of six observations each; sample size was 200 cm^3 of soil.

f Based on nine replications of six observations each; sample size was 200 cm^3 of soil.

Table 28. Soil nematodes (no. L^{-1} soil) associated with maize cultivation under a mucuna mulch trial (*Source:* NS 1986).

Treatment	Nonparasitic		Parasitic[a]			
			Spiral		Root-lesion	
	May	Aug	May	Aug	May	Aug
Mulch	6613	8,424	145	224	74	3757
No mulch	7497	11,202	5	26	874	2685

[a] Spiral = *Helicotylenchus pseudorobustus;* root-lesion = *Pratylenchus sefaensis, P. brachyurus.*

Mulches

Twenty-two different mulches were investigated in 1975 and 1976, but the interactions of mulch, host plant, and nematodes were too complex to analyze (NS 1976).

In a subsequent experiment, numbers of nematodes in soil under mulched and unmulched maize plots were determined. Mulched plots were planted with mucuna which remained through the dry season; no-mulch plots were planted to cowpea, then lay fallow through the dry season. Root-lesion nematodes were 29% more numerous in plots under mulch than in plots with no mulch. The spiral nematode occurred in low numbers in 97% of the mulched plots, and 13% of the no-mulch plots. The mean number of nonparasitic nematodes was slightly greater in the no-mulch plots (Table 28).

In a study of mulching and staking with white yam, mulch treatments were black and white plastic, and rice straw. No-mulch treatments were with and without stakes for the vines to climb on. Root-lesion, root-knot, and spiral nematodes occurred, but in low numbers. No clear changes were observed under the different treatments (NS 1986).

In an experiment on pawpaw, mulching with sawdust combined with chemicals was included as a treatment. The mulched plots tended to have higher numbers of reniform nematodes (NS 1988).

Intercropping

In the third year of a mixed cropping study, using a cassava-based system, samples were collected on 20 Apr (preplanting), 1 Sep (mid-wet season) and 11 Nov (dry season). Spiral, root-lesion and root-knot nematodes occurred in all plots. However, as in the two previous years of the trial, populations of plant-parasitic nematodes were less than the threshold level for crop damage. This suggests that multiple cropping, coupled with the effects of the dry season, was restricting the pathogens to a low density (Table 29). The root-knot nematode usually competes poorly with the root-lesion nematode, and was present in low numbers. It is also susceptible to desiccation and was not found in the dry season sampling (Table 30).

Egunjobi et al. (1986) studied the interaction between root-knot nematode (*M. javanica*) root-lesion nematode (*P. sefaensis*) and reniform nematode (*R. reniformis*) on two cultivars of cowpea and one of maize (Farz 27), grown alone and in association. They used a split-plot design, having nematode treatments in the main plots and cropping treatments in the subplots. Nematode treatments were the three species alone and all possible combinations. Cropping treatments were cowpea cv Ife BPC (C1), cowpea cv Ife brown (C2), maize (Mz), Mz + CI, and Mz + C2.

Seven days after planting, each plant was inoculated with 2000 root-knot nematodes and/or 2000 root-lesion nematodes, in addition to the natural soil populations of reniform nematodes (100 L^{-1} soil). The experiment was terminated 14 weeks after planting, with the following results.

Table 29. Seasonal nematode population densities (no. L^{-1} soil) in a root crop + legume + maize intercrop system (*Source*: NS 1988).

Season	Nonparasitic	Parasitic[a]		
		Spiral	Root-lesion	Root-knot
Jul 1985	4248	412	670	15
Aug 1986	4241	233	413	28
Dec 1986	2891	58	3	5
Apr 1987	1683	157	21	13
Sep 1987	4081	56	225	13
Nov 1987	1521	34	1	0

Spiral = *Helicotylenchus pseudorobustus*; root-lesion = *Pratylenchus sefaensis;* root-knot =*Meloidogyne* sp juveniles.

Table 30 Plant parasitic nematodes recovered from soil in a root crop + legume + maize intercrop system, 1987 (no. L^{-1} soil, based on fifteen 100 cm^3 soil samples in each of four replications) (*Source*: NS 1988).

Systems[b]	Non-parasitic			Spiral			Parasitic[a]					
							Root-lesion			Root-knot		
	Apr	Sep	Nov	Apr	Sep	Nov	Apr	Sep	Nov	Apr	Sep	Nov
Cs	1086	2835	874	25	42	21	2	77	1	2	5	
M - Cp	2527	3351	2031	138	89	28	38	190	3	61	23	0
Cs + M	998	4679	1561	23	61	48	9	582	2	2	5	0
Y + Cp	1902	7626	2289	419	24	14	39	126	0	2	2	0
Cs + M	1886	2847	1211	196	78	19	20	77	0	4	18	0
Cs + M + GM	1748	3147	1161	139	41	76	15	299	0	7	27	0

[a] Spiral = *Helicotylenchus pseudorobustus;* root-lesion = *Pratylenchus sefaensis*; root-knot = *Meloidogyne* sp juveniles; *Rotylenchulus reniformis* and *Criconemoides* sp occurred in trace numbers.

[b] Cp = cowpea; Cs = cassava; M = maize; Y = yams; GM = green manure.

Root-lesion nematode numbers were highest under maize and lowest under cowpea. Root-knot and reniform nematode populations were highest under cowpea and lowest under maize. Populations were intermediate under mixed cultures of maize and cowpea.

