PLANT-PARASITIC NEMATODES ASSOCIATED WITH MAIZE, SORGHUM AND PEARL MILLET AND INTERACTIONS OF *Pratylenchus brachyurus* WITH MAIZE AND SORGHUM IN THE NIGERIAN SAVANNAS

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A Desertation submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (CROP PROTECTION)

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DECLARATION

I hereby declare that this desertation has been written by me and that it is a record of my research work. It has not been presented before in any previous application for higher degree.

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CERTIFICATION

This thesis entitled PLANT-PARASITIC NEMATODES ASSOCIATED WITH MAIZE, SORGHUM AND PEARL MILLET AND INTERACTIONS OF *Pratylenchus brachyurus* WITH MAIZE AND SORGHUM IN THE NIGERIAN SAVANNAS meets the regulations governing the award of the degree of DOCTOR OF PHILOSOPHY of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to my late lovely wife, Mary, for her love, support and understanding during the period of this study.

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ABSTRACT

This study was undertaken to determine the identity, distribution and economic importance of plant-parasitic nematodes associated with maize, sorghum and pearl millet. Subsequently, the population dynamics of one of the most important nematodes was studied in order to develop management strategies for the nematode.

Twenty genera of plant-parasitic nematodes, occurring in varying frequencies and populations in farmers' fields were found associated with maize, sorghum, and pearl millet. Cluster analysis classified the nematodes into three broad groups. Group I, comprised nematodes that occurred frequently and usually of high population. Group II, consisted of nematodes that were not widely distributed and occurred usually in low numbers while Group III, was made up of nematodes of occasional occurrence and usually in very low numbers. Out of the twenty nematode genera, six genera, viz.; *Helicotylenchus, Tylenchus, Pratylenchus, Scutellonema, Aphelenchoid.es* and *Hoplolaimus* appeared to be the most important on account of the frequency of their occurrence, and population densities.

Further analysis on the pattern of distribution/and or association of the nematodes in the various fields resulted in eight field groups, the nematode populations of each genera varying from field to field. This suggests a close

relationship (interaction) between nematode species and field conditions. The cropping systems in the field were found to influence nematode occurrence and population densities. Maize-based systems were particularly found to favour the distribution and population densities of most nematode species compared to systems dominated by sorghum, millet, and legumes.

Out of the six nematode genera rated as important in this study, *Pratylenchus brachyurus* was selected and some detailed studies conducted on maize and sorghum. P. *brachyurus* was shown to be pathogenic on both maize and sorghum resulting in significant reduction in plant growth. This reduction was however more for maize than sorghum.

Results of the study on effect of different population densities of P. *brachyurus* on maize showed that all growth parameters were reduced at all populations tested when compared to the check. Nematode invasion reached a maximum at a density of 2000 nematodes and declined thereafter.

The reaction of thirteen maize cultivars to P. *brachyurus* was studied in the screenhouse. None of the cultivars was found to be resistant. Nematode multiplication was highest in improved cultivars especially hybrids.

Studies on the population dynamics of the nematode in June sown maize showed that P. *brachyurus* infected maize as soon as roots emerged. Populations increased rapidly and reached a maximum in roots and soil in early September and late August, respectively.

Economic importance of *P. brachyurus* was determined by treating infested field with furadan 3G at 2.0 kg a.i/ha. Pre-plant (about 300 nematodes/500 ml soil) populations were significantly reduced resulting in a yield increase of about 38%.

CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], and pearl millet [*Pennisetum glaucum* (L.) R. Br.] are the most important cereal crops in the savanna ecological zones of Nigeria. They account for over 80% of the total output of grains and about 85% of the annual hactarage in these zones (Abalu and D'Silva, 1980). They constitute the bulk of the diet and the largest share of the total intakes of calories and proteins in these zones (Abalu and D'Silva, 1980).

Both maize and sorghum are used extensively in Nigeria for ration formulation for livestock. The brewery industry is today utilizing large quantities of sorghum and maize for the manufacture of beer and malt drinks (ICRISAT, 1990). Sorghum, maize and millet are also constituents of table bread and biscuits (ICRISAT, 1990). Other uses include manufacture of starch and oils particularly from maize.

Yields of these crops are low in Nigeria as they are in other developing countries where the demand for food is increasing. For instance, although the potential grain yield of pearl millet in Nigeria is above 2 t/ha, the average yield in farmers' fields is about 561 kg/ha (Anon., 1974; NAERLS, 1996). Pests and diseases constitute one of the most important constraints to yield in most countries (Sharma, 1988).

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Plant parasitic nematodes are important agents of yield reduction and problems caused by them have gradually become more apparent, especially in the developed nations. However, information on nematode problems in developing tropical and sub-tropical countries, where the nematodes are suspected to cause more crop losses, is still limited.

Several genera of phytoparasitic nematodes have been reported to be associated with, and reducing yields of, these three crops. On a world wide basis, there are as many as 112, 60 and 52 species of plant-parasitic nematodes associated with sorghum, maize and pearl millet, respectively (Sharma, 1988; Swarup and Sosa-Moss, 1990).

In Ghana, Addoh (1971) found 11 genera of nematodes to be associated with maize, four with sorghum and two with pearl millet. *Pratylenchus brachyurus*, *Helicotylenchus multicinctus*, *Scutellonema bradys* and *Xiphinema* spp. were parasitic on all the three crops. Tiyagi et al. (1987) reported the association between plant-parasitic nematodes and pearl millet in India. Populations of *Hoplolaimus indicus* Sher, and *Tylenchorynchus brassicae* Siddiqi were found to be consistently high during the growth period, while those of *Helicotylenchus indicus* Sidiqi, *Tylenchus filiformis* Butschli, *Pratylenchus coffeae* (Zimmerman) Filip. & Sch. Stek., *Rotylenchulus reniformis* Lindford and Oliveira and *Heterodera* sp., were moderate. Johnson and Burton (1973) established

that sorghum and pearl millet are good hosts for many species of plant-parasitic nematodes. In his compilation of world list of nematodes of ICRISAT mandate crops, Sharma (1988) indicated that the most important nematodes attacking sorghum were *Pratylenchus* spp. and *Tylenchorynchus* spp. followed by *Meloidogyne* spp. Emechebe *et al.* (1980) reported association of *Aphelenchoides arachidis, P. brachyurus, P. coffeae, P. zeae, M. javanica, M. incognita* and *Paratrichodorus minor* with the three crops. *Rotylenchulus reniformis* and *Sarisodera africana* were restricted to sorghum while *Radopholus similis* was associated mainly with pearl millet.

Both the growth and yield of sorghum, maize and millet are reduced appreciably by these nematodes (Egunjobi, 1974; Tarte, 1971). Taylor (1967) reported a minimum 14.9 percent crop loss of sorghum due to plant-parasitic nematodes. Tarte (1971) found a highly significant negative correlation between numbers of *Pratylenchus zeae* and yield of maize in Panama. Yield reduction ranged from 11.9 to 38.3 percent.

Estimated economic losses in field corn associated with *Pratylenchus* spp. in South Africa is about 33% (Martin *et al.*, 1975). In south-western Nigeria, Egunjobi (1974) reported a yield reduction of 28-33 percent in maize due to *P. brachyurus*. According to Egunjobi (1987), a conservative estimate of financial losses based on a 20% maize yield loss and a government guaranteed price of ₦200.00/tonne amounted to

₦30,320,000 ($45,000,000) per annum (at 1986 values) based on an annual maize production of 758,000 tonnes. Today (1997), this value would be over 1.137 billion naira if price per tonne is ₦15,000. Information on losses associated with *P. brachyurus* and other nematode species on sorghum and millet in the savannas is lacking.

Given the staggering financial losses due to these nematodes and given the fact that such information is lacking in northern Nigeria, it becomes imperative that studies be conducted on the distribution and economic importance of the phytonematodes associated with these important crops so as to be able to formulate control measures that will reduce losses. It is against this background that these studies were initiated. The main objectives are as follows:

(1) To identify the various plant-parasitic nematode genera associated with sorghum, maize and millet in the Nigerian savannas with a view to determining the most important nematode pest based on their distribution and population densities.

(2) To conduct the following studies on the most important nematode pest:

  (i) Establish its pathogenicity on maize and sorghum;

  (ii) Determine the reaction of some maize cultivars to infection by the nematode;

(iii) Establish the relationship between initial population densities of the nematode and damage to maize;

(iv) Study population changes of the nematode and estimation of its yield losses on maize.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Introduction

Plant-parasitic nematodes cause considerable annual losses to many crop plants either directly through parasitic action or indirectly as vectors of other plant pathogens. Several genera of phyto- parasitic nematodes have been reported to reduce yields of sorghum, maize and millet in many parts of the world (Sasser and Freckman, 1994). Paddock (1967) estimated that nematodes were responsible for a 3 - 4% loss in yield of various crops including cereals. Brown (1984) reported that more than two million hectares in Victoria and South Australia were infested with *Heterodera avenae*, and annual losses in wheat yields were estimated to be US$70 million. In Ibadan (south-western Nigeria), Egunjobi (1974) reported yield reduction in maize due to *Pratylenchus spp.* to be 28 - 33%.

2.2 Nematodes Associated with Maize

Maize production is greatly impaired by several pests and diseases, including plant-parasitic nematodes. Over 60 nematode species have been found associated with maize in different parts of the world (Swarup and Sosa-Moss, 1990). However, most of them have been obtained from soil around maize roots with little information on their pest status.

The lesion nematodes, *Pratylenchus* spp., have been consistently found to be associated with maize wherever it is grown, and have often been reported to be associated with poor growth (Swarup and Sosa-Moss, 1990). *P. brachyurus*, *P. zeae* and *P. coffeae* are the most commonly encountered species in sub-tropical and tropical regions (Swarup and Sosa-Moss, 1990). These are followed by *P. delattrei*, *P. goodeyi*, *P. hexincisus*, *P. minyus*, *P. safaensis* and *P. thornei* (Swarup and Sosa-Moss, 1990). In India, Pall and Chand (1971) found *Pratylenchus zeae* to be associated with maize, while Norton and Hinz (1976) reported significant relationship between populations of *P. hexincisus* and corn yields in Iowa, U.S.A. Egunjobi (1974), Egunjobi and Larinde (1975), working in south-western Nigeria, and Norton and Hinz (1976) attributed damage to maize to infection by *Pratylenchus* spp. Emechebe *et al.* (1980) reported three species of *Pratylenchus* (*P. brachyurus*, *P. zeae* and *P. coffeae*) to be associated with maize in northern Nigeria.

Apart from the lesion nematodes, other plant-parasitic nematodes have been reported to be associated with maize. Norton and Hinz (1976) considered *Hoplolaimus galeatus* to be a major parasite of maize in Iowa, U.S.A. The root-knot nematodes, *Meloidogyne* spp., have also been reported on maize. *M. incognita* and *M. javanica* have been detected damaging maize in almost all maize growing regions of the world (Swarup and Sosa-Moss, 1990). In India and Pakistan, however, only *M.*

africana and *M. arenaria* have been recorded on maize (Krishnamurthy and Elias, 1967; Magbool, 1980; 1981). *M. incognita* and *M. javanica* were also reported on maize in the Nigerian savannas (Emechebe *et al.*, 1980).

Nine species of cyst-forming nematodes have been recorded from maize in sub-tropical and tropical countries; of these, only three *(Punctodera chalcoensis, Heterodera zeae* and *H. avenae)* are considered economically important (Luc, 1986). *H. cajani, H. delvii, H. gambiensis, H. graminis, H. oryzae* and *H. sorghi* have been recorded sporadically, but their role as parasites of maize remains uncertain (Koshy and Swarup, 1972; Merny and Cadet, 1978; Prasad *et al.*, 1980; Sharma and Swarup, 1984; Reversat and Germani, 1985).

2.3 Nematodes Associated with Sorghum

Although a number of phytoparasitic nematodes have been found to be associated with sorghum, little information is available on specific nematode problems of the crop. Increased yields after chemical treatment of soil, where high populations of specific nematodes were recorded, provide indirect evidence of significant economic damage due to nematodes.

Nematode genera that are cosmopolitan and are most likely to be implicated in sorghum yield losses are *Pratylenchus* spp., *Meloidogyne* spp., (Claflin, 1984; Emechebe *et al.* 1980) *Tylenchorynchus* spp., *Belonolaimus* spp., *Xiphinema* spp. and *Trichodorus* spp. (Claflin, 1984). According to Sharma (1988)

the most important nematodes parasitizing sorghum are *Pratylenchus* spp. and *Tylenchorynchus* spp. These are closely followed by *Meloidogyne* spp., *Helicotylenchus* spp. and *Paratrichodorus* spp.; others include *Paratrophurus* spp. and *Rotylenchulus* spp. Swarup and Sosa-Moss (1990) considered *Tylenchorynchus, Meloidogyne* spp. and *Pratylenchus* spp. to be the most important genera associated with sorghum. According to these authors, the most important lesion nematodes are *P. zeae* and *P. hexincisus*.

Ayala and Bee-Rodriguez (1978) reported that *P. zeae, Helicotylenchus* spp. and *Tylenchorynchus crassicaudatus* were commonly detected from sorghum fields in Puerto Rico. *Aphelenchus* spp., *Aphelenchoides* spp., *Tylenchus* spp., *Pseudhalenchus* spp. *Trophurus* spp., *Neotylenchus* spp., *Longidorus* spp., *Meloidogyne* spp. and *Rotylenchulus* spp. were other genera identified in smaller numbers from soil and root samples. *P. zeae* was implicated in causing death of 2 to 3 week old sorghum plants.

Starr (1979) detected populations of species of *Pratylenchus, Helicotylenchus, Hoplolaimus, Rotylenchulus*, and *Scutellonema* on sorghum and pearl millet in India. Although *Pratylenchus* spp. and *Hoplolaimus* spp. reproduced on sorghum and pearl millet, they did not appear to cause serious crop damage.

Longidorus africanus and *Heterodera zeae* were found to be associated with sorghum and also shown to be pathogenic in pot

experiments in U.S.A. (Lamberti, 1969; Singh *et al.*, 1979). *Heterodera gambiensis* has been found associated with the crop only in Gambia (Merny & Netscher, 1976).

From the foregoing, nematode species belonging to three genera appear to be most important on sorghum. These are *Pratylenchus, Tylenchorynchus* and *Meloidogyne* species. *T. martini, T. nudus* and *T. acutus* have been recorded to be associated with unthrifty growth of sorghum (Hafez and Claflin, 1982). Yield increase of 55% after nematicide treatment was recorded where *T. martini* was the dominant population. Similarly, *T. nudus* was reported in South Dakota, U.S.A. to reduce plant growth by 10 and 56% in fertilized and unfertilized plots, respectively (Smolik, 1977).

2.4 Nematodes Associated with Millet

Tiyagi *et al.* (1987) reported the association between several plant-parasitic nematodes and pearl millet in India. Populations of *Hoplolaimus indicus* and *Tylenchorynchus brassicae* were found to be consistently high during the growth period. Those with moderate populations were *Helicotylenchus indicus, Tylenchus filiformis, Pratylenchus coffeae, Rotylenchulus reniformis* and *Heterodera* spp.

Pearl millet was reported to be a host of *Meloidogyne incognita* and *M. javanica* in India (Handa *et al.*, 1971). In the north-western sector of India, *M. incognita* has been reported to be a field problem where it occurs in combined infection with the downy mildew fungus, *Sclerospora*

graminicola. The symptoms of the green ear disease caused by the fungus, were advanced by about a fortnight when root-knot nematodes were present (Vaishnav and Sethi, 1978). The crop is generally a poor/non host of *M. acronea* (Bridge *et al.*, 1976; Page, 1983).

In glasshouse tests in India, pearl millet proved to be the most favourable host for multiplication of *Tylenchorynchus vulgaris* (Upadhyaya & Swarup, 1972). Seshadri (1970), also in India suggested that the reniform nematode, *Rotylenchulus reniformis*, may be a problem on pearl millet.

Sharma (1988) in a review of nematodes associated with ICRISAT mandate crops, reported that *M. javanica*, *Helicotylenchus*, *Tylenchorynchus* and *Pratylenchus* species were most important on pearl millet. These were followed in decreasing order of importance, by *Paratrichodorus minor*, *Hoplolaimus*, *Rotylenchulus*, *Criconemella ornata* and *Trichodorus* spp.

It can be concluded from the foregoing that the most important species of plant-parasitic nematodes associated with sorghum, maize and pearl millet are species of *Pratylenchus*, *Tylenchorynchus* and *Meloidogyne*. However, *Pratylenchus* species appear to be the most important species. Reduction in yields of maize has been shown to be associated with *Pratylenchus* spp. (Chevres-Roman *et al.*, 1971; Dickerson *et al.*, 1964; Norton and Hinz, 1976; Olowe, 1969; Tarte, 1971). *P. brachyurus* and *P. safaensis* are considered to be very

important in Nigeria (Caveness, 1982; Egunjobi, 1974; Egunjobi *et al.*, 1986) especially in the southern parts of the country where numbers of lesion nematodes per gramme of fresh maize root range from 1 to 5000.

