PLANT PARASITIC NEMATODES ASSOCIATED WITH SUGARCANE IN WESTERN KENYA AND THEIR MANAGEMENT USING HOST RESISTANCE AND CROP MIXTURES

By

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DEDICATION

This work is dedicated to my parents, the late Wilson Taparsang araap Nyatogo (Korgoren) and Anna Tapsabei nebaraap Nyatogo (Chepoterik) for their shared love of education.

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ABSTRACT

Plant parasitic nematodes associated with sugarcane are known to cause losses in yields of up to 50% thus ranking among the most damaging pests. However, their occurrence, abundance and distribution in western Kenya sugarcane zones is not known. Therefore, this study was conducted to determine occurrence of the nematodes, the host resistance status of the varieties used and the influence of different intercrops on the population dynamics of the parasites. The survey and field trials were carried out in the western sugarcane zones of Nzoia, Mumias, West Kenya and Busia while the greenhouse experiment was conducted at Kabete field station. Samples were collected from farms in the four zones and nematodes extracted from 200 cm^3 soil. Nematodes were identified up to the genus level and then counted.

Seven sugarcane varieties were selected for evaluation to determine their host resistance status to nematodes. These were CO421, CO617, CO945, EAK70-97, KEN83-737, KEN82-808 and KEN82-216. N14 was used as the standard due to its known tolerance status. The experiment was carried out in a glasshouse at Kabete in a completely randomized design with three replications. Data on nematode populations and shoot length were collected at 0, 60 and 120 days after planting (DAP). At termination, data on root length and weight were taken and subjected to Analysis of Variance and means separated by Least Significant Difference test. The field trial to evaluate the effect of different intercrops on plant parasitic nematodes associated with sugarcane was carried out at Kibos, Kisumu in western Kenya. Five food crops namely bean, soya bean, pigeon pea, maize, and cowpea. The experiment was laid down in split-plot design with variety as the main plot.

The dominant genera of nematodes associated with sugarcane were *Pratylenchus*, *Scutellonema* and *Meloidogyne* with percentage densities of 21, 18 and 13 respectively. Soils in Nzoia were more heavily infested with plant parasitic nematodes given that 55% of the nematodes were recovered from the zone compared to 45% in all the other zones combined. Sandy soils haboured 40% more nematodes compared to clay soils. The varieties tested showed a higher level of resistance to plant parasitic nematodes compared to N14. Crop cycle, altitude, AEZ, management types and organic products were found to influence the parasites. Most nematodes are concentrated in Nzoia sugarcane scheme which is a marginal sugarcane zone as opposed to Mumias which is a typical sugarcane zone (LM1).

The highest density of nematodes in the rhizospheres of all varieties screened were those of *Pratylenchus* spp. at 188 per 200cm^3 of soil while the least were *Hoplolaimus* spp. at 92. Numbers of plant parasitic nematodes were 81% lower when variety CO421 was interplanted with beans compared to variety N14 with beans. Significant differences were also observed when different sugarcane varieties were interplanted with soya beans. Intercropping resulted in reduction of numbers of plant parasitic nematodes with the exception of members of the genus *Scutellonema* whose numbers increased in sugarcane interplanted with common bean.

This study has established the presence of 15 genera of plant parasitic nematodes associated with sugarcane in the western zones of Nzoia, Mumias, West Kenya and Busia with *Pratylenchus*, *Scutellonema* and *Meloidogyne* being the most predominant. It has also revealed the influence of soil texture, crop cycle and anthropogenic factors on abundance and distribution of these nematodes in western Kenya sugarcane zones. It has therefore set the justification of further work to determine the economic importance of the nematodes to sugarcane production.