For cowpea roots, root-lesion and reniform nematodes were significantly reduced by intercropping with maize. Higher populations of root-knot nematodes were maintained by Ife Brown than by Ife BPC. For maize roots, root-knot and reniform nematodes were present in significantly larger numbers when maize was grown with cowpea than when it was the sole crop; root-lesion nematodes were not affected. For cowpea, lowest yields were associated with the root-knot nematode, especially when present alone, but also in combination with root-lesion and reniform nematodes. Highest yields were associated with root-lesion and/or reniform nematodes (Table 31). No significant differences occurred between cowpea yields from sole and intercropped cowpea, although intercropping increased the weight and height of cowpea plants (Table 32). For maize, lowest yields were associated with the root-lesion nematode, especially when present alone, but also in combination with root-knot and/or reniform nematodes. Highest yields were associated with the root-knot, or the reniform nematode, or both (Table 33). Maize grain yields were significantly improved by intercropping with cowpea, by up to 11% (Table 34). The conclusion from the study was that it should be possible to use intercropping to help control nematodes.

Cover crops

In one experiment at IITA (NS 1976) nine different "live mulches" were grown for a period of 24 months. Treatments were *Stylosanthes gracilis*, *Centrosema pubescens*, *Pueraria phaseoloides*, *Paspalum notatum*, *Mucuna utilis*, *Brachiaria ruzizensis*, *Cynodon nlemfuensis* IB-8, *Psophocarpus palustris*, and weed cover (control). The nematodes found were: spiral (*Helicotylenchus pseudorobustus*, *H. cavenessi*), root-lesion (*Pratylenchus sefaensis*, *P. brachyurus*) and root-knot (*M.eloidogyne incognita*). Populations under all mulches declined to approximately one-third of preplanting means. Root-knot nematode was reduced under all the mulches except *Psophocarpus palutris* where it increased. Root-lesion nematodes were reduced by several mulches, of which *Centrosema pubescens* was the best. Spiral nematodes were reduced most by *Psophocarpus palustris*, and *Stylosanthes gracilis*, and to a lesser extent by *Pueraria phaseoloides* and *Centrosema pubescens*.

Table 31. Cowpea growth attributes as influenced by nematode treatments (means of 12 replicates) (*Source*: Egunjobi et al. 1986).

Nematodes[a]	Grain yield ($g\ plant^{-1}$)	Root wt ($g\ plant^{-1}$)	Shoot wt ($g\ plant^{-1}$)	Pod (no. $plant^{-1}$)	Seed (no. pod^{-1})	Pod ($g\ plant^{-1}$)	Plant ht (cm)
P+R	15.8	65	184	11.3	14.3	17.5	135
R	14.9	68	190	11.3	14.1	17.0	157
P	14.3	67	197	10.5	13.8	16.0	130
M+R	6.6	95	151	4.8	11.2	7.9	104
M+P	6.4	104	163	5.8	10.8	7.7	100
M+P+R	6.1	90	141	4.8	10.3	7.1	98
M	4.6	122	147	4.4	10.2	5.3	88
LSD (5%)	0.9	5	18	0.6	0.4	0.8	2

[a] M = *Meloidogyne javanica* (root-knot nematode); P = *Pratylenchus sefaensis* (root-lesion nematode); R = *Rotylenchulus reniformis* (reniform nematode).

Table 32. Cowpea growth attributes in mixed and monocultures of maize and cowpea (means of 21 replicates) (*Source*: Egunjobi et al. 1986).

Crops[a]	Grain yield (g plant^{-1})	Pod (g plant^{-1})	Seed (no. pod^{-1})	Pod (no. plant^{-1})	Shoot wt (g plant^{-1})	Root wt (g plant^{-1})	Plant ht (cm)
C2	10.1	11.4	12.4	8.0	185	88	120
Mz + C2	9.9	11.3	12.0	7.7	196	93	135
Mz + C1	9.7	11.0	12.1	7.6	149	86	110
C1	9.5	11.1	12.0	7.5	141	82	100
LSD (5%)	0.5	ns	ns	ns	2	8	9

Note: ns = differences not statistically significant ($P = 0.05$).

[a] C1 = cowpea cv Ife BPC; C2 = cowpea cv Ife brown; Mz = maize cv Farz 27.

Table 33. Maize growth attributes as influenced by nematode treatments (means of 12 replicates each) (*Source*: Egunjobi et al. 1986).

Nematodes[a]	Grain yield (g plant^{-1})	Root wt (g plant^{-1})	Shoot wt (g plant^{-1})	Plant ht (cm)
M	95	122	377	184
R	94	118	367	195
M + R	93	126	408	187
P + R	82	83	290	163
M + P	76	103	337	177
M + P+ R	76	76	286	173
P	63	65	284	160
LSD (5%)	8	8	25	2

[a] M = *Meloidogyne javanica* (root-knot nematode); P = *Pratylenchus sefaensis* (root-lesion nematode); R = *Rotylenchulus reniformis* (reniform nematode).

Table 34. Maize growth attributes in maize cropped alone or intercropped with cowpea (means of 21 replicates) (*Source*: Egunjobi et al. 1986).

Crops[a]	Grain yield (g plant^{-1})	Root wt (g plant^{-1})	Shoot wt (g plant^{-1})	Plant ht (cm)
Mz + C1	88	104	341	179
Mz + C2	82	100	339	180
Mz	79	94	327	171
LSD (5%)	5	5	10	2

[a] C1 = cowpea cv Ife BPC; C2 = cowpea cv Ife Brown; Mz = maize cv Farz 27.

In a second experiment *C. pubescens* was used as a cover crop on plots in Block A south vegetable garden terrace. Root-knot, spiral, root-lesion, and ring nematodes were found in the soil prior to planting and all increased under the cover crop (Table 35). This may have been due to the poor establishment of the cover crop, allowing broad-leaved weeds to become dominant, and negating the suppressive influence of the cover crop.