2.5 Symptoms of Damage

Plant-parasitic nematodes inflict damage on crop plants causing above-ground symptoms that are not highly specific. These are characterized by stunted growth, reduced root and shoot weight, and leaf chlorosis (Swarup and Sosa-Moss, 1990). Stunting occurs in patches when high populations of nematodes are present in a specific area. Leaf chlorosis is also common under severe soil infestation (Swarup and Sosa-Moss, 1990). When maize is infected with the Mexican corn-cyst nematode, *Punctodera chalcoensis*, the chlorotic symptoms are characterized by pale colour stripes in contrast to symptoms caused by the virus disease "Rayado Fino" (in Mexico), where the pale stripe lines are in green leaves rather than in yellowish leaves in the case of nematode infection.

Unlike above-ground symptoms, underground symptoms tend to vary according to the species. In maize, damage to the fibrous root system by *Pratylenchus* spp. result in destruction of cortical parenchyma which may cause sloughing-off of the tissues and severe necrosis (Swarup and Sosa-Moss, 1990). In addition, severe root prunning as well as proliferation of lateral roots, may occur (Ogiga and Estey, 1975; Zirakparvar,

1980). *P. zeae* causes a mechanical breakdown of cells,-and necrosis of stelar and cortical tissues resulting in formation of cavities (Olowe, 1977; Olowe and Corbett, 1976). This reduces uptake of nutrients and water from the soil as was observed in sorghum (Chevres-Roman *et al.*, 1971). Occasionally, slight hypertrophy may be observed. Damage by lesion nematodes can be diagnosed by the presence of small blackish lesions on the root surface.

Root-knot nematode infection is characterized by their characteristic galls. *M. incognita* infection of sorghum results in production of elongated swellings or discrete knots and proliferation of roots. Galls produced by *M. naasi*-infected sorghum roots may exhibit curving of the roots in the shape of hook or horseshoe or a complete spiral without excessive proliferation of secondary roots as is common with other *Meloidogyne* spp. (Swarup and Sosa-Moss, 1990). *M. acronea* induces extensive root proliferation but without conspicuous root galls (Page, 1985). Typical symptoms of root-knot may be absent when maize is infected (Becerra and Sosa-Moss, 1977; Idowu, 1981). This has made researchers to often consider maize to be a poor host or even immune to root-knot.

When maize is infected with cyst nematodes, the root system is generally poorly developed. Large numbers of white females can be observed on the root surface (Swarup and Sosa-Moss, 1990).

2.6 Economic Importance of Nematodes

Although plant- parasitic nematodes occur frequently in maize, sorghum and millet fields, information on economic losses caused by these nematodes is scanty. However, indirect observations, when nematicides are applied in nematode-infested fields, show that nematodes are economically important limiting factors in the cultivation of these crops. Walters (1979) obtained 33 to 128% yield increase in maize following application of nematicides in *Pratylenchus*-infested fields in South Africa. Bergeson (1978) and Norton *et al.* (1978) reported that treatment with nematicides increased yields of maize by 10 - 54%. In the Ibadan area of South-western Nigeria, *P. brachyurus* has been reported to be responsible for 28.5% yield reduction (Egunjobi, 1974). The reduction in yield was correlated with a 50% increase in nematode density.

Under glasshouse conditions in Mexico, Sosa-Moss and Gonzalez (1973) obtained a reduction of about 60% in yield of maize in soils heavily infested with the Mexican corn-cyst nematode, *Punctodera chalcoensis*.

Though the pathogenicity of *Heterodera zeae* has been demonstrated on maize in India (Koshy et al., 1970), data on economic damage to the crops (maize) is lacking. However, Srivastava and Sethi (1984b) also in India, showed that plant growth reductions are directly correlated with initial population density.

Information on economic importance of nematodes on sorghum has been obtained for only few species. The stunt nematodes, *Tylenchorynchus martini*, *T. nudus* and *T. acutus* have been demonstrated to be economically important on sorghum. Both
T. martini and *T. nudus* increase in number under sorghum monoculture and caused damage at levels of 2,000 - 5,000 nematodes per 250 cm^3 soil (Hafez and Claflin, 1982). Yield increased by 55% after nematicide treatment of soil in which *T. martini* was the dominant population (Hafez and Claflin, 1982).

The root-knot nematodes, *M. incognita*, *M. naasi* and *M. acronea* are reported to be associated with sorghum. In Malawi, for example, *M. acronea* was found to be responsible for delayed flowering and yield losses of 56% in sorghum cv. Lindse 555 in pot experiments (Page, 1985). Similar observations were made in the field.

Pratylenchus is considered to be of moderate importance to sorghum in tropical areas of the world (Swarup and Sosa-Moss, 1990). *Longidorus africanus* and *Heterodera zeae* were associated with sorghum and have been shown to be pathogenic in pot experiments in the U.S.A. (Lamberti, 1969; Singh *et al.*, 1979).

Although numerous nematode species are reported to be associated with pearl millet, information on their economic importance is lacking.

2.7 Nematode Threshold Levels

A very fundamental and important concept in plant nematology is "nematode threshold level". This decribes the relationship between nematode population density and crop performance.

Nematode-damage-threshold levels have been worked out for several nematodes on several crops (Barker *et al.*, 1976; Chindo and Khan, 1988; Olthof and Potter, 1972; Potter and Olthof, 1974). However, research involving tolerance levels of cereals to plant parasitic nematodes has received very limited attention. Various parameters including the reproductive potential of the nematode species, host genotype and the effect of environment must be ascertained before establishing threshold limits. Other considerations include interactions of nematodes with other nematodes, nematodes with soil micro-organisms like fungi and bacteria, and susceptibility or tolerance of the particular cultivar to the nematodes.

Inspite of these limitations, threshold levels have been reported for some nematode species on these cereal crops. Sharma (1988) reported threshold levels on sorghum for *Pratylenchus zeae* to be about 200 to 2,000 nematodes/litre of soil in India. Tarte (1971) found a highly significant negative correlation between initial population density of *P. zeae* and dry weight of tops of maize. Top weight reductions ranged from 11.9 to 38.3%.

According to Sharma (1988), threshold levels for *Hoplolaimus* sp. on sorghum in India was about 2000 per litre of soil. In the same report, threshold levels for one species each of *Hoplolaimus*, *Pratylenchus* and *Tylenchorynchus* were 2,000, 2000 and 1000 nematodes/litre of soil, respectively. Both *T. martini* and *T. nudus* caused damage to sorghum at levels of 2000 - 5000 nematodes/250 cm^3 soil (Hafez and Claflin, 1982).

2.8 Population Dynamics

The term population dynamics is used to refer to changes in the numbers, age class distribution, sex ratio, and behaviour of a nematode population through time and space as determined by inherent characteristics of the individuals and mediated by environmental conditions, food resources, and interacting biotic agents (Ferris and Wilson, 1987). In other words, the direction of change of any population, and consequently its effect on the plant, is determined by both intrinsic and extrinsic factors.

While the importance of some plant-parasitic nematodes has been shown on these three cereal crops (Bergeson, 1978; Egunjobi, 1974; Seshadri, 1970; Smolik, 1977; Walters, 1979), little attention has been given to the dynamics of the populations of most of the nematodes parasitising these crops.

Nematodes are known to invade and penetrate roots of susceptible hosts soon after root emergence culminating in a

build-up of populations. Koen (1967) reported a build-up of populations of *P. brachyurus* on peanut as soon as the crop germinated. Egunjobi (1974) made similar observations on maize. She reported that roots of maize were infected soon after germination and populations reached a peak inside the roots within 4 - 5 months and 2 - 3 months in the early and late planted crop, respectively. She attributed the population build-up to the high rainfall and cooler temperatures characteristic of the growing season in the Ibadan area of Nigeria.

Changes in nematode densities result in changes in both intrinsic and extrinsic factors that impinge on the nematodes, consequently its population. Invasion, reproduction and eventual development have been shown to be reduced with increase in nematode density (Olthof and Potter, 1977; Triantaphyllou, 1960; Wallace, 1969). Besides a decrease in embryonic development, males have been shown to predominate under high population densities. The preponderence of males in such situation results from insufficient food supply due to competition for infection sites (Wallace, 1971).

2.9 Factors Influencing the Development of Nematodes

In the soil ecosystem, several factors influence the degree of damage caused by plant-parasitic nematodes. While these may act directly on the nematodes, they may also do so on the plants thereby making them more susceptible or resistant to attack by the nematodes. Thus, the relationship

is a complex ecological situation, and therefore, it becomes difficult to wholly incriminate any of these factors as acting directly on the nematode and its characteristics that determine the host-parasite relationship. Some of the important factors include temperature, moisture, soil type, pH and nutrient levels.

Temperature, in addition to plant species, greatly affects the development of any nematode species. *Pratylenchus brachyurus, P. zeae* and *P. hexincisus* reproduced well on maize at 30°C, whereas

P. penetrans, also on maize, preferred lower temperatures of 20-24°C (Olowe and Corbett, 1976; Zirakparvar *et al.*, 1980). Frequently optimum temperature required for nematode development is correlated with the optimum temperature required for plant growth (Olowe and Corbett, 1976). For example, 20°C which is considered optimum temperature for good root development is simultaneously the optimum temperature for maximum root penetration and development of *P. brachyurus* (Swarup and Sosa-Moss, 1990). A similar effect was recorded in the U.S.A. by Dickerson *et al.* (1964) who found differences in the top weight of plants inoculated with *P. penetrans* over the uninoculated controls but not at 24°C.

The most favourable temperature for emergence of juveniles of *Heterodera zeae* from cysts in India was 25°C with 91% emergence (Srivastava and Sethi, 1985b). At temperature of only 10 - 15°C, only 10 to 20% of the juveniles emerged.

The development of root knot nematodes is greatly influenced by soil temperature. The optimum soil temperature for development of race 5 of *M. incognita* on sorghum in the U.S.A. was 26°C and it completed its life cycle in 34 days (Ediz and Dickerson, 1976).

Soil type and tillage operations have also been recorded to affect nematode population dynamics. Most nematode species. thrive well in a wide range of soil types, but for others, a particular soil type may be more suitable. Naganathan and Sivakumar (1975) working in India, reported higher population densities of *Pratylenchus delatteri* in sandy clay loam soil than in any other soil type. Conversely, *P. hexincisus* was found in a wide range of soil types but reproduced best in sandy soils (Swarup and Sosa-Moss, 1990).

Punctodera chalcoensis survived and reproduced well in all soil types with the exception of loamy soils, and caused severe damage on volcanic sandy soils (Swarup and Sosa-Moss, 1990). Similarly, *Heterodera zeae* reproduced well in moderately light soils. The addition of clay to soil mixtures in India resulted in proportional decline in nematode (*H. zeae*) levels (Srivastava and Sethi, 1984a).

Moisture is an important factor affecting the development of nematodes. In south-western Nigeria, Egunjobi (1974) demonstrated pathogenicity of *P. brachyurus* on maize and found increased nematode development during the rainy season. Damage to the maize plant on the other hand, increased with

decreasing moisture levels.

Plant cultivar is also an important factor. The ausceptibility or otherwise of a plant determines the reproduction, and consequently, the population of a nematode species in the soil. The four races of *M. incognita* reproduced well on maize (Oteifa and Elgindi, 1982) in Egypt.

2.10 Management of Nematode Problems

The objective of any nematode management strategy is to either reduce the nematode population to a level that is not injurious to the crop or, render it ineffective thereby reducing damage, with the subsequent improvement in crop growth and yield. For any control measure to be practicable, it must be economically viable and compatible with the environment.

Several control measures are being used to manage nematodes with varying levels of success. These fall into five broad categories namely, cultural, physical, and chemical, biological and host plant resistance. Chemical control stands supreme due to its effective and quick action. Nonetheless, it suffers from some drawbacks. First drawback is economics of its application. Nematicides used in Nigeria are manufactured outside the country. This makes them very expensive and beyond the reach of the farmers that produce the bulk of Nigeria's food. Secondly, because of frequent changes in government policy, availability of nematicides are highly

unreliable. A third problem is related to expertise required for effective and proper appliction of pesticides. Chemical nematicides require fairly high technical skills for safe and successful application because they are very toxic. These skills are lacking in Nigeria.

Inspite of these drawbacks, the world would have to contend with nematicides for sometime because of the enormous food loss due to nematode damage. At the moment, global food loss due to nematode pests is put at over US$100 billion per annum (Sasser and Freckman, 1987). The situation in Africa is worse than the more advanced temperate countries as average losses due to nematodes are 16.5 and 10.5% in Africa and temperate countries, respectively (Sasser and Freckman, 1987).

While nematicides will continue to be used to control nematodes for sometime to come, efforts have and are being made to develop other effective, economically viable and environmentally safe alternative strategies such as cultural, host plant resistance and biological control methods.

Cultural control involves the manipulation of agronomic practices with ultimate aim of reducing nematode populations to safe levels before a susceptible crop is grown again. This is achieved through the use of measures such as crop rotation, soil organic ammendments, optimum sowing dates and cropping systems.

Crop rotation has been used successfully to control root-knot nematodes in vegetables in several parts of the world

including Nigeria (Netscher and Taylor, 1976; Ogunfowora, 1981; Taylor and Sasser, 1978). Sorghum, millet and particularly maize, have been considered as poor hosts of root-knot nematodes and have been used as rotation crops (Swarup and Sosa-Moss, 1990). In some countries however, maize is damaged by root-knot nematode and reproduction may occur even though typical root galls are not visible (Becerra and Sosa-Moss, 1977; Idowu, 1981). Its use as a rotation crop should therefore be treated with caution.

Soil organic ammendments have been shown to effectively control phyto-parasitic nematodes. Chindo and Khan (1990) effectively controlled root-knot nematodes in tomato by using poultry manure in the field. Similarly, Egunjobi (1977) and Egunjobi and Afolami (1976) achieved good control of *P. brachyurus* in maize with cocoa pod husk and neem leaf extracts, respectively, both in *in vitro* and in pot culture.

In Mexico, it has been observed that early sowing dates, as well as adequate fertilization reduce damage caused to maize by *P. chalcoensis* (Sosa-Moss and Gonzalez, 1973; Sosa-Moss, 1987).

The use of inter-cropping (Egunjobi, 1984; Egunjobi *et al.*, 1986) and crop rotations (Johnson, 1985) as effective tools for the control of plant-parasitic nematodes have been widely demonstrated. These methods, good as they are, need to be improved upon and incorporated into an integrated control programme.

Several cultivars of maize have been reported to be resistant/ tolerant to a number of nematodes in several parts of the world. In Georgia, U.S.A., Johnson (1975) reported multiple resistance of Seneca 110 and Seneca Explorer to species of *Meloidogyne, Helicotylenchus* and *Paratrichodorus*. Nishizawa (1981) reported that all 72 maize cultivars tested in Japan were immune to *M. hapla*. On the contrary, none was immune to either *M. incognita* or *M. javanica*. Oteifa and Elgindi (1982) reported twelve maize cultivars to be resistant to *M. incognita* and/or *M. javanica* in Egypt. Similarly, Sasser and Kirby (1979) reported eight maize cultivars to be resistant to *M. incognita, M. javanica* and *M. arenaria* in the U.S.A. In addition, Lordello, *et al* (1985) identified several maize genotypes resistant to *Pratylenchus zeae* and *P. brachyurus* in Brazil. According to Hutton (1981), sweet maize cultivars in Jamaica are generally tolerant to nematode attack. Little of such information is available for the three cereal crops in Nigeria.

While it is most desirable to concentrate efforts on the use of resistant/tolerant cultivars as a cheap and sustainable management strategy, the formulation of integrated management strategies needs to be vigorously exploited.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Survey of Plant-parasitic Nematodes Associated With Maize, Sorghum and Pearl Millet

The survey was conducted in the savanna agro-ecological zones covering parts of Bauchi, Gombe and Kano States (in the northern Guinea savanna zone), Adamawa and kaduna States (in both the northern and southern Guinea savannas), and Nassarawa, Niger, Plateau and Taraba States (in the southern Guinea savanna zone) of Nigeria (Fig. 1). This was usually done in the month of September in 1989, 1990 and 1991, when most of the nematodes would have attained peak populations in the soil.

A total of 175 soil samples were taken from locations about 50 km from each other. Soil samples were collected with soil auger. Sampling was done in a systematic random pattern (Barker and Campbell, 1981).

At each location, about 3 - 5 farms, each measuring about 0.5 ha, were randomly selected. From each of these farms was collected a sub-sample, comprising 30 soil cores. These were later bulked to give one sample.

Observations were made on soil type, crops grown, cropping systems and cropping history. Information on cropping history was obtained through interviews with farmers. Crops were, in addition, examined, for obvious symptoms of nematode attack.



Fig.1: Map of Nigeria showing the Ecological zones and Areas surveyed.

Samples collected were taken to the laboratory and nematodes extracted within 2 - 3 weeks of collection. Five hundred milliliter of soil was taken for nematode extraction using Cobb's sieving and decanting method (Cobb, 1918) in combination with Baermann trays. Extract was left on the laboratory bench for about 48 hours after which it was decanted into a beaker. Extract (nematode suspension) was later transferred into a measuring cylinder and made to 100 ml with tap water. Nematode populations were counted in 10 ml aliquot taken from the above homogenized nematode suspension in Doncaster counting dishes and a mean of three counts taken. Nematodes were identified to genera level only using Commonwealth Institute of Helminthology Descriptions of Plant Parasitic Nematodes. Nematode counts/data obtained were then subjected to statistical analysis using cluster and contribution analysis based on genotype X environment programme (Byth and Mongomery, 1981). The technique arranges the nematodes in clusters/groups based on their similarities in occurrence and population density relative to the environment.