Table 35. **Plant-parasitic nematodes associated with *Centrosema pubescens* fallow in the south vegetable garden (means of 99 samples, each of 100 cm^3 soil) (*Source*: NS 1982).**

Sampling time	Root-knot[a]	Spiral[b]	Root-lesion[c]	Ring[d]
May	24	89	373	1.7
Oct	41	201	940	32
x increase	1.7	2.3	2.5	18.8

[a] Root-knot = *Meloidogyne* sp juveniles.
[b] Spiral = *Helicotylenchus pseudorobustus.*
[c] Root-lesion = *Pratylenchus sefaensis and P. brachyurus.*
[d] Ring = *Criconemoides* sp.

Alley cropping

Alley cropping has been proposed as a stable, low input substitute for the traditional bush fallow or slash-and-burn system of farming. The trees used in the hedgerows are *Gliricidia sepium, Alchornea cordifolia, Leucaena leucocephala* and *Acioa barteri.* At the suggestion of the Farming Systems Program, nematode populations were monitored after four years of alley cropping trials (NS 1985). In 1985, root-lesion, root-knot, and spiral nematodes occurred in low numbers in the soil under both hedgerows and alleys. Ring and dagger nematodes were present, but only in trace numbers. Nonparasitic nematodes were low, suggesting a reduction in the general biotic activity of the soil (lowest under *A. barteri*).

The following year similar results were reported (NS 1986). Maize was the first season crop (sampling in August), and cowpea the second season crop (sampling in November). In 1987, numbers of parasitic nematodes were still low in terms of their potential to damage crops (NS 1988). A possible exception was the root-lesion nematode, which became moderately high under maize. Rotation of crops and the dry fallow periods appear to be effective in controlling nematode populations (Table 36).

The vegetable alley cropping system in the IITA Farm Management Market Garden Block A was also monitored. Before planting, spiral, root-lesion, and false-spiral nematodes were present in low numbers. Leucaena leaves and small branches were used as mulch in the plots with hedgerows. Six, 12, and 18 months after the start of the trial, root-knot nematodes were also found, but in very low numbers. Under cultivation, nonparasitic nematodes declined, for both the leucaena and the control plots (Table 37). Plant-parasitic nematodes were not a factor in this trial, and no population trends developed under the leucaena mulch treatment or the vegetable crop rotations used (NS 1986, 1988).

Table 36. **Three-year grand means for soil nematodes (no. L^{-1} soil) recovered from hedgerows and alley crops in 1985, 1986, and 1987 (*Source*: NS 1986).**

Period	Nonparasitic		Parasitic[a]					
	Hedge	Alley	Root-lesion		Root-knot		Spiral	
			Hedge	Alley	Hedge	Alley	Hedge	Alley
Sep 1985	4642	4758	90	223	64	0.4	35	30
Aug 1986	4044	4151	94	241	42	6	54	33
Nov 1986	7016	7025	36	231	65	9	43	40
Aug 1987	3545	3430	192	1040	9	1	30	54
Nov 1987	1273	1030	2	5	0	0	18	9

[a] Root-lesion = *Pratylenchus sefaensis*, *P. brachyurus*; root-knot = *Meloidogyne* sp juveniles; spiral = *Helicotylenchus pseudorobustus*; trace numbers of reniform nematode, *Rotylenchulus reniformis*, were also present.

Table 37. **Seasonal variation in nematode numbers (no. L^{-1} soil in the leucaena + vegetable plot at the IITA block A market garden (*Source*: NS 1985, 1988).**

Season	Nonparasitic		Parasitica							
			Spiral		Root-lesion		False spiral		Root-knot	
	L	C	L	C	L	C	L	C	L	C
Oct 1985[b]	11,896	12,173	90	45	0.8	2.9	0.8	0.3	0	0
Apr 1986	5,721	5,074	215	409	0.8	5.8	0.08	0.08	3.8	9.5
Oct 1986	5,627	4,714	147	174	7	50	2	0	4	2
Apr 1987	2,649	1,286	120	92	2.3	7	0	0	7.7	0

Note: L = leucaena mulch plot; C = control (no mulch).

[a] Spiral = *Helicotylenchus pseudorobustus*; lesion = *Pratylenchus sefaensis*; false spiral = *Scutellonema clathricaudatum*; root-knot = *Meloidogyne* sp juveniles; trace numbers of reniform nematode, *Rotylenchulus reniformis*, were also present in Oct 1986.

[b] Preplant sampling.

Minimum tillage

After seven consecutive cropping seasons of maize (3.5 years), root-lesion nematode: (*Pratylenchus* spp) were five times more numerous in conventionally tilled soils than in non tilled soils (Table 38). For the roots the difference was threefold (Table 39). The spira nematode (*Helicotylenchus pseudorobustus*) and the root-knot nematode (*Meloidogyn incognita*) were more numerous in non-tilled than in tilled soils, by 6:1 and 3.5: respectively, but at much lower population densities than the root-lesion nematodes. Afte 13 consecutive cropping seasons of maize, results were similar (Table 38).

Under various rotation crops (especially cowpea) following maize, root-lesion and root-knot nematodes were reduced in the soil, the reduction being proportionately greater under the tillage regime. Only cowpea reduced soil populations of the spiral nematode (Table 40). Numbers of nematodes recovered from the roots of the rotation crops are given in Table 41. In practical terms, population densities were low.

In a fumigation trial, numbers of the root-lesion nematode in the soil were lowest under no-tillage combined with fumigation (Table 42). The numbers of this nematode in the roots of maize were reduced by fumigation, but there was little difference between tilled and untilled regimes (Table 43). However, for nonfumigated soil, the number in the roots under the tilled regime was almost double that under no-tillage. Grain yields under the different regimes were not significantly different (Table 44).

Table 38. Plant-parasitic nematodes (no. L^{-1} soil) recovered from soil around roots of maize grown under till and no-till regimes (*Source*: Caveness 1965, 1979b).

No. cropping seasons	Root-lesion[a]		Spiral[b]		Root-knot[c]	
	Till	No-till	Till	No-till	Till	No-till
7[d]	21,480	4078	171	1075	235	825
7[e]	4,148	956	139	665	13	267
13[f]	19,114	3750	169	175	22	56

[a] Root-lesion = *Pratylenchus sefaensis and P. brachyurus.*
[b] Spiral = *Helicotylenchus pseudorobustus.*
[c] Root-knot = *Meloidogyne incognita* juveniles.
[d] Based on 120 samples of 200 cm^3 soil each.
[e] Based on 200 samples of 115 cm^3 soil each.
[f] Based on 80 samples of 115 cm^3 soil each.

Table 39. Plant-parasitic nematodes recovered from roots of maize grown under till and no-till regimes for seven consecutive cropping seasons (no. g^{-1} root tissue based on 120 samples of 5g) (*Source*: Caveness 1975b).

Treatment	Root-lesion[a]	Spiral[b]	Root-knot[c]
Till	5111	0.00	0
No-till	1629	0.08	124

[a] Root-lesion = *Pratylenchus* spp.
[b] Spiral = *Helicotylenchus pseudorobustus.*
[c] Root-knot = *Meloidogyne incognita* juveniles.

Table 40. **Plant-parasitic nematodes recovered from soil around roots of rotation crops following seven consecutive cropping seasons of maize grown under till and no-till regimes (no. L^{-1} soil based on 120 samples of 200 cm^3 soil for each crop) (*Source*: Caveness 1975b).**

Rotation crop	Root-lesion[a]		Spiral[b]		Root-knot[c]	
	Till	No-till	Till	No-till	Till	No-till
Pigeon pea	1155	395	160	435	0	25
Soybean	1695	745	415	340	25	75
Cowpea	5	55	10	115	0	35
Weed fallow	231	31	556	150	0	19
Mean	772	307	285	260	6	39

[a] Root-lesion = *Pratylenchus* spp. [b] Spiral = *Helicotylenchus pseudorobustus*.
[c] Root-knot = *Meloidogyne incognita*.

Table 41. **Plant-parasitic nematodes recovered from roots of rotation crops grown following seven consecutive cropping seasons of maize grown under till and no-till regimes (no. g^{-1} root tissue, based on 120 samples of 5 g for each crop) (*Source*: Caveness 1975b).**

Rotation crop	Root-lesion[a]		Spiral[b]		Root-knot[c]	
	Till	No-till	Till	No-till	Till	No-till
Pigeon pea	4	25	0.2	0.7	0	0
Soybean	8	47	8	19	28	41
Cowpea	30	10	0	5	8	14
Weed fallow	68	13	5	10	10	0.6
Mean	28	24	3.3	8.7	11	14

[a] Root-lesion = *Pratylenchus* spp. [b] Spiral = *Helicotylenchus pseudorobustus*.
[c] Root-knot = *Meloidogyne incognita*.

Table 42. **Root-lesion nematodes (*Pratylenchus* spp) recovered from soil under till vs no-till and fumigated vs nonfumigated soil treatments (no. L^{-1} soil, based on 160 samples of 200cm^3 soil for each treatment).**

Treatment	No tillage soil		Tilled	
	Preplant	77 DAP[a]	Preplant	77 DAP[a]
Fumigated	53	390	52	1,390
Nonfumigated	2225	1598	2632	12,818

[a] DAP = days after planting

Table 43. **Root-lesion nematodes (*Pratylenchus* spp) recovered from roots of maize grown under till vs no-till and fumigated vs nonfumigated soil treatments.**

Treatment	No tillage		Tilled	
	14 DAP[ac]	77 DAP[bc]	14 DAP[ac]	77 DAP[bc]
Fumigated	5	3262	0.4	3,004
Nonfumigated	42	6004	6	10,124

[a] Mean number of nematodes per seedling, based on 30 plants per treatment.

[b] Mean number of nematodes per gram of root, based on 30 samples of 5g each per treatment.

[c] DAP = days after planting.

Table 44. **Grain yield (kg ha^{-1}) of maize grown under till vs no-till and fumigated vs nonfumigated soil treatments (six replicates of for each treatment; plot size $28m^2$) (*Source*: Caveness 1979b).**

Treatment	No tillage	Tilled
Fumigated	1974	2070
Nonfumigated	2067	2440

No significant differences ($P = 0.05$).

VII. Other control methods

Physical control (by heat)

In an on-farm experiment, the practice of slash-and-burn did not control nematodes (Caveness 1982). The farm site had an average of 352 nematodes L^{-1} soil at clearing. After burning, the average was 76 L^{-1}. However, at the time of planting 40 days later, the density was 705 L^{-1}. Heat did not affect the nematodes at depth (10 to 20cm deep, depending on the species).

However, burning of wood over seedbeds kills most nematodes to a depth of 30-40cm. Recent research using solar heat trapped under black plastic sheets suggests that nematode control over larger areas is feasible (NS 1984).

In a test of the tolerance of white yam to dry heat, temperatures of 45-55°C for 20-60 minutes were not found to be detrimental to survival of yam tubers (NS 1981).

Seed yams may be treated with warm water to control infestation by root-knot, root-lesion, and yam nematode. Three clones (TDr 179, TDr 291 and TDr 747) were tested by being steeped in water at 50°C for 40 minutes, or 55°C for 30 minutes. The tubers were harvested in December, treated in February, and planted in June, when all were still sound (NS 1988).

Chemical control

Fumigation of the soil reduced populations of the root-lesion nematode (Table 42).

Root and tuber crops

A toxicity test of carbofuran was conducted on various root-crops (NS 1981). At rates up to 32 kg ai ha^{-1}, it was not toxic to cassava cv 30572, white yam cv Nwapoko, water yam, sweet potato cv TIb 4, or two cocoyams *(C.olocasia esculenta* cv TCe-44 and *Xanthosaoma mafaffa* cv TXS-17).