3.2 Pathogenicity of *Pratylenchus brachyurus* on Maize and Sorghum

Prior to the start of the experiment, a pure culture of *P. brachyurus* was established. *P. brachyurus* was isolated by hand-picking individual nematodes (using dissecting needle

mounted with pig hair) from macerated infected maize roots into syracuse dishes containing distilled water. These were inoculated and maintained on maize variety TZESR(w) grown in heat-sterilized soil contained in drums and pots and placed outside glasshouses. Inoculation was done by pouring the nematode suspension from the syracuse dishes into holes made round the plants and close to the roots. Soil composition was 3:2:1 of loam:sand:organic manure.

Initial inoculum density was obtained by first extracting nematodes from 100 g of maize roots using Stermeding's maceration technique (Stermeding, 1964). Nematodes were then counted in 10 ml homogenized extract in Doncaster counting dish. The intial inoculum was then obtained by macerating a proportionate quantity of roots that will give the required number of nematodes.

Five litre plastic pots were filled with heat-sterilized soil prepared as above. The soil was mixed with macerated infected maize roots capable of giving population density of approximately 2000 nematodes per pot. NPK (15:15:15) fertilizer was applied at the rate of 10 g per pot as basal application. Two maize seeds (cultivar TZESR (w)) or five sorghum seeds (cultivars KSV8) were planted in each pot; three days after germination, the seedlings were thinned to one per pot. Selection of the varieties was based on an earlier study which showed that each of them supported high population of *Pratylenchus* spp. (Chindo and Ajayi, unpublished). Plants

grown in uninoculated sterilized soil served as control. Each treatment (inoculated and uninoculated) was replicated four times for each of the crops. Pots were arranged in the screenhouse bench in a randomized complete block design. Three weeks after planting, plants were top-dressed with 5 g calcium ammonium nitrate (CAN) fertilizer.

During and at the end of the experiment, observations on the following were made:

(i) plant height and stem diameter at 20, 40 and 60 days after inoculation (DAI),

(ii) fresh shoot and root weight, at the end of the experiment (i.e. 60 days after inoculation)

(iii) nematode population in 500 ml soil and roots at the end of experiment.

(iv) multiplication rate, given by the reproduction factor (R) = $\frac{Pf}{Pi}$

where Pf is final population density

Pi is initial population density

Nematode populations in roots was obtained by counting the nematodes directly in 100 ml of root tissue using Olympus stereo microscope at 10 x 4 magnification. Roots were stained in boiling cotton blue lactophenol for 2 - 3 minutes and cleared in plain lactophenol. The experiment was carried out for two years (1991 and 1992) between the months of June to August. Data were subjected to statistical analysis using

Analysis of Variance.

Temperature of the Screenhouse ranged between 18 and 28°C.

3.3 Effect of Different Population Densities of *P. brachyurus* on Maize

The experiment consisted of six treatments made up of 0, 500, 1,000, 2,000, 4,000 and 8,000 nematodes per pot. The different population densities were prepared as in section 3.2 above.

Five 5-litre plastic pots were filled for each infestation level. Heat-sterilized soil served as control. Ten grammes NPK (15:15:15) fertilizer was added to each pot which was subsequently well-watered. Two maize seeds (cv. TZESR (w)) were planted in each pot and the seedlings thinned to one three days after germination. Pots were arranged in the screenhouse bench in a randomized complete block design. Plants were topdressed with 5 g of CAN three weeks after sowing. The experiment was carried out for two years (1991 and 1992) between the months of July to September (rainy season). Temperature in the screenhouse during the study ranged from 18 to 28°C.

Data were collected as described in section 3.2.

3.4 Reaction of Maize Cultivars to *P. brachyurus*

Fourteen maize varieties were tested. Two seeds of each variety were planted in 5 l plastic pots containing heat-

sterilized soil mixed with macerated infected maize roots to give an initial population density of 2000 nematodes/pot. Ten grammes of NPK fertilizer (15:15:15) was applied per pot.

Seedlings were thinned to one per pot three days after germination. Each cultivar (treatment) was replicated five times. Cultivar TZESR (w) known to be susceptible to *P. brachyurus* was used as check. The pots were arranged in the screenhouse in a randomized complete block design. Temperature in the screenhouse during the study ranged from 18 to 28°C.

Sixty days after inoculation, the experiment was terminated and the following data taken:

(i) Nematode population density both in the soil and roots.
(ii) Reproduction factor. These were determined as above described in 3.2.

The experiment was carried out in 1991 and 1992 from August to October.

3.5 Population Dynamics and Estimation of Economic Importance of *P. brachyurus* on Maize

The experiment was conducted during the 1992 and 1993 rainy seasons between 15th and 20th June to October in a field in the Institute for Agricultural Research, Samaru (11°11'N and 7°38'E), Ahmadu Bello University, Zaria research farm. The field had been planted with maize on two consecutive years before 1992 (i.e. 1990 and 1991). The trial consisted of two

treatments - carbofuran-treated and untreated plots. Carbofuran (Furadan 3G) was applied by drilling into the ridges at the rate of 2.0 kg a.i./ha. Each treatment was replicated four times in a randomized complete block design. Each replicate consisted of five, 75-cm ridges, each ridge being 5 m long. Prior to treatment with carbofuran, soil samples were taken to determine the initial population density (Pi). NPK (15:15:15) fertilizer and CAN were spot applied at the rate of 100 kg and 50 kg P_2O_5 per ha, respectively.

Seeds of maize variety, TZESR (w), were sown (three seeds/hill) 30 cm apart immediately after application of carbofuran. One week after germination, seedlings were thinned to two per hill. Plants were topdressed with CAN six weeks after planting.

Nematode populations were estimated by taking soil and root samples from the three inner rows, at three-weekly intervals beginning from 5th July, and terminating on 18th October of each year (1992 and 1993).

To obtain soil nematode populations, 20 soil cores were randomly taken from each replication and bulked. Samples were taken at a distance of 5 cm from the base of the plant, the depth being 20 cm. Nematodes were extracted as in 3.1. For nematode population in the roots, three plants, chosen at random, were carefully uprooted (using a hoe) from each replicate (i.e. 12 plants per treatment). They were taken to the laboratory, carefully washed, cut and bulked. From this,

two 100 g roots were taken, stained and nematodes counted as in 3.2. Data were subjected to statistical analysis using Analysis of Variance (ANOVA).

Yield was also determined from the remaining plants in three inner rows, and percentage yield loss calculated using the yield difference between carbofuran-treated and untreated plots.

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CHAPTER FOUR

4.0 RESULTS

4.1 Plant-parasitic Nematodes Associated with Maize, Sorghum and Pearl Millet in the Nigerian Savannas

Twenty genera of plant-parasitic nematodes were found to be associated with maize, sorghum and pearl millet in varying populations and frequencies in the Nigerian savannas. Six of these genera, namely, *Helicotylenchus, Pratylenchus, Tylenchus, Scutellonema, Ditylenchus* and *Hoplolaimus* appeared to be the most important both in terms of their population densities in the soil and frequencies of occurrence (Table 1). *Helicotylenchus* spp., which occurred in 94% of the samples was the most widely distributed.

Analysis of variance was done to determine the factors that contributed to the variation in nematode distribution and population densities in the various fields. The analysis showed that both nematodes (N) and fields (F) contributed to the total variance (Appendix 2). Contribution due to fields was slightly higher than that due to nematodes. Contribution associated with interaction between fields and nematodes (F x N) was not measured due to the size of the data set which was too large for the analytical programme.

In order to understand the pattern of distribution and/or association of nematodes in the fields, the data were analysed using Euclidian distance technique (De Lacy, 1981). This resulted in seven nematode sub-groups (Group 1 to 7) which

Table 1. Population density and frequency of occurrence of plant-parasitic nematodes associated with maize, sorghum and pearl millet in the Nigerian savannas

Nematode genera	Frequency of occurrence (%)	Mean population density per 500ml of soil
Helicotylenchus spp.	94	433
Pratylenchus spp.	85	202
Tylenchus spp.	82	280
Scutellonema spp.	70	198
Ditylenchus spp.	68	64
Hoplolaimus spp.	62	125
Tylenchorynchus spp.	43	52
Xiphinema spp.	38	48
Criconemoides spp.	37	33
Aphelenchoides spp.	31	252
Longidorus spp.	28	62
Paratrichodorus spp.	25	19
Dorylaimus spp.	25	53
Aphelenchus spp.	22	67
Hemicriconemoides spp.	20	28
Meloidogyne spp.	20	107
Hirschmanniella spp.	9	186
Paralongidorus spp.	8	32
Paratylenchus spp.	3	142
Trichodorus spp.	0.006	10

were classified into three broad groups (GI, II and III) (Fig. 2).

GI: Comprised of *Helicotylenchus, Tylenchus, Pratylenchus, Scutellonema, Aphelenchoides* and *Hoplolaimus*. Members of this group occurred uniquely in the 175 fields; each of them occurring in most of the fields and in relatively high numbers (densities), or less frequently but in most cases very high numbers as was the case with *Aphelenchoides* for which population of over 2000 per 500 ml of soil was recorded near Paiko in Niger State. This unique behaviour is shown in the dendrogram by classifying them distinctly (nematode groups 1 to 5).

GII: Comprised of nematodes that were infrequently associated with the crops and usually in low numbers. However, some of the species occurred in fairly high numbers. These nematodes are linked together by cluster group 9 on the dendrogram.

GIII: Comprised of nematodes that were of occasional occurrence and occurred, in all cases, at very low numbers (members of group 8). Because there is no marked difference in the nature of occurrence and population densities of nematodes in GIII with nematodes in GII, they (GIII and II) have been closely linked in the dendrogram as belonging to the same group (cluster group 7).

Based on this classification, six nematode genera namely, *Helicotylenchus, Tylenchus, Pratylenchus, Scutellonema, Aphelenchoides* and *Hoplolaimus* appear to be the most important

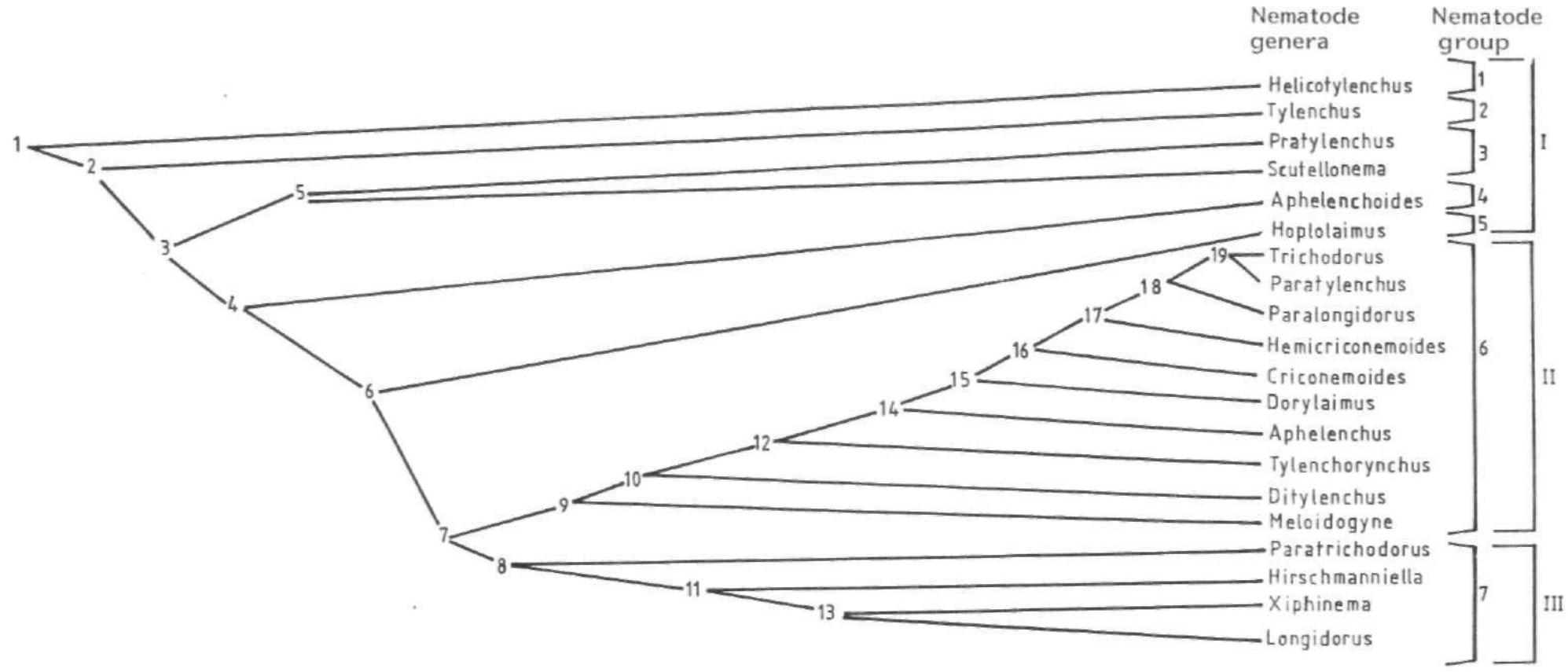


Fig. 2 Dendrogram showing nematode classification based on mean of nematode densities in 175 fields in the Nigerian savannas from 1989 to 1991

on maize, sorghum and pearl millet in the Nigerian savannas.

The association of nematode genera and distribution patterns across the fields was further analysed through field clustering based on the six genera. Eight field groups were formed (Fig. 3) with varying frequencies of occurrence (Table 2). The pattern of distribution and nematode densities showed a marked difference among field groups (Fig. 4). For instance, while the population of *Helicotylenchus* was relatively low in most fields, it was moderate and very high in field groups 17 and 1151, respectively. *Tylenchus* spp. population was high in one field group only (1006). This indicates a possible significant interaction between field conditions (F) and nematode characteristics (N) (F x N interaction). The classification of nematode populations into genera associations and field groups revealed that nematode populations vary from field to field depending on prevailing factors. These factors may be species specific. The effect of cropping systems on the distribution and population densities of the nematodes was considered in this study.

Analysis of the data showed that cropping systems dominated by maize had higher frequency of occurrence of plant-parasitic nematodes (Table 3). This was closely followed by sorghum, maize/sorghum, maize/millet dominated cropping systems. Pearl millet-based systems and cropping systems involving pearl/millet and legumes recorded the least occurrence of nematodes in the fields.

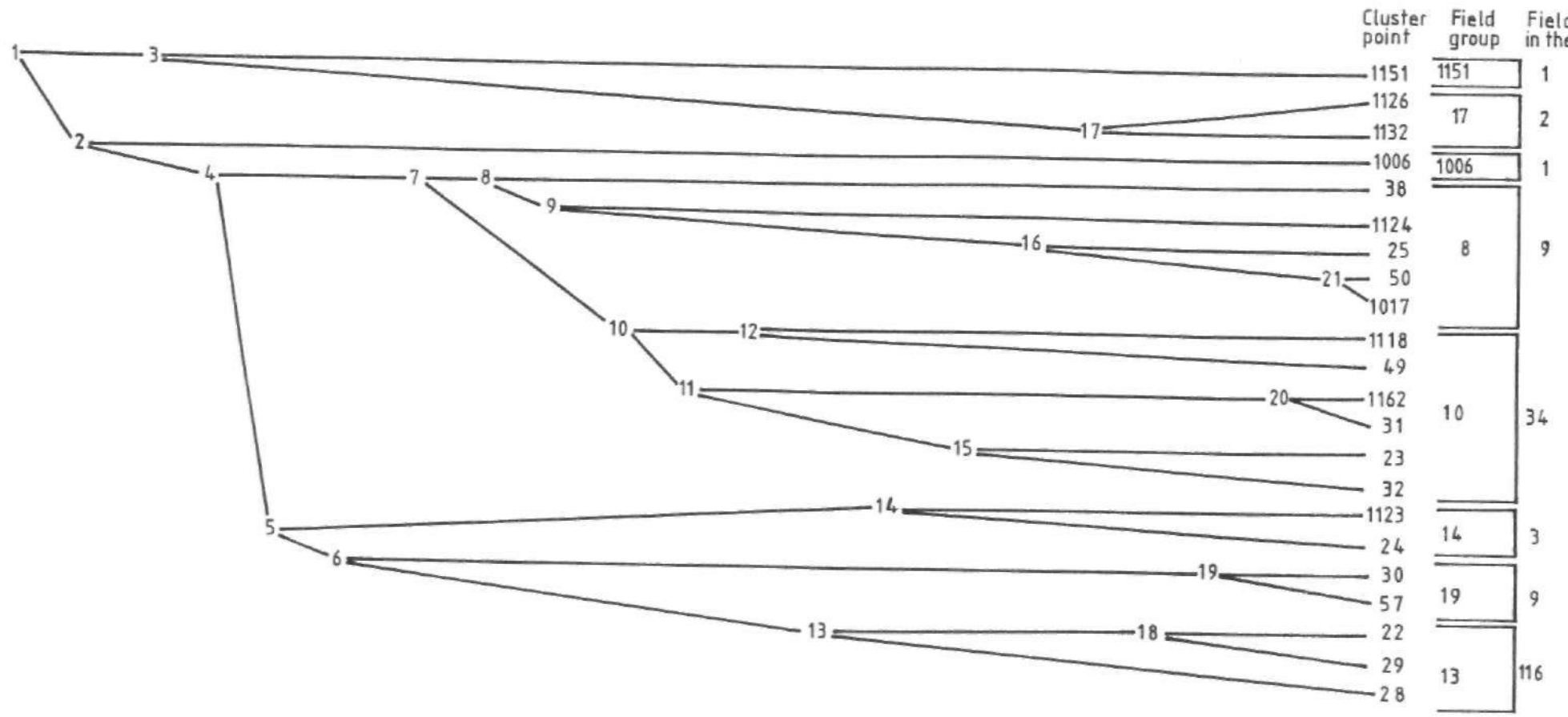


Fig. 3 Dendrogram showing field classification based on nematode groups shown in Fig.2; eight field groups, each having a similar composition of nematode population densities were formed.