Yam. Seed-pieces of greater yam *(D. alata)* were treated with chemicals for disinfestation of the yam nematode *(Scutellonema bradys)*. The seed-pieces were steeped in 1000 ppm aqueous solutions of nematicides, nitrogenous fertilizers, or disinfectants for 30 minutes. The treatments effectively controlled nematode infection and tuber damage. Shoot emergence was not affected by D-D, oxamyl, or calcium nitrate; but was reduced 14% by ammonium sulphate, and 29% by carbofuran or formalin. After 6 months growth (in the greenhouse) mean weights of tuber were all significantly increased, with the best yields from tubers treated with formalin, carbofuran, and D-D. Untreated seed-pieces had reduced tubers and dry rot (Badra and Caveness, 1979).

The efficacy of oxamyl as a non-fumigant nematicide in controlling damage caused by root-knot nematode *(Meloidogyne javanica)* and root-lesion nematode *(Pratylenchus brachyurus)* to white yam was investigated under field and storage conditions. Infection of yams by these nematodes in the field affects the survival of tubers in storage, and threatens the maintenance of yams as vegetatively propagated clones. Populations of both nematodes in the yam root and tuber biosphere increased greatly during the growing season in untreated controls. Oxamyl 10 G applied at the rate of 6 kg ai ha^{-1} as row treatment was most effective

Table 45. Effects of oxamyl alone and in combination with nitrogenous fertilizers on tuber yield, quality, and sprouting of yam (*Source*: Badra et al. 1980).

Treatment[a] and rate (ai ha^{-1})	Application method and no. of 4-week intervals	Tuber yield ($t\ ha^{-1}$)	Tuber rotting in storage %	Tuber sprouting in storage (%)	Tuber sprouting in the field (%)
Single treatments:					
Oxamyl L 3kg	Foliar, 3	28.8	44	32	74
Oxamyl L 6kg	Foliar, 3	26.6	41	18	76
Oxamyl G 3kg	Row, 3	24.0	45	38	84
Oxamyl G 6kg	Row, 3	25.7	38	29	79
Combined treatments:					
Oxamyl L 2kg +Oxamyl G 2kg +Oxamyl L 2kg	Set steeping[b]; Row, 1;1 Foliar, 1	19.9	54	32	75
Oxamyl G 3kg + CN[c] 180kg N	Row[b]; Row, 3	33.651	23	76	
Oxamyl G 3kg + AS[d]m180kg N	Row[b]; Row, 3	32.0	42	34	79
Untreated control		22.654	28	79	
LSD (5%)		5.311.6	7	ns	

Note: ns = not significant ($P = 0.5$) [a] L= liquid; G = granular. [b] At planting. [c] CN = calcium nitrate. [d] AS = ammonium sulphate.

in the control of the root-knot nematode, whereas oxamyl 24L at 6 kg ai ha^{-1} as a foliar spray was most effective against the root-lesion nematode. Tuber yields increased by 49% and 42% over untreated controls, where granular oxamyl at 3 kg ai ha^{-1} was combined with calcium nitrate or ammonium sulphate at 180 kg ha^{-1} N, respectively. In 4 months of storage after harvest, 54% of tubers from untreated control plots rotted, compared with 38% from the best nematicide treatment. Thenematicide slightly increased sprouting in storage, but did not reduce emergence of tubers after planting out the following growing season (Table 45).

Legume crops

Cowpea. Plots of cowpea cv Prima were treated with DDT against insects (Badra and Caveness 1984). Over a period of 8 cropping seasons (4 years), there was no significant change in nematode populations, whether root-knot *(Meloidogyne incognita)*, root-lesion *(Pratylenchus sefaensis, P. brachyurus)* or spiral *(Helicotylenchus pseudorobustus)* (NSR 1976).

Lima bean. Two cultivars of lima bean were planted in late June, and two weeks later, four granular nematicides were separately applied at 2.5 kg ai ha^{-1}. There was also an untreated control. The cultivars were Taiwan acc. 1066 (susceptible to *Meloidogyne javanica*) and Davis white (resistant). The nematicides were aldicarb (A), carbofuran (C), miral (M), and oxamyl (O). The numbers of spiral (*Helicotylenchus microcephalus*), root-knot (*Meloidogyne javanica*), and root-lesion (*Pratylenchus sefaensis*) nematodes were determined monthly. Pods were harvested (from Davis white only) in September and October.

Treatment with C and A significantly increased seed yields, but M and O were not significantly different from the control (Table 46). M and A were most effective in controlling spiral and root-knot nematodes on either cultivar. However, against the root-lesion nematode, M was best for Taiwan, and O for Davis white. M and A caused alterations in species interactions of the three nematodes, but C was passive. Spiral nematode was more influenced by rainfall than the other two.

Table 46. Effect of nematicides on yield (t ha^{-1}) of lima bean cv Davis white, 1979 (plot size: $4.5m^2$) (*Source*: Badra and Caveness 1984).

Treatment (2.5kg ai ha^{-1})	First harvest 21 Sep	Second harvest 8 Oct	Total seed yield
Carbofuran	1.26 a	0.89 a	2.15 a
Aldicarb	1.26 a	0.83 b	2.09 a
Miral	1.06 b	0.72 b	1.78 a
Oxamyl	0.95 b	0.68 b	1.63 b
Nil (control)	0.92 b	0.54 b	1.46 b

Values within a column followed by the same letter are not significantly different ($P = 0.05$).