Table 2. Frequency of occurrence of field groups and number of fields in each group.

Field group*	% frequency	No. of fields in the group
8	5.1	9
10	19.4	34
13	66.3	116
14	1.7	3
17	1.1	3
19	5.1	9
1006	0.6	1
1151	0.6	1

*A group of fields with similar characteristics of nematode occurrence and density

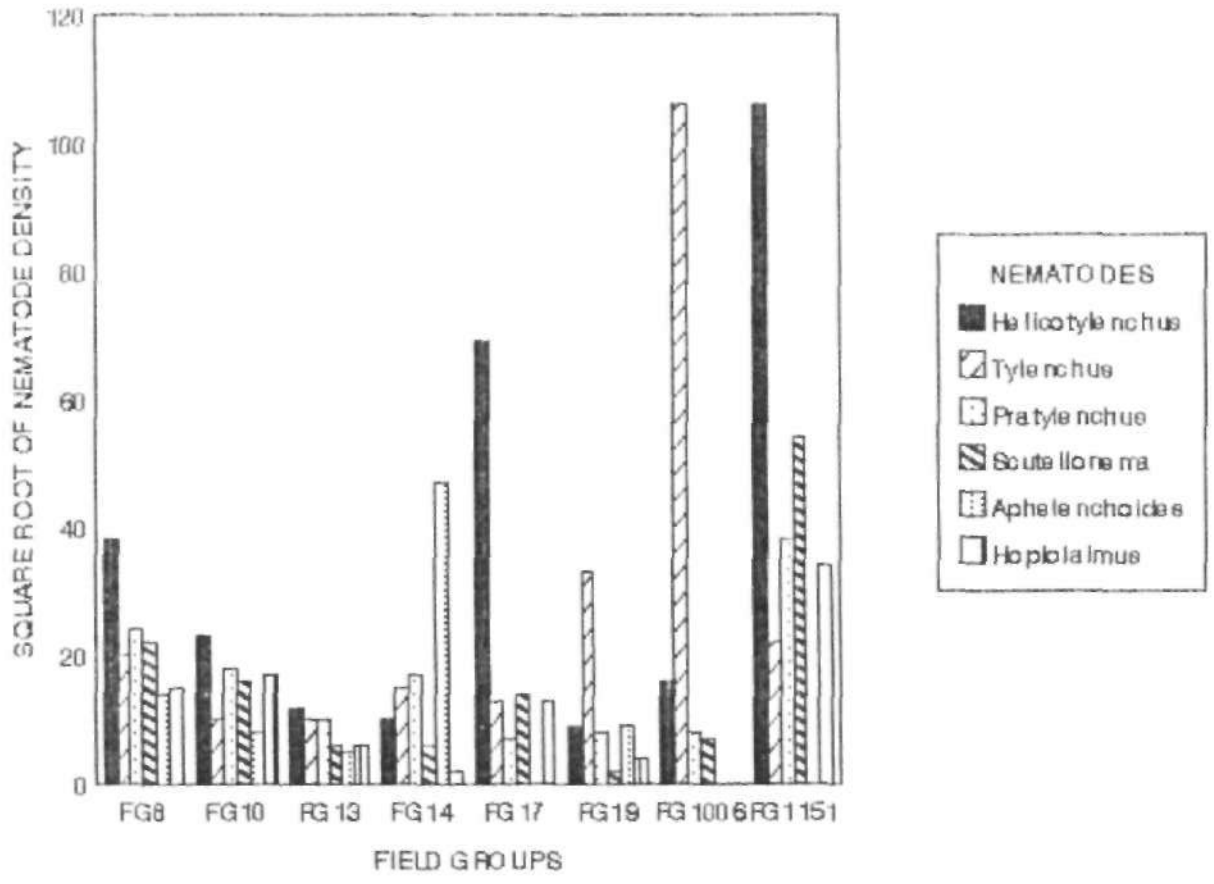


Fig. 4. Mean nematode densities in the field groups formed in Fig. 3.

Table 3. Effect of cropping systems on the frequency of occurrence of nematodes in cereal based systems.

	Frequency of occurrence (%) in cropping system								
Field group	1	2	3	12	13	21	32	34	236
8	78	0	0	11	0	0	0	0	0
10	29	12	9	21	0	0	0	0	0
13	16	19	4	6	0	0	9	9	0
14	0	0	0	0	34	0	9	9	0
17	50	50	0	0	0	0	0	0	0
19	33	0	0	0	0	11	0	0	22
1006	0	0	0	0	0	0	0	0	100
1151	100	0	0	0	0	0	0	0	0

1 = maize-based system only
2 = sorghum-based system only
3 = pearl millet-based system only
12 = maize/sorghum system
13 = maize/pearl millet system
21 = sorghum/maize system
32 = pearl millet/sorghum system
34 = pearl millet/cowpea system
236 = sorghum/pearl millet/groundnut system

The relationship between the population densities of the six nematode genera and cropping systems was similar to that described above between the frequency of occurrence of these nematodes and the cropping systems (Table 4). Maize-based systems generally had relatively higher populations of most of the nematodes than the other systems. Populations were particularly low for the legume-based systems except for *Tylenchus* and *Aphelenchoides* spp. which occurred at very high populations in sorghum/millet/groundnut and maize/millet systems, respectively. *Pratylenchus* species occurred in high populations mainly in maize and maize/millet mixtures. *Helicotylenchus*, on the other hand, tended to occur uniformly and in relatively high populations in all systems.

4.2 Pathogenicity of *Pratylenchus brachyurus* on Maize and Sorghum and reaction of some Maize Cultivars to the Nematode

Results of the study in 1991 and 1992 show that plant height and stem diameter of both sorghum and maize inoculated with *P. brachyurus* were significantly (P=0.05) reduced compared to those of uninoculated plants (Table 5 and Plate 1). Reduction in both parameters was more in maize than in sorghum. Plant height of maize was reduced by 29 and 29% compared to 12 and 23% for sorghum in 1991 and 1992, respectively. Corresponding values for stem diameter were 35 and 46% for maize and 25 and 35% for sorghum.

Table 4. Effect of cropping systems on the population densities of six nematode genera

Nematode genera	Mean nematode population densities (per 500ml of soil) in cropping system								
	1	2	3	12	13	21	32	34	236
Helicotylenchus	878	406	197	299	173	173	289	263	110
Tylenchus	197	119	86	105	57	228	47	22	3490
Pratylenchus	309	109	93	303	310	172	69	45	64
Scutellonema	278	82	201	91	40	57	98	23	14
Aphelenchoides	108	17	9	18	1307	130	5	0	16
Hoplolaimus	160	34	102	183	2	65	89	12	0

1 = maize-based system only
2 = sorghum-based system only
3 = pearl millet-based system only
12 = maize/sorghum system
13 = maize/pearl millet system
21 = sorghum/maize system
32 = pearl millet/sorghum system
34 = pearl millet/cowpea system
236 = sorghum/pearl millet/groundnut system

Table 5: Effect of *P. brachyurus* on growth of maize and sorghum in pot culture in a screenhouse at Samaru in 1991 and 1992.

Crop	Combine data for 1991 and 1992				Growth data for:							
	Plant height (cm)		Stem diameter		1991				1992			
					Plant height		Stem diameter		Plant height		Stem diameter	
	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN
Maize	44.5	62.8	3.0	5.1	44.0	62.0	3.1	4.8	45.0	63.7	2.9	5.4
Sorghum	37.2	45.2	2.9	4.1	38.3	43.7	2.7	3.6	36.0	46.7	3.0	4.6
LSD(0.05)	3.1		0.2		4.5		0.3		4.6		0.3	

IN = Inoculated
UN = Uninoculated

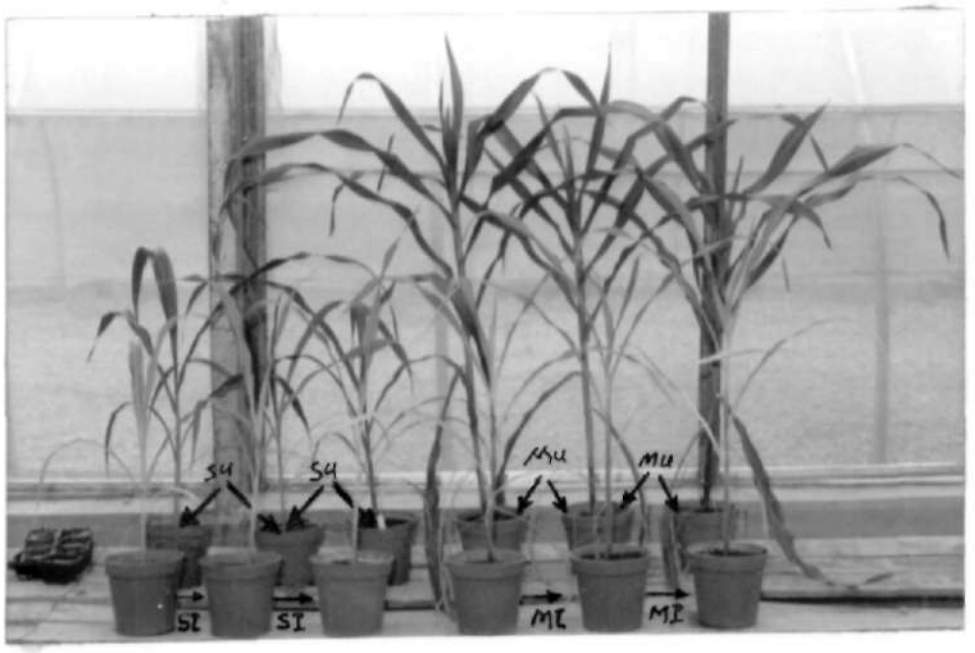


Plate 1. Effect of *P. brachyurus* on the growth of maize and sorghum at 60 days after inoculation.

MU = uninoculated maize (tall and green with thick stem)

MI = inoculated maize (stunted plants with chlorotic shoot; stems slender).

SU = uninoculated sorghum (tall and green with thick stem)

SI = inoculated sorghum (short with chlorotic leaves; stems slender).

Growth measurement at various stages of plant development showed that the rate of reduction in plant height and stem diameter was more at early stages of growth (between 20 and 40 days after inoculation) than at later stages (Table 6). Plant height of maize was reduced by 11, 29 and 39% at 20, 40, and 60 days after inoculation in 1991, and 16, 28 and 35 for corresponding periods in 1992. Reduction in stem diameter in 1991 and 1992 was 46, 47 and 44% and 40, 41 and 46% at 20, 40 and 60 days, respectively, after inoculation.

In the case of sorghum, plant height reduction associated with inoculation with *P. brachyurus* was 6, 14 and 15% in 1991, and 6, 24 and 31%, at 20, 40 and 60 days after inoculation, in 1992. Values for combined data for the two years were 6, 19 and 24%. Stem diameter on the other hand tended to be decreased more at 20 than at 40 days after inoculation. Thus, in 1991 percent decrease was 39 and 24% at 20 and 40 days after inoculation, respectively, and 34 and 32% in 1992, respectively. Combining the data for the two years showed a reduction of 36 and 29% at 20 and 40 days after inoculation.

Analysis of the combined data showed a similar trend as in the two years. Reduction in plant height and stem diameter at 20, 40 and 60 days after inoculation was 14, 30 and 37% for maize and 6, 19 and 24% for sorghum. There was no statistical difference in plant height and stem diameter between inoculated and uninoculated plants of both crops at 40 and 60 days after inoculation.

Table 6: Effect of *P. brachyurus* on growth of maize and sorghum at 20, 40, and 60 days after inoculation in pot culture in the screen house at Samaru in 1991 and 1992.

		Combine data for 1991 and 1992						Plant height of maize and sorghum in 1991 and 1992											
		20DAI		40DAI		60DAI		Data for 1991						Data for 1992					
								20DAI		40DAI		60DAI		20DAI		40DAI		60DAI	
Crop	Growth parameter	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN	IN	UN
Maize	PH	38.0cd	44.0cd	46.5cd	66.5ab	49.0cd	78.0a	50.0bc	45.0bc	45.0bc	63.0ab	47.0bc	78.0a	36.0	43.0	48.0	70.0	51.0	78.0
	SD	2.6bc	4.4a	3.0bc	5.1a	3.6b	5.9a	2.5bc	3.9b	3.0bc	4.6a	3.9b	5.9a	2.6bc	4.8a	2.9bc	5.5a	3.3bc	5.9a
Sorghum	PH	32.0d	34.0d	37.5d	46.5cd	42.0cd	55.0bc	33.0c	35.0c	38.0c	44.0bc	44.0bc	52.0bc	31.0	33.0	37.0	49.0	40.0	58.0
	SD	2.3bc	3.6bc	3.0bc	4.2	3.4bc	4.6a	1.9c	3.1bc	2.8bc	3.7b	3.4bc	4.0b	2.7bc	4.1b	3.1bc	4.6a	3.3bcNS	5.2a

Mean followed by the same letter within a row are not significantly different (p=0.05) as determined by Duncan's Multiple Range Test.
IN = Inoculated
UN = Uninoculated
NS = Not significant
DAI = Days after inoculation
PH = Plant Height
SD = Stem Diameter

Reduction in plant height and stem diameter resulted in 49a reduction in fresh weight of both shoots and roots (Table 7). Shoot weight of maize dereased by 40% in 1991 and 26% in 1992. Corresponding values for sorghum for the two years were 24 and 29%, respectively. Root weight was similarly affected for both crops. Percent reduction for maize was 52 and 55% in 1991 and 1992, respectively, but was lower for sorghum being 32% in 1991 and 27% in 1992.

Root system was generally reduced for both crops (Plates 2 and 3). Primary roots were poorly developed with a few secondary roots. Root hairs were particularly few in maize. Roots of maize exhibited small dark-brown to black lesions with necrosis in some cases (Plate 3). Infected plants were chlorotic (Plate 1).

Nematode multiplication was higher in maize than in sorghum (Table 8) as can be seen from the number of nematodes per 100 g of roots. Populations of nematodes in both soil and roots were about two times more in maize than in sorghum in both years. However, the root:soil nematode ratio was about the same (1:1:4) for both crops.

4.3 Effect of Initial Population Density of *P. brachyurus* on growth of maize

Plant height declined significantly with increasing initial nematode population density in both years (1991 and 1992) compared to the check. Reduction in plant height (Plate 4) was significant (P=0.05) even at the lowest initial nematode population density of 500 nematodes per pot (Table

Table 7. Effect of *P. brachyurus* on root and shoot weight of maize and sorghum in pot culture in the screenhouse at Samaru in 1991 and 1992.

Crop	Shoot weight (g)				Root weight (g)			
	1991		1992		1991		1992	
	In	Un	In	Un	In	Un	In	Un
Maize	34.0	56.4	37.0	49.8	9.5	19.6	6.3	14.1
Sorghum	28.0	37.0	23.3	29.1	7.3	10.8	6.1	8.3



Plate 2. Effect of *P. brachyurus* on sorghum root development at 60 days after inoculation

SI = Roots of inoculated sorghum (roots reduced in length)

SU = Roots of uninoculated sorghum (well developed root system).

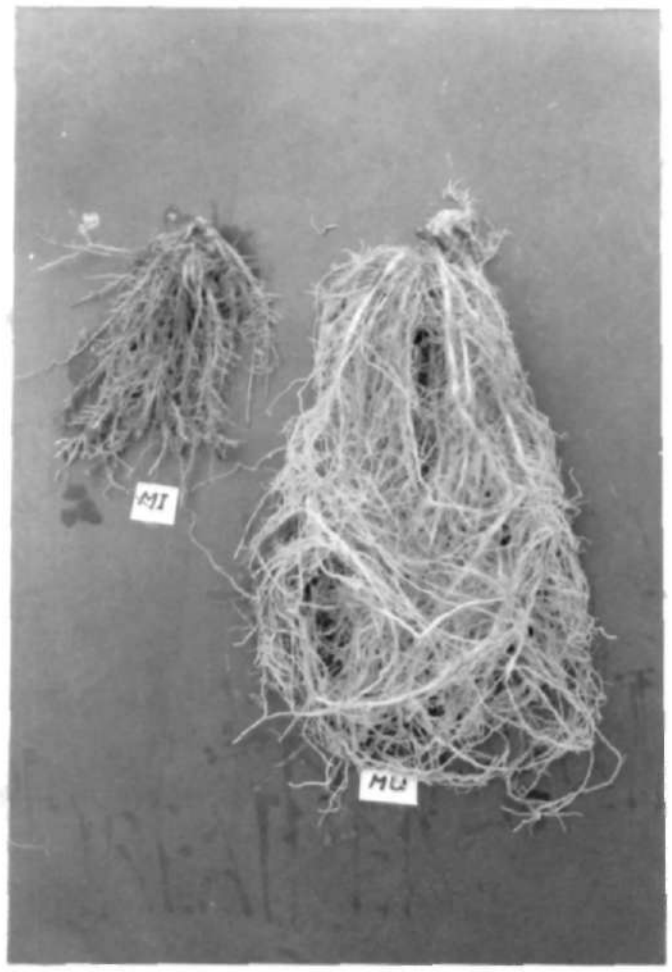


Plate 3. Effect of *P. brachyurus* on maize root development at 60 days after inoculation.