Cereal crops

Maize. Maize was grown at five levels of nitrogen fertilizer and treated with carbofuran (Furadan® 3G) for insect and nematode control (Ballaux et al. 1975). Carbofuran at 10mg ai $plant^{-1}$ in capsular form was applied with the seed. There was a second treatment five weeks after planting. The highest mean yields for nitrogen plus carbofuran were 5.1t ha^{-1} for Yellow C and 4.1t ha^{-1} for TZBC-3. The number of usable ears per 100 plants was not affected by carbofuran treatment but was increased from 75 to 90 with the first 50kg ha^{-1} N applied. Total stand per plot was not affected by nitrogen levels but was increased by 11 and 15% by one or two capsules of carbofuran, respectively. Numbers of soil nematodes, or of a mixed population of *Pratylenchus sefaensis* and *P. brachyurus* were not affected by carbofuran. There was a slight but consistent increase of *Pratylenchus* spp within roots with increased nitrogen.

Also for maize, root-lesion nematodes were controlled by soil fumigation (D-D mixture) equally well in tilled and untilled soil (Table 42). However, fumigation did not result in increased grain yield (Table 44). Carbofuran (16 kg ha^{-1}) did not control root-lesion nematodes on maize (Caveness 1982).

Rice. One variety of upland rice showed a yield increase of 25% when the spiral nematode was controlled by soil fumigation (Caveness 1982).

Other crops

Plantain. For plantain (*Musa* AAB cv Agbagba), nematode control was tested using oxamyl and carbofuran, at 3g ai $plant^{-1}$ early in the rainy season, followed after 4 months by another application at 1.2g ai $plant^{-1}$. Treatment appreciably reduced nematode populations, and significantly increased vigor and yield of plantain. In nontreated soils, both spiral nematodes *(Helicotylenchus multicinctus)* and root-knot nematode *(Meloidogyne javanica)* juveniles increased or decreased, depending on the amount of rainfall (Caveness and Badra 1980).

The effect of aldicarb, with and without gibberellic acid (GA), was studied on plantains infested with spiral and root-knot nematodes (Badra and Caveness 1981). The planting date was early March 1979. The treatments were applied to the plantains grown in field microplots and consisted of three sprays of GA at 150, 300, and 450 ppm; two soil treatments of aldicarb at a total of 3g ai $tree^{-1}$; and combinations of GA and aldicarb. GA 10WP was sprayed on the foliage (150ml $tree^{-1}$) in July, September, and October. Aldicarb (Temik® 15G) was incorporated into the soil in September and October. The plants grew under natural rainfall until early December and were irrigated weekly during the dry season. The trial was terminated in April 1980.

The two higher rates of GA alone increased height and number of developing suckers (significant at $P = 0.05$). Aldicarb alone markedly increased the height and girth, number of developing suckers, and induced plants to flower and fruit earlier (Table 47). With GA alone, nematode populations in the soil tended to be above the untreated level, while aldicarb alone, or in combinations with GA, was relatively suppressive. At the end of the trial, under GA alone at 450ppm, root-knot nematodes had declined to low numbers in the soil (from 500 to 25 $100g^{-1}$ soil), but spiral nematodes had increased to peak numbers (from 25 to 500 $100g^{-1}$ soil). Thus, aldicarb controlled the spiral nematode better than the root-knot. Root-knot nematode infestation was higher than that of spiral nematode in roots. Nematode densities in soil fluctuated with rainfall during the wet season. The number of spiral nematodes was negatively correlated with monthly rainfall ($r = -0.86^{*}$) and number of rainy days per month ($r = -0.88^{**}$), whereas number of root-knot nematodes was positively correlated with rainfall ($r = 0.54$) and number of rainy days ($r = 0.42$). The residual effects of GA on root populations were striking 8 weeks after the last treatment (Dec 1979) but had little prolonged effect 20 weeks thereafter (Mar1980).

Chemical treatment of plantain was further studied by Badra and Caveness (1983). Four nonfumigant nematicides were applied three times during the wet season, in different sequences. The nematodes were aldicarb (A), carbofuran (C), miral (M), and oxamyl (O). The sequences were 2, 3, and 2g ai $tree^{-1}$ in Mar, Jul and Oct (I); and 3, 2, and 2g ai $tree^{-1}$ in Mar, Jun and Sep (II).

Table 47. Effect of gibberellic acid (GA) and aldicarb alone and in combination, on growth rate of plantain (means of four replications of one tree each; planted in early March 1979) *(Source:* Badra and Caveness 1981)

Treatment: ppm (GA) or g ai tree^{-1} (AD)	8 Jan 1980				21 Mar 1980			
	Ht incr[a] (cm)	Circ. incr[a] (cm)	Leaves (no. tr^{-1})	Suckers (no. tr^{-1})	Ht incr[a] (cm)	Circ. incr[ab] (cm)	Leaves (no. tr^{-1})	Suckers (no. tr^{-1})
GA 150	63.2	15.0*	6.0	0.3	65.7	16.0	7.0	0.7
GA 300	67.7*	13.0	6.7	1.7*	76.0*	14.0	7.0	1.7
GA 450	66.3*	14.3	6.8	2.0*	76.8*	16.4	8.0	2.8*
AD 3	63.0	16.5*	7.4	3.4*	82.8*	18.0*	7.9	3.8*
GA 150 + AD 3	50.0	13.0	6.6	1.2	60.0	16.0	7.0	2.0
GA 300 + AD 3	53.9	12.0	6.1	1.3	61.0	15.0	6.7	1.7
GA 450 + AD 3	70.4*	15.6	6.8	1.5	78.5*	17.2	7.8	2.5
Nil (control)	53.3	11.2	5.8	0.8	58.1	14.0	6.1	1.5

[a] Height and circumference increase represents the difference in the measurements taken at the beginning
of the trial and stated date.
[b] Circumference increase at 25 cm.
* Significantly different from untreated control ($P = 0.05$).