MI = Roots of inoculated maize (highly reduced and necrosed).

MU = Roots of uninoculated maize (well developed root system without necrosis).

Table 8: Population of *P. brachyurus* in maize and sorghum roots and in the soil 60 days after inoculation in pot culture in the screen house at Samaru in 1991 and 1992.

Crop	1991 Nematode population in:				1992 Nematode population in:			
	500ml of soil	100g of roots	R	Soil: root ratio	500ml of soil	100g of root	R	soil: root ratio
Maize	4,760	7,118	2.4	1:1.5	4,977	8,150	2.5	1:1.6
Sorghum	2,355	3,884	1.2	1:1.6	2,864	4,120	1.4	1:1.4



Plate 4. Effect of initial population density of *P. brachyurus* on the growth of maize at 60 days after inoculation

T1 = 0 (control) - tall plant

T3 = 1000 nematodes/pot - shorter plant than control

T6 = 8000 nematodes/pot - shortest plant.

9). In 1991, reduction in plant height was not different statistically at pre-plant populations of between 500 and 2000 nematodes; however, the heights of these plants were significantly lower than those of plants grown in soil with initial populations of 4000 and 8000. In 1992, the heights of plants were significantly different at each of the initial population densities.

Results of the combined analysis showed a similar effect with those of 1992. Reduction in height of plants ranged from 13% at P_i of 500 nematodes to 51% at P_i of 8000 nematodes/5-litre pot. Further analysis showed that the rate of reduction in height was more at earlier than at later stages of growth. For instance, plant height decreased by 7%, 18% and 10% at 20, 40 and 60 days respectively after inoculation with P_i of 500 nematodes per pot (Tables 10a and 10b). Corresponding values at P_i of 8000 nematodes per pot were 39, 55 and 54%.

Similar observations were made in the combined data for stem diameter. It decreased from 10% at P_i of 500 nematodes to 50% at P_i of 8000 nematodes per pot. Decrease of 3, 11 and 13% were recorded at 20, 40 and 60 DAI at P_i of 500 nematodes compared to 35, 46 and 54% at P_i of 8000 nematodes per 5-litre pot.

Reduction in plant height was associated with a decline in shoot and root weight (Table 9). In 1991, there was no statistical difference between the shoot weight of the check plants and that of plants grown in soil inoculated with 500

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Table 9. Effect of initial population densities of *P. brachyurus* on the growth of maize and development of the nematode 60 days after inoculation in pot culture in the screenhous at Samaru in 1991 and 1992

Initial nematode population density	Combined data for 1991 and 1992							1991							1992						
	PH (cm)	SD (cm)	Sw (g)	RW (g)	1R	Pf	R	PH (cm)	SD (cm)	Sw (g)	RW (g)	1R	Pf	R	PH (cm)	SD (cm)	Sw (g)	RW (g)	1R	Pf	R
0(Control)	64.0a	5.2a	126.1a	22.1a	0.0d	0.0f	0.0	64.0a	4.9a	130.1a	19.6a	0.0c	0.0	0.0	64.0a	5.5a	122.0a	24.5a	0.0c	0.0d	0.0
500	55.8b	4.7b	110.3b	19.7a	105.5c	895	1.8	56.7b	4.6a	112.2a	17.8a	98.0b	825d	1.7	55.0b	4.8b	108.3b	21.6a	113b	965cd	1.9
1000	52.7c	3.9c	83.6c	15.4b	116.0b	2107	2.1	54.7b	4.0b	70.2b	14.7b	106.0b	2165c	2.2	50.7c	3.8c	97.1b	16.0b	126b	2048c	2.0
2000	45.3d	3.4d	61.5d	11.5c	155.5a	4848c	2.4	51.3b	3.6bc	54.5bc	9.7c	155.0a	4685b	2.3	39.3d	3.3cd	68.4c	13.3bc	156a	5011b	2.5
4000	36.7e	3.0e	52.8de	8.6d	155.5a	6592b	1.6	39.8c	3.0cd	48.6c	7.6cd	162.0a	6965a	1.7	33.7e	2.9de	57.1cd	9.6cd	149a	6218ab	1.6
8000	31.3f	2.6f	46.5e	5.9e	152.5a	7513a	0.9	34.0c	2.8d	40.1c	5.9d	158.0a	7812a	1.0	28.7f	2.6e	53.0d	5.8d	147a	7214a	0.9

Means followed by the same letter within a column are not significantly different different (P = 0.05) as determined by Duncan's Multiple Range Test.

PH = Plant height
SD = Stem diameter
SW = Shoot weight
RW = Root weight
IR = Infection rate
Pf = Final population density in the soil
R = Reproduction factor

Table 10a. Combined analysis of effect of initial population densities of *P. brachyurus* on growth of maize at 20, 40 and 60 days after inoculation in pot culture at Samaru in 1991 and 1992

Initial nematode population density	Combined data for 19991 and 1992					
	Plant height (cm) at:			Stem diameter (cm) at:		
	20 DAI	40 DAI	60 DAI	20 DAI	40 DAI	60 DAI
0(control)	47.0defg	70.5ab	74.5a	4.0cdef	5.6ab	6.1a
500	43.5efgh	57.5bcde	66.5ab	3.9defg	5.0abc	5.3abc
1000	40.5fgh	56.5bcde	61.0abcd	3.3efg	4.1cdef	4.4bcde
2000	35.5gh	48.0def	52.5cdef	3.1efg	3.4efg	3.8defg
4000	32.5h	38.2fgh	39.5fgh	2.7fg	3.0fg	3.2fg
8000	28.5h	31.5h	34.0gh	2.6g	2.7fg	2.8fg

Means followed by the same letter in the same column or row are not statistically different (P = 0.05) based on Duncan's Multiple Range Test.
DAI = Days after Inoculation

Table 10b. Effect of initial population densities of *P. brachyurus* on growth of maize at 20, 40 and 60 days after inoculation in pot culture at Samaru in 1991 and 1992

Initial nematode population density	Data obtained in 1991						Data obtained in 1992					
	Plant height (cm) at:			Stem diameter (cm) at:			Plant height (cm) at:			Stem Diameter (cm) at:		
	20 DAI	40 DAI	60 DAI	20 DAI	40DAI	60 DAI	20 DAI	40 DAI	60 DAI	20 DAI	40 DAI	60 DAI
0 (control)	48bcdef	72a	72a	4.2abcde	5.0abc	5.6a	46.0bcd	69.0a	77.0a	3.8cde	6.2ab	6.5a
500	45cdef	57abcde	68ab	4.1abcde	4.7abc	5.1ab	42.0bcde	58.0ab	65.0ab	3.6cde	5.3abcd	5.4abc
1000	41cdef	60abcd	63abc	3.4bcd	4.1abcde	4.5abcd	40.0cde	53.0ab	59.0ab	3.1e	4.1bcde	4.3bcde
2000	40def	55abcde	59abcd	3.3cde	3.7bcde	3.8bcde	31.0de	41.0cde	46.0bcd	2.9e	3.2de	3.7cde
4000	38def	40def	41cdef	2.8de	3.0de	3.3cde	27.0de	36.0de	38.0cde	2.6e	2.9e	3.1e
8000	33f	34f	35ef	2.6e	2.9de	2.9de	24.0e	29.0de	33.0de	2.5e	2.5e	2.7e

Means followed by the same letter in the same column or row are not statistically different (P = 0.05) based on Duncan's Multiple Range Test.
DAI = Days after Inoculation

nematodes per 5-litre pot. Statistical difference was, however, observed in 1992. Results of the combined data showed a significant difference between the control and the lowest P_i. However, the root weight of plants inoculated with the lowest preplant nematode population (500/5-litre pot) was significantly lower than that of the check plants. P_i of 1000 to 8000 reduced both plant height and root weight significantly when compared with the control. Decrease in shoot weight ranged from 13 to 63% while that of root weight ranged from 11 to 73% at P_i of 500 to 8000 nematodes per 5-litre pot.

Invasion of the root and the subsequent reproduction within the root by the nematode increased with increasing P_i (Table 9). The combined data showed that invasion increased from 105.5 nematodes at initial population of 500 nematode/5-litre pot to a maximum value of 155.5 nematodes at initial population of 2000 and 4000 nematodes per 5-litre pot; the value of 152.5 nematodes at 8000 nematodes/pot was not statistically less than 155.5 nematodes.

Increase in invasion with increasing P_i was accompanied by increase in multiplication of the nematode as can be seen from the final nematode population density (Pf) and reproduction factor (R) of the combined data (Table 9). Reproduction increased at a declining rate as the initial population density of the nematode is increased. Percentage increase in reproduction was 44% at initial population density

of 500 nematodes per 5-litre pot, whereas it (reproduction) increased by 53, 58, 39 and 6% at Pi of 1000, 2000, 4000 and 8000 nematodes, respectively.

The effects of initial population density ($P_{i)}$ of *P. brachyurus*, on the growth parameter of maize were also subjected to correlation analysis (Tables 11 a and b). There was a high negative correlation between the P_i on the one hand and each of plant height, stem diameter, shoot weight and root weight, on the other. On the other hand, invasion and final nematode population density (Pf) were positively correlated with P_i. Plant height was positively correlated with stem diameter and root weight.

Regression analysis showed that a quadratic model best described the ralationship between initial population density and the parameters measured.

Populations of total variation accounted for by linear regression models were 0.47, 0.45, 0.57, 0.65, 0.35 and 0.73 for plant height, stem diameter, shoot weight, root weight, infection rate and final nematode population density, respectively.

Table 11a. Correlation between initial population density and plant growth and nematode population density.

Plant height	1.0000		
Stem diameter	0.8240	1.0000	
Initial population density (Pi)	-0.6885	-0.6764	1.0000

	Plant height	Stem diameter	Initial population density (Pi)

Table 11b. Matrix of correlation between plant and nematode characteristics as influenced by initial population density

		I	II	III	IV	V
I	Shoot weight	1.0000				
II	Root weight	0.8376	1.0000			
III	Invasion	-0.8095	-0.7475	1.0000		
IV	Final population density (pf)	-0.8769	-0.8750	0.7650		
V	Initial population density (Pi)	-0.7646	-0.8066	0.5995	0.8554	1.0000
		Shoot weight	Root weight	Invasion	Final population density (Pf)	Initial population density (Pi)

		I	II	III	IV	V

Corresponding values for quadratic model were 0.55, 0.60, 0.82, 0.78, 0.70 and 0.89.

The analysis showed that plant height, stem diameter, shoot weight and root weight (growth parameters) declined almost linearly as the initial nematode population density increased from 500 up to 4000 nematodes per pot up to 4000 nematodes/pot (Figs. 5 - 8), but began to decline thereafter. Only a slight decrease in all parameters was observed thereafter except shoot weight in which a slight increase was recorded at P_i of 8000 nematodes.

Nematode invasion and final population density on the other hand increased with increase in P_i (Figs. 9 and 10). Increase in both parameters was almost linear until at P_i of 4000 when a plateau was attained.

4.4 Reaction of Some Maize Cultivars to *P. brachyurus*

Results presented in Table 12 show that *P. brachyurus* multiplied successfully in all the varieties of maize screened. However, three varieties, namely, open pollinated variety (TZESR - W) and two bybrids (8505-13 and 8505-5) were most suitable for the namatode, having nematode populations of over 10,000 nematodes per 100 g of roots, consequently high percentage invasion.

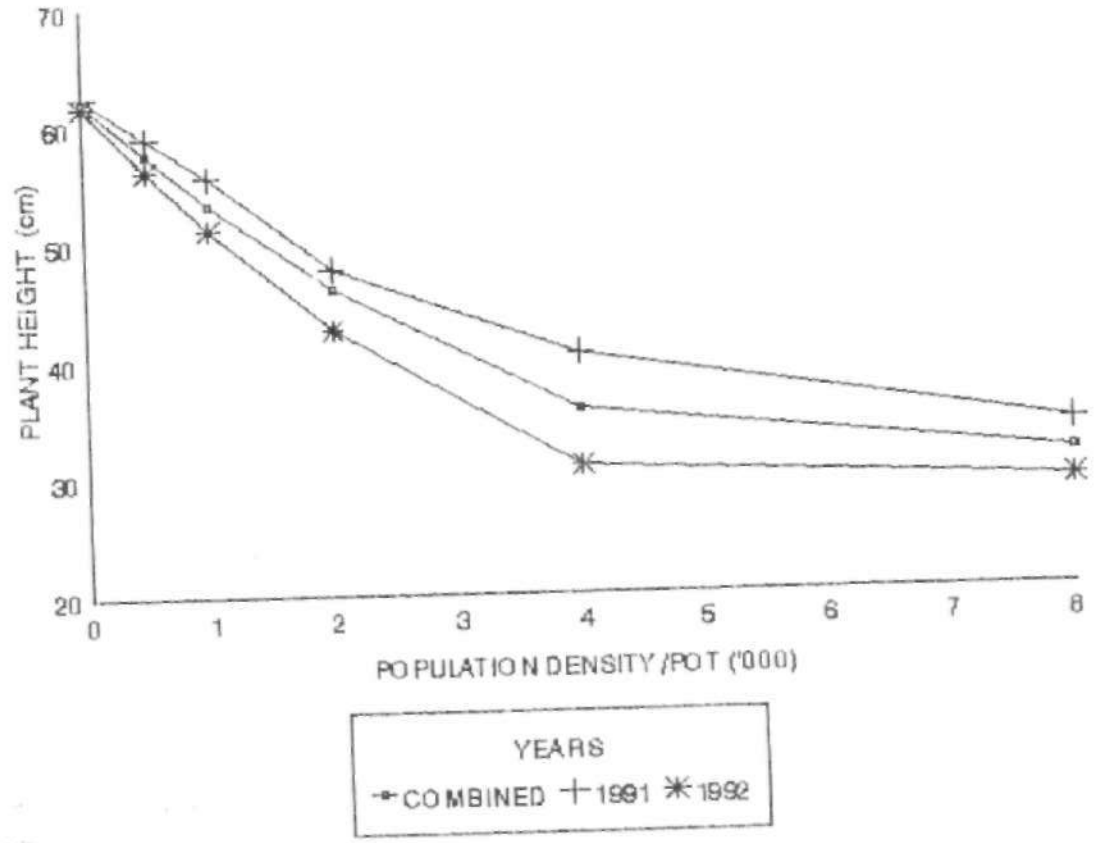


Fig. 5. Relationship of height of maize plant on initial Population density of P. brachyurus

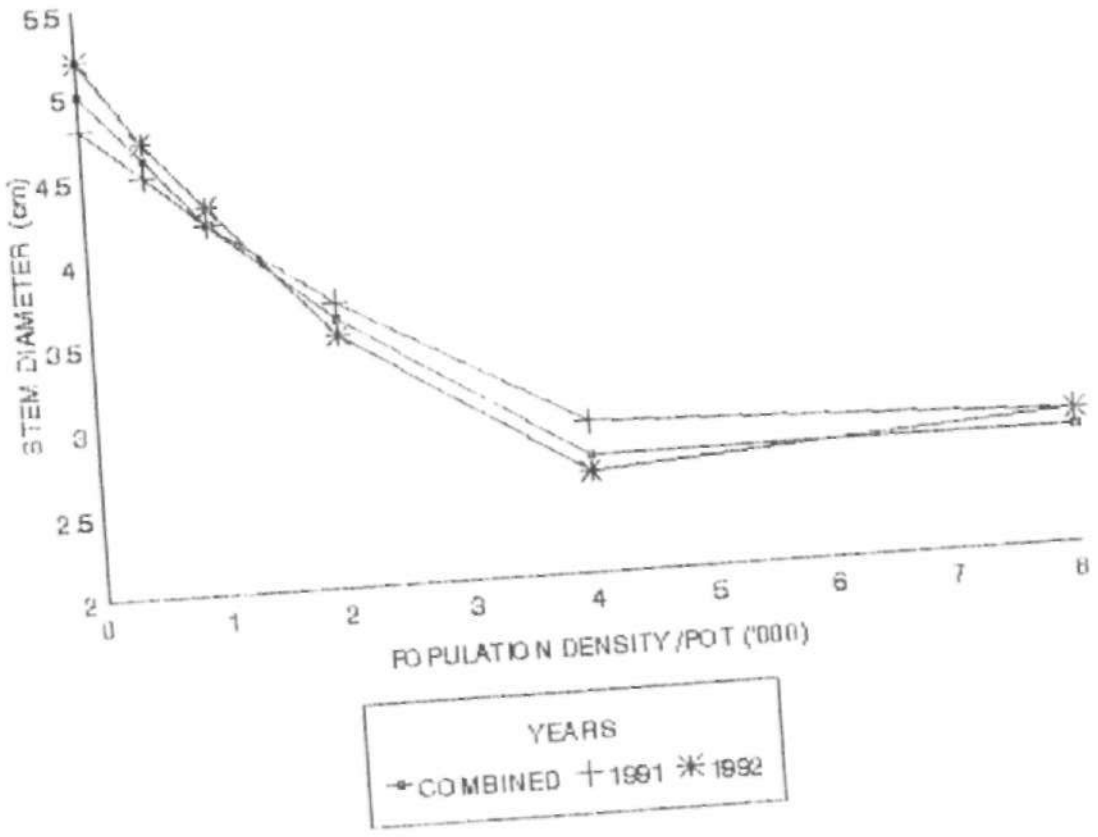


Fig. 6. Relationship of diameter of maize stem on initial population density of P. brachyurus

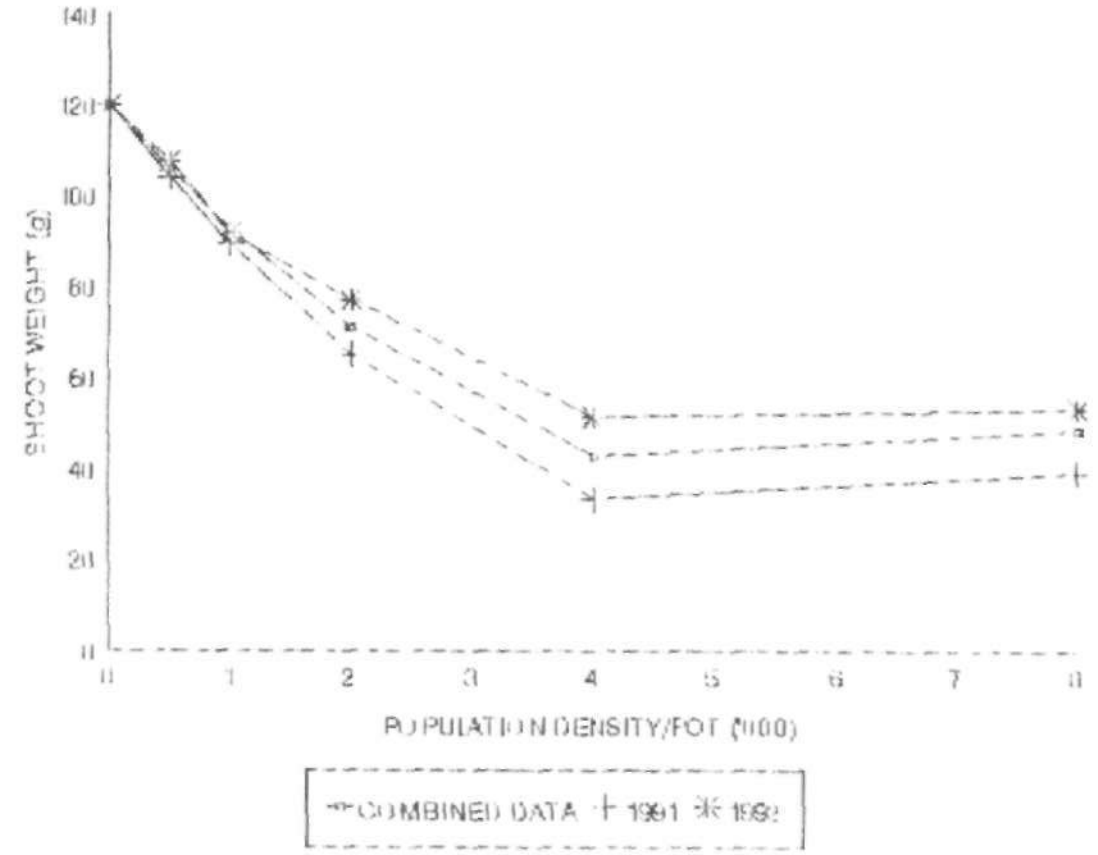


Fig. 7. Relationship of shoot weight of maize on the initial population density of P. brachyurus

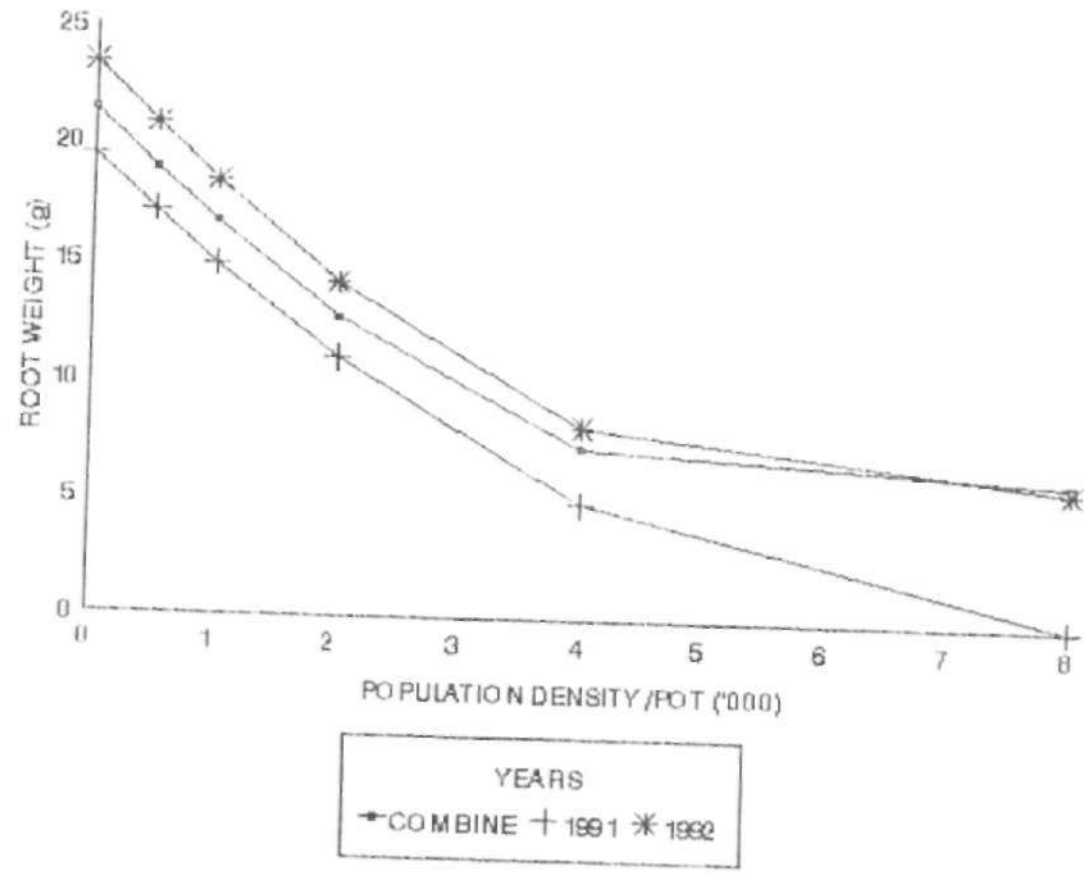


Fig. 8. Relationship of root weight of maize on the initial population density of P. brachyurus

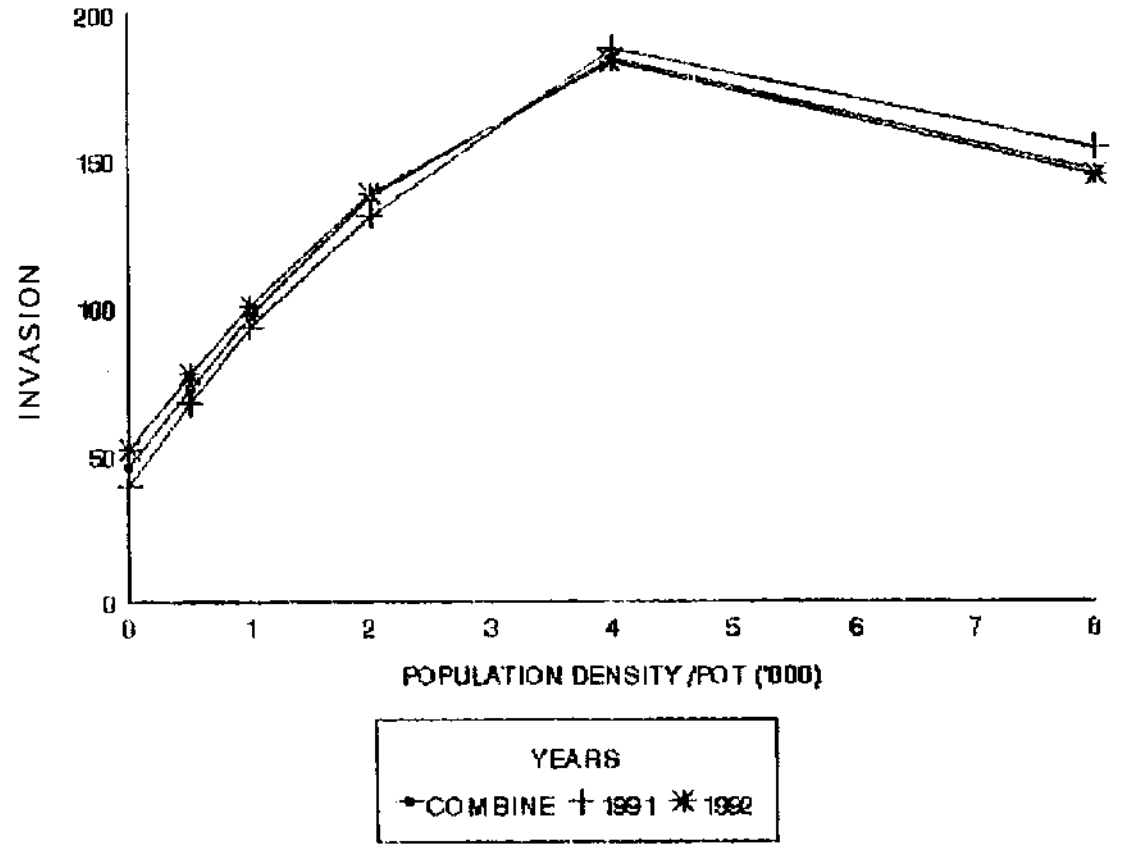


Fig. 9. Relationship of penetration of P. brachyurus on its initial population density

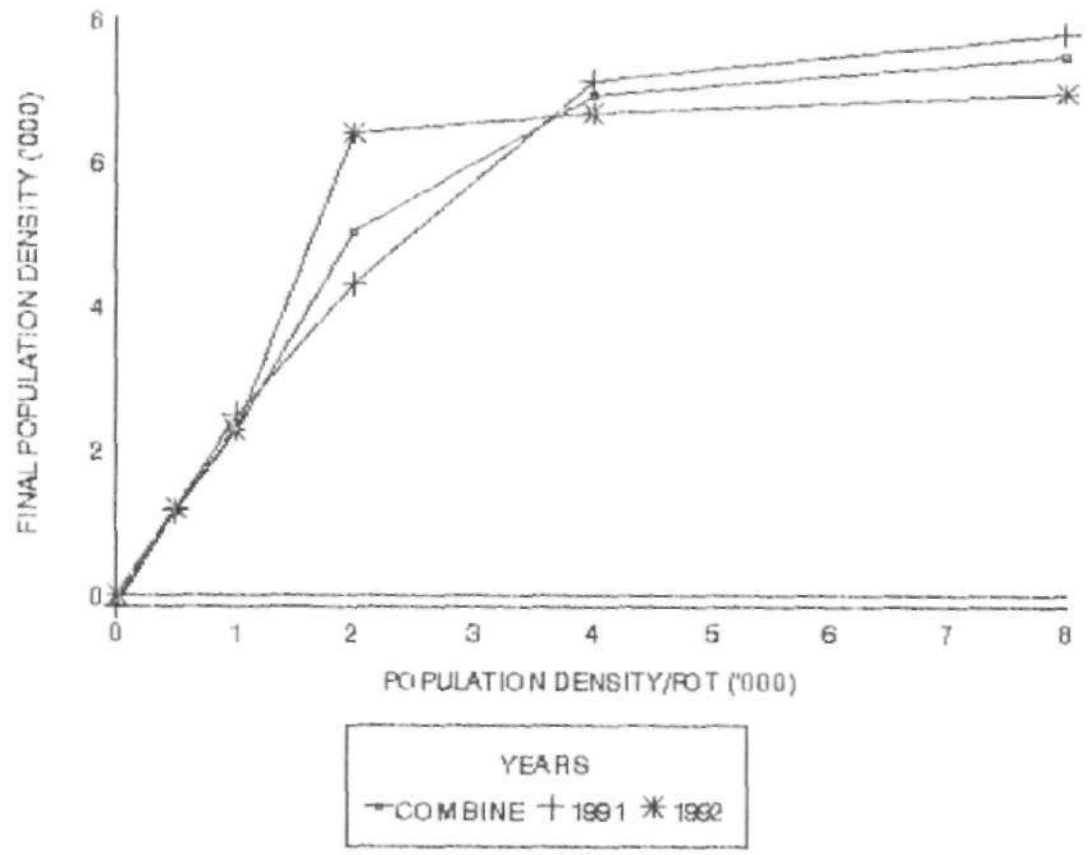


Fig. 10. Relationship of final population density of P. brachyurus on its initial population density

Table 12. Reaction of maize cultivars to the lesion nematode, *Pratylenchus brachyurus* in pot culture in the screenhouse at 60 days after sowing at Samaru in 1992.

Maize variety	Nematode population/ 500 ml of soil	Nematode population/100g of roots	Percent Invasion
TZESR-W	6,010	10,020	5.
TZESR-Y	5,468	8,793	4.4
TZB	6,163	9,208	4.6
TZBSR	5,495	8,250	4.1
$TZPBSRC_2$	5,040	8,253	4.1
8434-11	5,128	9,295	4.6
8505-2	5,500	8,960	4.5
8505-13	6,281	10,395	5.2
8505-5	6,263	10,435	5.2
8321-21	6,475	8,445	4.2
8321-18	5,885	9,525	4.8
AG-Samaru	5,776	9,315	4.7
AG-Ilorin	5,103	8,755	4.4
NG3WC-2	5,780	8,603	4.3
LSD	316.8	549.41	

4.5 Population Changes of *P. brachyurus* in Furadan-treated and untreated Maize

Soil and root population changes of *P. brachyurus* on maize were monitored in the field during the 1992 and 1993 cropping seasons. Results obtained are presented in Table 13.

Nematode population density at planting was 299 and 270 per 500 ml of soil in 1992 and 1993, respectively. Nematode populations in untreated soil increased from 37% by 5th July to 82% by 18th October, 1992. Peak populations were attained towards the end of September. In 1993 however, increase in nematode population was 14% by 5th July to 79% by 18th October. Unlike in 1992, peak populations were attained by early September in 1993. Peak populations went down by 40% after September in 1992, and 56% between 6th and 28th September, 1993. Combined data from the two years suggested that peak populations were attained by early September.

Nematode populations in Furadan-treated soil on the other hand, declined sharply after furadan application. Percent reduction was 71 and 77% by 5th July in 1992 and 1993, respectively. Populations began to increase thereafter but never reached the P_i.

Population changes in the roots were similar to those in the soil. Thus, in 1992, the nematode population in roots of untreated soil increased from 1180 per 100 g of root on 5th July to 6905 on 16th August and declined thereafter to 1950 on 28th September and 304 on 18th October. Similarly, in 1993, the root population of nematodes increased from 1103 on 5th

Table 13. Population changes of *P. brachyurus* in furadan-treated and untreated maize

Date of sampling	Data obtaibed in:											
	Combined data for 1992 and 1993				1992				1993			
	Nematode population in 500ml of soil		Nematode population in 100g of roots		Nematode population in 500ml of soil		Nematode population in 100g roots		Nematode population in 500ml of soil		Nematode population in 100g roots	
	Treated	Un-treated	Treated	Un-treated	Treated	Un-treated	Treated	Un-treated	Treated	Un-treated	Treated	Un-treated
5th July	77b	396e	42									
16th August	284a	2317b	169	6948	294a	2217b	181	6905	275	2416b	156	6992
6th Sept.	225ab	2863a	272	5592	186ab	2714a	315	5782	263	3012a	229	5403
28th Sept.	186ab	2387b	41	1885 2053	171ab	2856a	27	1950	201	1917c	54	1825
18th Oct.	86b	1511c	25	377	95b	1710c	21	304	77	1312d	29	450
LSD	177.4		300.7		191		314.1		316		542.3	
CV(%)	18.9		23.1		13.4		16.3		23.6		28.5	

All values are a mean of three counts.

July to 6992 on 16th August; subsequently, it declined to 1825 on 28th September and 450 on 18th October.

Results also show that few nematodes invaded maize roots in both years after treating the soil with furadan. Out of 299 and 270 nematodes, only 54 and 30 invaded the roots by 5th July in 1992 and 1993, respectively. Nematode populations increased thereafter but never reached the initial population densities in both years.

Untreated plants were stunted and had chlorotic leaves. Roots of untreated plants had begun to decay and slough-off by the end of September. Roots of plants grown in furadan-treated soil did not decay. Root system of plants in untreated soil was reduced compared to that of plants grown in furadan treated soil.

Soil treatment with furadan and its attendant reduction in namatode population culminated in enhanced maize growth and, consequently increased yield. Yield loss in untreated plants was as high as 38%. Yield of furadan-treated maize was 3.7 kg/600 m^2 while that of untreated maize was 2.3 kg/600 m^2.