Sequence I gave better control of root-knot nematode *(Meloidogyne javanica)* than sequence II. Sequence II was more effective against the spiral nematode *(Helicotylenchus multicinctus)*. By the end of two seasons, the effectiveness of the nematodes was in the order A (most effective), C, O, and M (Table 48). The largest yield increases over controls were 97% for C, sequence II; 90% for A, II; 78% for A, I; and 70% for O, II. Sequences I and II were significantly different for A and C, but not for M and O. Nematode populations fluctuated with rainfall and dropped to low (spiral nematode) or undetectable (root-knot juveniles) levels during the dry season. Since the spiral nematode is maintained even in very dry soils, sequences of application should be aimed at the spiral rather than the root-knot nematode, and rainfall patterns should be considered in designing control strategies.

Pawpaw. A trial was carried out in the IITA farm market garden using telone and carbofuran at different rates (NS 1988). Sampling was carried out in Apr 1986, Jan 1987, and Oct 1987. The reniform nematode became the dominant parasitic species in Jan; the spiral, root-lesion, and root-knot nematodes had declined in population by Jan, and were only present as trace numbers in Oct. Nonparasitic nematodes had also declined by Oct. Field observations strongly suggested that the principal cause of decline for all nematodes was excessive soil moisture; the soil in trial area was waterlogged by the end of the rainy season, and many pawpaw trees showed signs of distress. The number of fruit per tree and fruit weight per tree were not significantly different from the control in any treatment. It appears, therefore, that nematode parasitism was not a limiting factor in this trial.

Table 48. Influence of application sequence on efficacy of nematicide treatments on plantain production (marketable fruit) (means of six replications of one tree each) (*Source*: Badra and Caveness 1983).

Nematicide	Application sequence[a]	Bunch weight[b] (kg)	Yield increase over untreated (%)
Aldicarb 15%G	I	17.3 a	78
	II	18.5 b	90
Carbofuran 10%G	I	15.3 a	58
	II	19.1 b	97
Miral 10%G	I	14.0 a	44
	II	15.1 a	56
Oxamyl 10%G	I	14.6 a	50
	II	16.5 a	70
Nil (control)		9.7 c	

[a] Sequence I: 2, 3, and 2 g ai $tree^{-1}$ in March, July, and October.Sequence II: 3, 2 and 2 g ai $tree^{-1}$ in March, June, and September.

[b] Values within a column followed by the same letter are not significantly different (P=0.05).

Biological control

Nematode-destroying fungi

Nematode-destroying fungi belonging to several genera were isolated from soil and litter at IITA. Certain genera of predatory fungi (*Trichothecium*, *Dactylaria*, *Dactylella*, and *Arthrobotrys*) possess trapping devices, while other, nonpredatory kinds (*Verticillium*, *Meristacrum*, and *Haposporium*) infect the nematodes and produce spores (IITA 1984). However, the possibility of using fungi for biological control has not been studied.

Antagonistic plants

In the USA, asparagus had been found to be antagonistic to certain plant parasitic nematodes. A trial was carried out in the IITA market garden using cucumber and tomato, with asparagus as hedgerows between the vegetables (NS 1988). The vegetable plots (alleys) were of various widths (75cm, 150cm, 225cm) and the crops planted at different distances from the asparagus. However, no antagonistic effect was observed. Root-knot, reniform, spiral, and root-lesion nematodes were distributed randomly in the soil. After 26 months, the reniform nematode was most common. Final numbers of root-knot juveniles in the soil were moderate to low, but the gall index on cucumber roots was high in all treatments. Spiral and root-lesion nematodes were at low (nondamaging) levels, and were not affected by the asparagus, nor were the nonparasitic nematodes.

VIII. Future research needs

Nematodes are persistent in the soil. Weeds, shrubs and trees can support maintenance populations of plant-parasitic nematodes indefinitely. Nematodes can also increase within two years to levels that cause damage to the more susceptible hosts. Therefore, sustainable agriculture is not possible without imposing control measures on parasitic nematodes. Effective control practices requiring only low inputs include plant resistance and cultural methods. These take time to develop and the effort should be continuous to have the cultivars and practices available as land-use becomes increasingly intensive in Africa. Each IITA crop improvement program should have its own nematologist, analogous to the staffing pattern for entomologists and plant pathologists. Crop systems should be investigated by a nematologist in the Resource and Crop Management Program. He would need plenty of well-qualified support staff because of the large amount of sampling and microscopy involved.

Cassava. Further work is needed on varieties resistant to root-knot nematode. A broader germplasm base should be explored, including wild species of *Manihot*. To date, germination of hybrid seed has been poor.

Yam. Host-parasite relationships should be studied. There is a complex relationship between the yam nematode and yam tuber-rot. *Dioscorea rotundata* and *D. cayenensis* need further investigation, including greenhouse and tissue culture screening for resistance, nematode culture maintenance, and pathogenicity studies.

Cowpea. There should be further testing of varieties resistant to the root-knot nematode; and screening for resistance to reniform nematode. The role of other nematode parasites should be studied.

Soybean. Further screening for resistant varieties is needed, and host-parasite relationships should be worked out.

Maize. Relationships of nematodes to maize are not well understood - high nematode populations do not always result in yield losses, and control does not always result in a yield increase. Host-parasite relationships of the root-lesion nematode need to be studied, also ecological factors and the role of mixed cropping systems.

Rice. All phases of rice and nematode interactions need study.

Banana and plantain. Priority should be given to basic studies on the role of nematodes in these crops.

Farming systems

Priority should be given to studies on crop rotations, cover crops, soil management schemes, nematode population dynamics, effects of organic and inorganic fertilizers, and effects of nematode control agents.

Other studies

1. Economic effects of nematode problems.
2. Germplasm base of some crops to be broadened and screened.
3. Biology of tropical nematodes.
4. Collation of data on host range and distribution of nematode species.
5. Fundamental study of newly identified races of root-knot nematodes.
6. Taxonomy of African nematodes.
7. Role of nonparasitic nematodes in nutrient balance and recycling.