CHAPTER FIVE

5.0 DISCUSSION

Results of the present study on plant-parasitic nematodes associated with maize, sorghum and pearl millet show that twenty genera of plant-parasitic nematodes are closely associated with the three crops. This agrees with earlier reports by Caveness (1967) on plant-parasitic nematodes associated with field crops in Nigeria Claflin (1984) in a review of nematodes of sorghum, and Emechebe *et al.* (1980) on diseases of crops in Nigeria. Similarly, Norton and Agudelo (1984) on plant-parasitic nematodes associated with maize in two locations in Columbia, Tiyagi *et al.* (1987) on population build-up of phytonematodes associated with pearl millet in India, Sharma (1988) on nematode diseases of ICRISAT mandate crops and Weber *et al.* (1995) on nematodes as production constraints in cereal-based cropping systems of the northern guinea savanna of Nigeria, reported close association of some of these nematodes with the three crops.

Cluster analysis of the data shows that of the twenty nematode genera identified, six (*Helicotylenchus, Pratylenchus, Tylenchus, Scutellonema, Ditylenchus* and *Hoplolaimus)* occurred more frequently and in high populations on the three crops. These nematodes, except *Ditylenchus* and *Tylenchus,* have similarly been reported elsewhere to predominate the nematode fauna associated with these crops. Thus, Addoh, (1971) working in Ghana, reported that

Helicotylenchus multicinctus, *Pratylenchus brachyurus* and *Scutellonema bradys* were the main nematodes on the three crops; Claflin (1984) reported *Pratylenchus* spp., *Meloidogyne* spp., *Tylenchorynchus* spp. and *Belonolaimus* spp. to be implicated in most of sorghum yield losses; Norton and Agudelo (1984) working on maize in Columbia found that the predominant nematode pests were *Pratylenchus* and *Helicotylenchus*; Tiyagi et al. (1987) working on pearl millet in India, found *Hoplolaimus indicus* and *Tylenchorynchus brassicae* to be consitently high, with *Helicotylenchus indicus* and *Pratylenchus coffeae* maintaining moderate populations; and Swarup and Sosa-Moss (1990) on the three crops, reported that the main nematode genera were *Pratylenchus* and *Heterodera* species (on maize), *Pratylenchus*, *Tylenchorynchus* and *Meloidogyne* species (on sorghum) and *Meloidogyne*, *Tylenchorynchus* and *Pratylenchus* species (on perarl millet). Nevertheless, widespread occurrence of *Ditylenchus* and *Tylenchus* species on maize in the northern guinea savanna zone of Nigeria has been reported by Weber *et al.* (1995) and Chindo et al. (1997).

The preponderance of some of these nematodes suggests that they may be important in maize, sorghum and pearl millet production. Results of the present study on pathogenicity of *P. brachyurus* on maize and sorghum and of assessment of yield loss in maize associated with the nematode suggests that *P. brachyurus* is an important pathogen on maize in the Nigerian

savannas. The importance of *Pratylenchus* spp. on maize has been demonstrated elsewhere. Walters (1979) reported yield increases of 33 - 128% following the application of nematicides on maize infested with *Pratylenchus* spp. in South Africa. Bergeson (1978) obtained yield increase of 10 - 54% after applying carbofuran in *Pratylenchus* - infested maize in the U.S.A. In South-western Nigeria, Egunjobi (1974) found that *P. brachyurus* was responsible for 28.5% yield reduction in maize. No such work has been reported on *P. brachyurus* on maize or sorghum in the savanna ecologies of Nigeria. The yield loss recorded in this study is considered to be on the high side. Yield loss due to *P. brachyurus* is likely to be lower than 38% since yield loss attributable to other nematodes was not measured.

Nematode distribution and abundance varied from field to field, suggesting that the relative occurrence and abundance is determined by several factors within the environment. The effects of these may or may not be species-specific.

Effect of cropping systems on the frequency and populations of the nematodes was considered in this study. Frequency of occurrence and population densities of nematodes were higher in fields with systems containing any of the cereal crops alone or in combination than in fields of systems involving both cereals and legumes. Maize-based systems generally had higher frequencies and population densities of nematodes than the other systems, suggesting that

intensification of sole cropping of maize is likely to be associated with risk of nematode build-up, while rotation and/or inter-cropping with legumes would probably minimize nematode problems. These results agree with results of Webber *et al.* (1995) and Chindo *et al.* (1997), who reported an increasing risk of nematode build-up, particularly *Pratylenchus* and *Aphelenchoides* species as maize production is intensified in the northern Guinea savanna of Nigeria. The results also agree with those of Johnson (1985) in a crop rotation study involving eight crops in root-knot infested field in the U.S.A., and Hackeney and Dickerson (1975) in the use of four crops for the control of *M. incognita* and *P. alleni* also in the U.S.A. who reported that crop rotations and inter-cropping of susceptible crops with less susceptible ones greatly reduce nematode problems. These results are however at variance with those of Abd-Elgawad and Saad (1989) in Egypt who reported a quick build-up of *P. brachyurus* after only three consecutive cycles of maize/common bean inter-cropping. The apparent discrepancy may be ascribed to the nematode species and/or the choice of inter-crop.

The studies of pathogenicity of *P. brachyurus* on maize and sorghum showed that the nematode was pathogenic on both crops. *P. brachyurus* invaded and reproduced in both maize and sorghum. Nematode reproduction and damage resulted in corresponding reduction in plant growth as shown by reductions in plant height, stem diameter and shoot and root weights.

This agrees with earlier reports by Tarte (1971) in Panama on maize and *P. zeae* and Egunjobi (1974) in south-western Nigeria on maize and *P. brachyurus*. Reduction of tops in this study was as height as 37% for plant height of maize and 26% of sorghum, while stem diameter was reduced by 41 and 29% for maize and sorghum, respectively. Decrease in shoot weight was about 33 and 22% for maize and sorghum. These values compare favourably with those of Tarte (1971) in which dry weight of tops of maize was reduced by 11.9 to 38% depending on initial population density.

The relative reduction in plant growth was higher at earlier than at later stages of plant growth. This may be due to greater activity of the nematodes on plants that are young and inherent tolerance of the plants. It has been shown in Panama that at high nematode population density (over 5000 nematodes/pot) initial population densities of *P. zeae* are not maintained on maize (Tarte, 1971). In cases of high Pi, plants may die. Death of plants, even at the highest Pi (8000 nematodes) was not recorded in this study.

Results of the study in pot culture on effect of initial population density of *P. brachyurus* on the maize cultivar TZESR - W, show that plant growth (shown by plant height, stem diameter and shoot weight) was significantly reduced at all populations tested (500 to 8000 nematodes per pot). Reduction in plant height ranged from 13% at 500 nematodes to 51% at 8000 nematodes/5-litre of potted soil, while stem diameter and

shoot weight were reduced by 10 to 50% and 13 to 63% at the same range of initial soil population densities. This implies that nematode populations of *P. brachyurus* as low as 500 are capable of causing significant damage on maize. This is in consonance with the report of Sharma (1988) who reported damaging population levels of *P. zeae* on sorghum in India to be between 200 and 2000 nematodes per litre of soil.

Invasion and multiplication of the nematode in maize was found to increase as the initial population increased. Both parameters increased to a maximum at pre-plant population density of 2000 nematodes per 5 litres of potted soil and declined thereafter. Such observations were made by Gokte and Swarup (1984) who reported that an increase of 1000 eggs and juveniles per gramme of soil resulted in a four-fold increase in penetration, whereas the next ten-fold increase caused only a two-fold increase in cyst production of *Heterodera avenae* on wheat. Such decline in cyst production is attributable to competition for food and space, which becomes severe at higher initial nematode population densities (Olthof and Potter, 1977). In another study, Tarte (1971) found that population of *P. zeae* increased linearly on maize up to 1,900 nematodes/pot but began to decrease thereafter so that P_i of over 5000 could not maintain the P_i levels.

Correlation analysis between P_i and the growth parameters of maize studied showed a negative correlation between the P_i on the one hand and each of maize plant height, stem diameter,

shoot weight and root weight on the other. Similar observations were made by Tarte (1971) who found a significant negative correlation between initial population density of *P. zeae* and dry weight of maize in Panama. This indicates that root development greatly influences the growth of tops. Well-developed roots will support good growth of tops which ultimately determine crop yield. On the other hand, invasion and nematode multiplication were positively correlated with P_i. Plant height was positively correlated with stem diameter and root weight.

Population changes of *P. brachyurus* and its effect on yield of maize were studied in the field in furadan-treated and untreated soil. Nematode populations in the soil in untreated maize planted on 25th June, 1992 and 1993 began to increase two weeks after planting and reached a peak towards end and early September in 1992 and 1993, respectively. Populations began to decline in early September towards October. Nematode populations in the roots both peaked by mid-August in both years.

The build-up of nematode populations in the soil up to September implies that environmental conditions during the rainy season were favourable for the multiplication of the nematodes. The cool rainy season characteristic of the Zaria area with atmospheric temperatures ranging from 18 - 30°C (Appendix 2 and 3) and light sandy loam soil appear to have favoured the reproduction of *P. brachyurus*, both in the roots

and in the soil. This is supported by the report of Olowe and Corbett (1976) and Zirakparva *et al*. (1980) who reported that *P. brachyurus* reproduces well at 30°C. Similarly, Egunjobi (1974) in her own study in south western Nigeria, showed that the development of *P. brachyurus* increased during the rainy season. Peak populations in soil and roots of maize sown in February were attained in June (3 - 4 months after sowing) and in July (4 - 5 months after sowing), respectively. This does not agree with the results of this study in which peak populations both in the soil and roots were attained two months after sowing. The apparent discrepancy may be due to varietal reaction. The results of the study on the reaction of maize cultivars to infection by *P. brachyurus* tend to support this view. Most of the hybrids (improved varieties) appeared to be more susceptible to *P. brachurus* than less improved ones, e.g. TZB.

SUMMARY AND CONCLUSIONS

This study was undertaken in order to:

(i) identify the plant-parasitic nematodes that are associated with maize, pearl millet and sorghum in the Nigerian savannas;

(ii) to study the pathogenicity of one of the most important parasitic nematodes on maize, and the reactions of some maize cultivars to the nematode;

(iii) study the effect of varying population densties of the nematode in (ii) above with the view to determining the lowest population capable of causing economic damage on maize;

(iv) study the population dynamics and estimation of economic importance of the nematode in (ii) above under field conditions.

The results of these studies have shown that 20 genera of plant-parasitic nematodes were associated with maize, pearl millet and sorghum at varying frequencies and population densities in farmers' fields. Data analysis classified the nematodes into three broad groups. Group I, consisted of nematodes that occurred frequently and usually in high numbers (e.g. *Helicotylenchus*, spp.), or relatively less frequently but in very high numbers, e.g. *Aphelenchoides* spp.; Group II comprises nematodes that were not widely distributed and

usually occurred in low numbers. Group III, which consists mainly of nematodes that occurred occasionally and in all cases, in very low numbers. Out of the 20 nematode genera identified, six (*Helicotylenchus, Tylenchus, Pratylenchus, Scutellonema, Aphelenchoides* and *Hoplolaimus)* appear to be the most important in terms of their frequency of distribution and their soil population densities.

Further analysis of the association and distribution patterns of the six nematode genera in the fields resulted in eight field groups; each group exhibiting differing distribution patterns for the nematode species, depending, apparently, on prevailing biotic and abiotic factors in the field. Analysis of variance showed that field conditions and nematode characteristics affected nematode distribution and population densities minimally (less than 20%). A greater percentage of the variability (over 80%) was accounted for by other factors that were not measured. Cropping systems was found to be one of the field variables influencing nematode distribution. Nematode distribution and population densities were higher in maize-based systems than in sorghum, sorghum/millet or systems involving cereals and legumes.

A study of the pathogenicity of *Pratylenchus brachyurus,* one of the widely occurring species on maize and sorghum showed that it is pathogenic on both crops. Invasion and multiplication of the nematode, and its attendant effects on the crops, showed that pathogenicity was higher in maize than

on sorghum.

The effect of different population densities of *P. brachyurus* on maize was also studied. The results showed that growth of maize was significantly reduced at all population densities tested when compared to the check.

Nematode invasion, on the otherhand, increased at all population densities but reached a maximum at Pi of 2000 nematodes. Correlation analysis showed that population density was negatively correlated with plant growth parameters. Plant height however showed a strong positive correlation with stem diameter and root weight. Significant damage of maize would appear to be caused at pre-plant population density of over 500 nematodes per 500 g of soil, depending on field conditions.

Evaluation of maize cultivars for their reaction to *P. brachyurus* showed that none of the cultivars tested was resistant to *P. brachyurus*. *P. brachyurus* multipled readily in the cultivars. Improved varieties, particularly Hybrids, appeared to be more susceptible to the nematode than open pollinated cultivars.

Field populations of *P. brachyurus* in late June sown maize increased progressively during the growing seasons but began to decline by late September. Peak populations both in the roots and soil were attained by early September and mid-August, respectively. By mid-October populations declined significantly due to a decline in soil moisture resulting from

the cessation of the rains.

Pre-planting soil treatment with furadan significantly reduced populations of the nematode. Reduction in nematode population resulted in a yield increase of about 38%.

This study shows that several plant-parasitic nematodes, in addition to other production constraints, may be important yield reducers in some cereal-based crop production. This is suggested by the pathogenicity of the lesion nematode, *P. brachyurus*, and yield increase in maize resulting from pre-sowing soil treatment with furadan. Populations of *P. brachyurus* capable of causing economic damage appear to be low and these are easily attainable at the begining of the rainy season. Therefore, control measures should be directed at reducing population densities to prevent a build-up of the nematodes to damaging levels.

Results of these studies suggest that plant-parasitic nematodes can be very important production constraint in cereal crop production in the Nigerian savannas. However, further research needs to be conducted in order to properly understand the role of these pests in order to develop management strategies that would effectively control the nematodes under the circumstances of the resource-poor farmers. The following research and issues can be suggested:

a. Determination of the pest status of most of the nematodes found associated with the crops. Although some of the nematodes may not be widely occurring,

their damage potential may be high.

b. Studies on the interactions between plant parasitic nematodes and other pathogens. *Fusarium moniliforme*, for instance, has been shown to be important in maize in the Nigerian savannas and is thought to be aggravated in the presence of nematodes. Such studies will provide key information useful in developing control strategies of these problems.

c. Several cultivars of maize, millet and sorghum should be screened against nematodes of economic importance in order to determine cultivars resistant to the nematodes. Such resistant cultivars can be used in an integrated strategy for nematode control.

d. Development of control options that will be effective, economically feasible and compatible with the production practices of the relatively small scale farmers is urgently desirable.

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Appendix 1. Environmental conditions during 1992 and 1993

1992	Rainfall	Temperature		Relative Humidity
		Maximum	Minimum	
January	0	26.7	12.3	21.5
February	0	30.0	18.8	12.6
March	0	35.0	19.5	23.4
April	32.3	35.4	22.4	41.3
May	73.1	33.0	22.1	66.4
June	112.4	29.6	19.7	71.3
July	243.6	28.4	19.8	82.6
August	286.9	29.5	20.0	83.0
September	229.7	29.5	20.2	78.6
October	39.2	31.5	17.7	61.1
November	2.6	29.7	15.1	32.4
December	0	29.6	12.3	25.1
1993				
January	0	26.3	11.6	23.6
February	0	31.8	14.6	19.5
March	0	34.4	18.2	29.7
April	8.3	36.5	23.5	33.8
May	113.6	37.8	22.0	62.9
June	155.8	31.7	20.9	72.7
July	260.0	29.5	20.2	78.4
August	300.8	28.4	19.5	81.8
September	181.8	30.2	19.3	76.7
October	32.4	34.1	18.7	63.1
November	0	33.6	14.1	NA
December	0	29.1	14.1	31.1

Appendix 2. ANOVA of densities of 20 nematode genera in 175 fields in the Nigerian savannas

Source	DF	SS	% total SS
Fields	174	36131986.57	8.74
Nematodes	19	33552404.90	8.11
F x N	NC	NC	NC

NC = Not Calculated.

Appendix 3. Combine ANOVA for effect of *P. brachyurus* on plant height of maize and sorghum

(a) Plant height

Source	DF	SS	MS	F
Years	1	16.67	16.67	3.3
Crop	1	3750.0	3750.0	127.3***
Date	2	5937.3	2968.7	100.8*
Regm	1	4160.7	4160.7	141.3**
Crop x Date	2	244.0	122.0	4.1*
Crop x Regm.	1	640.7	640.7	21.8**
Date x Regm.	2	1177.3	588.7	20.0**
Years x Crop	1	6.0	6.0	0.2
Years x Date	2	149.3	74.7	2.5
Years x Regm.	1	54.0	54.0	1.8
Crop x Date x Regm.	2	145.3	72.7	2.5
Years x Crop x date	2	16.0	8.0	0.3
Years x Crop x Regm.	1	32.7	32.7	1.1
Years x Date x regm.	2	16.0	8.0	0.3
Years x Crop x Date x regm.	2	69.3	34.7	1.2
Residual	66	1943.8	29.5	
Total	88	18265.5	208.4	

** Highly significant (P = 0.05)
* Significant (P = 0.05)
Regm = Treatment inoculated with nematode

Appendix 4. Combine ANOVA for effect of *P. bracyurus* on stem diameter of maize and sorghum

Source	DF	SS	MS	F
Years	1	4.6376	4.6376	8.8*
Crop	1	7.8776	7.8776	58.1**
Date	2	21.5077	10.7539	79.3**
Regm.	2	65.8359	65.8359	485.3**
Crop x Date	2	0.4977	0.2489	1.8
Crop x Regm.	1	4.0426	4.0426	29.8**
Date x Regm.	2	0.2144	0.1072	0.8
Years x Crop	1	1.3776	1.3776	10.2*
Years x Date	2	1.3377	0.6689	4.93*
Years x Regm.	1	3.4126	3.4126	25.2**
Crop x Date x Regm.	2	0.3077	0.1539	1.1
Years x Crop x Date	2	0.4477	0.2239	1.7
Years x Crop x Regm.	1	0.0126	0.0126	0.1
Years x Date x Regm.	2	0.1977	0.0989	0.7
Years x Crop x Date x Regm.	2	0.4779	0.2389	1.8
Residual	66	8.9535	0.1357	

** Highly significant (P = 0.05)
* Significant (P = 0.05)
Regm = Treatment inoculated with nematode

Appendix 5. ANOVA for effect of *P. brachyurus* on growth (plant height) of maize and sorghum (1991)

Source	DF	SS	MS	F
Reps.	3	10.0	3.33	0.116
Crop	1	1728.0	1728.0	60.0**
Date	2	2318.0	1159.0	40.3**
Regm.	1	1633.3	1633.3	56.7**
Crop x Date	2	78.0	39.0	1.4
Crop x Regm.	1	481.3	481.3	16.7*
Date x Regm.	2	512.7	256.3	8.9*
Crop x Date x Regm.	2	200.7	100.3	3.5*
Residual	33	950.0	28.8	

Appendix 6. ANOVA for effect of *P. brachyurus* on stem diameter of maize and sorghum (1991)

Source	DF	SS	MS	F
Reps.	3	2.9190	0.9730	7.153*
Crop	1	7.9219	7.9219	58.2**
Date	2	16.7054	8.3527	61.410**
Regm.	1	19.6352	19.6352	144.359**
Crop x Date	2	0.9388	0.4694	3.451*
Crop x Regm.	1	1.8019	1.8019	13.247*
Date x Regm.	2	0.0054	0.0027	0.020
Crop x Date x Regm.	2	0.6987	0.3494	2.569
Residual	33	4.4885	0.1360	

** Highly significant (P = 0.05)

* Significant (P = 0.05)

Appendix 7. ANOVA for effect of *P. brachyurus* on plant height of maize and sorghum (1992)

Source	DF	SS	MS	F
Reps	3	20.17	6.72	0.223
Crop	1	2028.0	20208.00	67.3**
Date	2	3768.67	1884.33	62.6**
Regm.	1	2581.33	2581.33	85.7**
Crop x Date	2	182.00	91.00	3.0
Crop x Regm.	1	192.00	192.00	6.4*
Date x Regm.	2	680.67	340.33	11.3*
Crop x Date x Regm.	2	14.00	7.00	0.2
Residual	33	993.83	30.12	

** Highly significant (P = 0.05)
* Significant (P = 0.05)

Appendix 8. ANOVA for effect of *P. brachyurus* on stem diameter of maize and sorghum (1992)

Source	DF	SS	MS	F
Reps	3	0.2550	0.2550	0.6
Crop	1	1.3333	1.3333	9.9*
Date	2	6.1400	3.0700	22.7**
Regm	1	49.6133	49.6133	366.7**
Crop x Date	2	0.0067	0.0033	0.02
Crop x Regm	1	2.2533	2.2533	16.7*
Date x Regm	2	0.4067	0.2033	1.5
Crop x Date x Regm	2	0.0867	0.0433	0.3
Residual	33	4.4650	0.1353	

** Highly significant (P = 0.05)
* Significant (P = 0.05)

Appendix 9. Combine ANOVA for effect of different population densities of *P. brachyurus* on plant height

Source	DF	SS	MS	F
Reps	4	180.48	45.12	1.66
Years	1	1060.94	1060.94	8.87
Popn.	5	22506.92	4501.38	165.98*
Date	2	9081.10	4540.55	167.43**
Popn. x Date	10	2322.83	232.28	8.57*
Years x Popn.	5	655.36	131.07	4.83*
Years x Date	2	53.54	26.77	0.99
Years x Popn. x Date	10	301.06	30.11	1.11
Residual	136	3688.24	27.12	

Appendix 10. Combine ANOVA for effect of different population densities of *P. brachyurus* on stem diameter of maize

Source	DF	SS	MS	F
Reps	4	0.8692	0.2173	0.95
Years	1	0.0405	0.0405	0.21
Popn.	5	147.8578	29.5716	129.88**
Date	2	32.0803	16.0402	70.45**
Popn. x Date	10	13.3263	1.3326	5.85*
Years x Popn.	5	4.1512	0.8302	3.65*
Years x Date	2	1.8303	0.9152	4.02*
Years x Popn. x Date	10	3.7430	0.3743	1.64
Residual	136	30.9649	0.2277	

Appendix 11. Combine ANOVA for effect of different population densities of *P. brachyurus* on shoot weight

Source	DF	SS	MS	F
Reps	4	500.06	125.01	1.53
Years	1	1059.24	1059.24	26.16**
Popn.	5	52552.95	10510.59	128.59**
Years x Popn.	5	2029.99	406.00	4.97*
Residual	40	3269.52	81.74	

Appendix 12. Combine ANOVA for effect of different population densities of *P. brachyurus* on root weight

Source	DF	SS	MS	F
Reps	4	33.69	8.42	1.33
Years	1	100.10	100.10	15.00**
Popn.	5	2007.97	401.59	63.24**
Years x Popn.	5	42.67	8.53	1.3
Residual	40	254.01	6.35	

Appendix 13. Combine ANOVA for effect of different population densities of *P. brachyurus* on infection rate

Source	DF	SS	MS	F
Reps	4	632.2	158.0	1.37
Years	1	60.0	60.0	1.74
Popn.	5	179988.3	35997.7	311.29*
Years x Popn.	5	2230.0	446.0	3.86
Residual	40	4625.7	115.6	

Appendix 14. Combine ANOVA for effect of initial population density of *P. brachyurus* on the final population density

Source	DF	SS	MS	F
Reps	4	1537067	384267	0.39
Years	1	413672	413672	0.25
Popn.	5	483060000	966120000	97.81
Years x Popn.	5	2225768	445154	0.45
Residual	40	39508968	987724	

Appendix 15. ANOVA for effect of different population densities of *P. brachyurus* on plant height of maize in 1991

Source	DF	SS	MS	F
Reps	4	242.18	60.54	2.05
Popn.	5	9360.06	1872.01	63.36**
Date	2	4005.76	2002.88	67.79**
Popn. x date	10	1699.44	169.94	5.75*
Residual	68	2009.02	29.54	

Appendix 16. ANOVA for effect of different population densities of *P. brachyurus* on plant height of maize in 1992

Source	DF	SS	MS	F
Reps	4	416.78	104.19	4.22
Popn.	5	13802.22	2760.44	111.78**
Date	2	5128.89	2564.44	103.85**
Popn. x Date	10	924.44	92.44	3.74
Residual	68	1679.22	24.69	

Appendix 17. ANOVA for effect of different population densities of *P. brachyurus* on stem diameter of maize in 1991

Source	DF	SS	MS	F
Reps	4	0.59	0.15	0.84
Popn.	5	54.48	10.90	62.40**
Date	2	9.86	4.93	28.24**
Popn. x Date	10	2.45	0.25	1.41
Residual	68	11.87	0.17	

Appendix 18. ANOVA for effect of different population densities of *P. brachyurus* on stem diameter of maize in 1992

Source	DF	SS	MS	F
Reps	4	1.07	0.27	0.95
Popn.	5	97.53	19.51	69.48**
Date	2	24.05	12.03	42.83**
Popn. x Date	10	14.62	1.46	5.21*
Residual	68	19.09	0.28	

Appendix 19. ANOVA for effect of different population densities of *P. brachyurus* on shoot weight of maize in 1991

Source	DF	SS	MS	F
Reps	4	595.20	148.80	1.32
Popn.	5	33870.60	6774.1	59.92**
Residual	20	2261.00	113.10	

Appendix 20. ANOVA for effect of different population densities of *P. brachyurus* on shoot weight of maize in 1991

Source	DF	SS	MS	F
Reps	4	66.87	16.72	0.33
Popn.	5	20712.29	4142.46	82.15**
Residual	20	1008.52	50.43	

Appendix 21. ANOVA for effect of different population densities of *P. brachyurus* on root weight of maize in 1990

Source	DF	SS	MS	F
Reps	4	15.44	3.86	1.28
Popn.	5	793.68	158.74	52.63**
Residual	20	60.32	3.02	

Appendix 22. ANOVA for effect of different population densities of *P. brachyurus* on root weight of maize in 1991

Source	DF	SS	MS	F
Reps	4	44.94	11.24	1.16
Popn.	5	1256.97	251.39	25.96**
Residual	20	193.70	9.69	

Appendix 23. ANOVA for effect of different population densities of *P. brachyurus* on its infection rate in 1990

Source	DF	SS	MS	F
Reps	4	542.0	135.5	1.06
Popn.	5	96164.2	19232.8	150.49**
Residual	20	2556.0	127.8	

Appendix 24. ANOVA for effect of different population densities of *P. brachyurus* on its infection rate in 1991

Source	DF	SS	MS	F
Reps	4	228.3	57.1	0.55
Popn.	5	86054.2	17210.8	166.32**
Residual	20	2069.7	103.5	

Appendix 25. ANOVA for effect of different population densities of *P. brachyurus* on final population density in 1990

Source	DF	SS	MS	F
Reps	4	1788916	447229	0.45
Popn.	5	264214208	52842840	53.29**
Residual	20	19831664	991583	

Appendix 26. ANOVA for effect of different population densities of *P. brachyurus* on final population density in 1991

Source	DF	SS	MS	F
Reps	4	6373443	1593361	1.62
Popn.	5	221071568	44214312	44.92**
Residual	20	19677302	983865	

Appendix 27. Combine ANOVA for soil population changes of *P. brachyurus* (1991 & 1992)

Source	DF	SS	MS	F
Reps	3	333923	111308	3.40
Years	1	82544	82544	2.58
Period	5	20169354	4033871	123.21**
Regm.	1	60548852	60548852	1849.35**
Period x Regm.	5	15060864	3012173	92.00**
Years x Period	5	1185398	237080	7.24**
Years x Regm.	1	118793	118793	3.63
Years x Period x Regm.	5	1126370	225274	6.88*
Residual	66	2160883	32741	

Appendix 28. ANOVA for soil population changes of *P. brachyurus* in 1991.

Source	DF	SS	MS	F
Reps	3	46736	15579	0.89
Period	5	10335677	2067135	118.25**
Regm.	1	33015760	33015760	1888.66**
Period x Regm.	5	8414779	1682956	96.27**
Residual	33	576875	17481	

Appendix 29. ANOVA for soil population changes of *P. brachyurus* in 1992

Source	DF	SS	MS	F
Reps	3	383114	127705	2.66
Period	5	11019076	2203815	45.91**
Regm.	1	27651888	27651888	576.08**
Period x Regm.	5	7772456	1554491	32.39**
Residual	33	1584008	448000	

Appendix 30. Combine ANOVA for population changes of *P. brachyurus* in maize roots (1991 & 1992)

Source	DF	SS	MS	F
Years	1	12686	12686	0.14
Period	6	181409088	30234848	321.02**
Regm.	1	169459552	169459552	1799.22**
Period x Regm.	6	159885728	26647622	282.93**
Years x Period	6	275002	45834	0.49
Years x Regm.	1	1	1	0.00
Years x Period x Regm.	6	206340	34390	0.37
Residual	78	7346416	94185	

Appendix 31. ANOVA for population changes of *P. brachyurus* in maize roots in 1991.

Source	DF	SS	MS	F
Reps	3	154346	51449	1.09
Period	6	93705808	15617635	329.96**
Regm.	1	84717480	84717480	1789.88**
Period x Regm.	6	81324688	13554115	286.37**
Residual	39	1845921	47331	

Appendix 32. ANOVA for soil population changes of *P. brachyurus* in maize roots in 1992

Source	DF	SS	MS	F
Reps	3	399298	133099	0.94
Period	6	87978288	14663048	103.97**
Regm.	1	84742080	84742080	600.84**
Period x Regm.	6	7876376	13127896	93.08**
Residual	39	5500495	141038	

Appendix 33. Combine ANOVA for effect of *P. brachyurus* on plant height of maize cultivars.

Source	DF	SS	MS	F
Years	1	0.72	0.72	0.03
Varieties	13	593.40	45.65	3.11*
Years x Varieties	13	228.40	17.57	1.20
Residual	78	1145.41	14.68	

Appendix 34. Combine ANOVA for effect of *P. brachyurus* on shoot weight of maize cultivars.

Source	DF	SS	MS	F
Years	1	124.32	124.32	5.65*
Varieties	13	1278.46	98.34	7.57*
Years x Varieties	13	140.18	10.78	0.83
Residual	78	1013.07	12.99	

Appendix 35. Combine ANOVA for effect of *P. brachyurus* on root weight of maize cultivars.

Source	DF	SS	MS	F
Years	1	0.38	0.38	0.09
Varieties	13	370.98	28.54	10.70*
Years x Varieties	13	101.78	7.83	2.94*

Appendix 36. Combine ANOVA for final population density of *P. brachyurus* in the soil

Source	DF	SS	MS	F
Years	1	6157032	6157032	25.49
Varieties	13	2275310	1750562	4.36
Years x Varieties	13	22625970	1740459	4.34
Residual	78	31313394	401454	

Appendix 37. Combine ANOVA for final population density of *P. brachyurus* in the roots.

Source	DF	SS	MS	F
Years	1	103214	103214	0.09
Varieties	13	55098104	4238316	3.51*
Years x Varieties	13	59305072	4561929	3.78
Residual	78	94189832	1207562	

Appendix 38. ANOVA for effect of *P. brachyurus* on plant height of maize cultivars in 1991.

Source	DF	SS	MS	F
Years	3	71.29	23.76	1.59
Varieties	13	606.00	46.62	3.12*
Residual	39	582.71	14.94	

Appendix 39. ANOVA for effect of *P. brachyurus* on plant height of maize cultivars in 1992

Sources	DF	SS	MS	F
Reps	3	82.05	27.35	1.90
Varieties	13	215.80	16.60	1.15
Residual	39	562.70	14.43	

Appendix 40. ANOVA for effect of *P. brachyurus* on shoot weight of maize cultivars in 1991

Sources	DF	SS	MS	F
Reps.	3	112.36	37.45	2.28

Appendix 41. ANOVA for effect of *P. brachyurus* on shoot weight of maize cultivars in 1992

Sources	DF	SS	MS	F
Reps	3	19.57	6.52	0.68
Varieties	13	525.71	40.44	4.24*
Residual	39	372.43	9.55	

Appendix 42. ANOVA for effect of *P. brachyurus* on root weight of maize cultivars in 1991

Sources	DF	SS	MS	F
Reps.	3	9.81	3.27	0.90
Varieties	13	189.81	14.60	4.00*
Residual	39	142.32	3.65	

Appendix 43. ANOVA for effect of *P. brachyurus* on root weight of maize cultivars in 1992

Sources	DF	SS	MS	F
Reps.	3	14.86	4.95	2.94
Varieties	13	282.96	21.77	12.92**
Residual	39	65.72	1.69	

Appendix 44. ANOVA for final soil population density of *P. brachyurus* in 1991

Sources	DF	SS	MS	F
Reps.	3	665498	221833	1.25
Varieties	13	17469494	1343807	7.54**
Residual	39	6949832	178201	

Appendix 45. ANOVA for final soil population density of *P. brachyurus* in 1992.

Sources	DF	SS	MS	F
Reps.	3	783582	261194	0.42
Varieties	13	27913786	2147214	3.44*
Residual	39	24363562	624707	

Appendix 46. ANOVA for population densities of *P. brachyurus* in the roots in 1991

Sources	DF	SS	MS	F
Reps.	3	1225128	408376	0.24
Varieties	13	78242168	6018629	3.54*
Residual	39	66321048	1700540	

Appendix 47. ANOVA for population densities of *P. brachyurus* in the roots in 1992

Source	DF	SS	MS	F
Reps	3	5437786	1812595	2.54
Varieties	13	36161004	42781616	3.89*
Residual	39	27868788	714584	

BIOGRAPHY

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Ahmadu Bello University, Zaria	1983	1986	M.Sc. (Crop Protection)
Ahmadu Bello University, Zaria	1977	1981	B.Sc. (Agriculture)
Federal School of Arts and Science, Mubi	1974	1977	G.C.E. 'A' Level, G.C.E. 'O' Level
Government Secondary School, Fadan Kaje	1969	1973	WASC
St. Gregory's L.E.A. Primary School, Kankada	1961	1968	First School Leaving Certificate

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Government Teachers' College, Ilesa	1981	1982	Education Officer, N.Y.S.C.
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	1986	1989	Assistant Res. Fellow
	1989	1992	Research Fellow II
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