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Crop plants mentioned in this report (in alphabetical order by common name)

Common name	Scientific name
Banana	*Musa* spp
Cassava	*Manihot esculenta* Crantz
Celosia	*Celosia argentea* L.
Cocoyam (tannia)	*Xanthosoma mafaffa* Schott (syn X. sagittifolium (L.) Schott)
Cocoyam (taro)	*Colocasia esculenta* (L.) Schott
Cowpea	*Vigna unguiculata* (L.) Walp.
Lima bean	*Phaseolus lunatus* L.
Maize	*Zea mays* L.
Plantain	*Musa* spp
Pigeonpea	*Cajanus cajan* (L.) Millsp.
Pawpaw	*Carica papaya*
Rice	*Oryza* spp
Soybean	*Glycine max* Merrill
Sweet potato	*Ipomoea batatas* (L.) Lam.
Winged bean	*Psophocarpus tetragonolobus* (L.) DC.
Yam, greater	*Diocorea alata* L.
Yam	*Dioscorea cayenensis*
Yam	*Dioscorea dumetorum* (Kunth) Pax
Yam	*Dioscorea praehensilis* Benth.
Yam, white guinea	*Dioscorea rotundata* Poir

Annex 2.

Nematodes mentioned in this report (in alphabetic order by common name)

Common name	Scientific name
Annular nematode	*Tetylenchus annulatus*
Banana spiral nematode	*Helicotylenchus multicinctus*
Burrowing nematode	*Radopholus similis*
Citrus nematode	*Tylenchulus semipenetrans*
Cyst nematode	*Heterodera* spp
Dagger nematode	*Xiphinema ifacolum*
	Xiphinema nigeriense
False spiral nematode	*Peltamigratus* spp
	Scutellonema clathricaudatum
Gracil nematode	
Lance nematode	*Hoplolaimus* spp
Needle nematode	*Longidorus* spp
Pin nematode	*Paratylenchus* spp
Reniform nematode	*Rotylenchulus reniformis*
Rice-root nematode	*Hirschmannia oryzae*
Ring nematode	*Criconemoides* spp
Root-knot nematode	*Meloidogyne arenaria* (2 host races)
	Meloidogyne hapla (1 host race)
	Meloidogyne incognita (4 host races)
	Meloidogyne javanica (1 host race)
	Meloidogyne spp
Root-lesion nematode	*Pratylenchus brachyurus*
	Pratylenchus sefaensis
	Pratylenchus zeae
	Pratylenchus spp
Rotoid nematode	*Rotylenchoides intermedius*
Sheathoid nematode	*Hemicriconemoides* spp
Sheath nematode	*Hemicycliophora* spp
Sting nematode	
Spiral nematode	*Helicotylenchus erythrinae*
	Helicotylenchus microcephalus
	Helicotylenchus multicinctus
	Helicotylenchus pseudorobustus
	Helicotylenchus spp
	Peltamigratus nigeriensis

Stubby root nematode	*Trichodorus* spp
Stunt nematode	*Tylenchorhynchus nudus*
	Tylenchorhynchus spp
Stylet nematode	*Tylenchorhynchus martini*
Sugarcane cyst nematode	*Tylenchorhynchus* spp
Yam nematode	*Scuttellonema bradys*
No common name	*Aphasmatylenchus*
	Caloosia
	Dolichodorus
	Telotylenchus
	Trichotylenchus
	Trophurus

Annex 3.

One hundred highly susceptible cowpea lines, with root-knot index ranging from 2.5 to 5.0, egg count per plant ranging from 2000 to 260,000, and R value ranging from1.2 to 79

IT81D-709	IT81D-897	IT81D-975	IT81D-994	IT81D-1032
IT81D-1137	IT81D-1228-14	IT82D-511-3	IT82D-513-1	IT82D-513-5
IT82D-663	IT82D-703	IT82D-744	IT82D-752	IT82D-786
IT82D-789	IT82D-885	IT82D-889	IT82D-927	IT82D-952
IT82D-378	IT82E-18	IT82E-32	IT83D-198	IT83D-205
IT83D-206	IT83D-210	IT83D-216	IT83D-217	IT83D-219
IT83D-221	IT83D-229	IT83D-235	IT83D-237	IT83D-320-10
IT83D-326-2	IT83D-328-1	IT83D-328-3	IT83D-328-4	IT83D-328-5
IT83D-336-1	IT83D-338-1	IT83D-340-5	IT83D-356-1	IT83D-357-8
IT83D-374	IT83D-379	IT83S-321-3	IT83S-325-1	IT83S-339-13
IT83S-344-4	IT83S-346-2	IT83S-346-5	IT83S-380-5	IT83S-418-3
IT83S-495-1	IT83S-495-5	IT83S-497-5	IT83S-519-2	IT83S-581-1
IT83S-590-1	IT83S-606-1	IT83S-677-6	IT83S-681-2	IT83S-683-3
IT83S-687-15	IT83S-689-4	IT83S-719-3	IT83S-720-2	IT83S-723-2
IT83S-723-4	IT83S-725-9	IT83S-725-15	IT83S-725-18	IT83S-728-3
IT83S-728-4	IT83zS-728-10	IT83S-728-13	IT83S-728-14	IT83S-742-1
IT83S-742-2	IT83S-742-11	IT83S-742-13	IT83S-775-4	IT83S-793
IT83S-801	IT83S-853	IT83S-878	IT83S-881	IT83S-883
IT83S-891	IT83S-899	IT83S-927	IT83S-928	IT83S-929
IT83S-979	IT83S-988	TVx 3236	TVx 3236-6-1	Ife Brown

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