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CHAPTER ONE

1.0 INTRODUCTION

Sugarcane, a tall perennial, thick stemmed grass is a complex hybrid between *Saccharam officinarum* L. and S. spontaneum L. (Cadet and Spaull, 2003). It is grown in more than 80 countries throughout the tropics and subtropics where it is the major source of revenue, fiber and fuel. It was introduced in Kenya in the late 19th century and has developed in to a key sub-sector in the Agricultural Sector of the economy. Indeed it is the second largest contributor to agricultural gross domestic product after tea (ESK, 2005). The industry directly employs about 17,000 workers, supports over six million Kenyans, and is the major source of income for the more than 200,000 small-scale sugarcane farmers who produce over 85% of the total sugarcane supplied to all the factories (KSB, 2005). Sugarcane is mainly grown in Western, Nyanza and Rift Valley provinces. In Western Province, it is found in four zones namely Mumias, Nzoia, West Kenya and Busia Sugarcane Schemes. Within Nyanza province, sugarcane is grown in Muhoroni, Chemelil, Miwani and South Nyanza, while in the Rift Valley it is produced in Kericho and Nandi Districts.

Although the sugar sub-sector is seemingly performing well, overall sugarcane yields have declined from an average of 90.86 tonnes per hectare in 1996 to 71.46 tonnes per hectare by 2005 (KSB, 2005; Appendices 1a & b). This implies that although the land under sugarcane production has been expanding, the productivity per unit area has been declining (Appendix 1a). The decline has been attributed to several factors which include pests and diseases, declining plot sizes, high cost of production and soil exhaustion due to extended monoculture (KESREF, 2004; KSB, 2005)

The most common sugarcane diseases include the sugarcane smut, ratoon stunting disease (RSD), sugarcane mosaic, eye spot, red rot, rust, pineapple disease, leaf scald and yellow leaf. Termites, early shoot borer, root borer, top borer, lady bug, sugarcane whitefly and plant parasitic nematodes are among the main pests that infest sugarcane. Plant parasitic nematodes associated with sugarcane are among the most damaging pests but their effects are insidious (Spaull and Cadet, 1991). Severe infestation may reduce yield by 20-50% due to a reduction in the number and length of stalks (Stirling and Blair, 1999). Their diversity in sugarcane is greater than in most other cultivated crops, with more than 310 species of 48 genera of endo- and ectoparasitic nematodes having been recorded from its roots and/or rhizosphere (Cadet and Spaull, 2005). Factors that are known to influence occurrence, abundance and distribution of plant parasitic nematodes include; soil, Agro-ecological Zone (AEZ), variety, altitude, crop cycle, age and cultural practices (Stirling *et al,* 2002 and 2001; Blair *et al*, 1999a).

Management of plant parasitic nematodes involves the use of multiple control procedures aimed at reducing the numbers of the nematodes to non-injurious levels. Nematode management programmes employed are guided by the knowledge that plant parasitic nematodes have a wide host range and their dispersal is usually passive but may be active or aided by vectors. While control methods employed should be more preventive rather than curative and aimed at preventing build-up of high population densities, sustainable management of plant parasitic nematodes requires that all viable strategies be combined into integrated pest management packages (Brown and Kerry, 1987). This may be achieved through integration of different tactics that include preventing introduction and spread of nematodes; cultural practices, particularly cropping systems, fallowing, resistant/tolerant cultivars and organic amendments; physical agents especially heat; chemicals (nematicides); and biological control (Sharma *et al.*, 1994; Bridge, 1996; Sikora, 1992; Hafeez *et al.*, 2000).

In order to develop effective management measures, knowledge of the major plant parasitic nematodes associated with sugarcane, their population and distribution in the area is a prerequisite. Therefore, this study was designed to determine the effect of these factors on the distribution of plant parasitic nematodes associated with sugarcane. Thus the specific objectives of this study were as follows:

1. To determine the occurrence, abundance and distribution of plant parasitic nematodes associated with sugarcane in the western Kenya sugarcane zones
2. To determine the reactions of some locally grown sugarcane varieties to nematode infestation
3. To determine the effect of different intercrops with sugarcane on nematode population dynamics

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Plant Parasitic Nematodes

Nematodes are a group of multicellular organisms which are thread like or filiform in shape and which are common in soil, fresh water and seas. Some of them are plant parasites while some are free-living (saprophagous) in soil. They exhibit bilateral symmetry while the neck region has triradiate symmetry. Their body is not segmented and has pseudocoelomate body cavity. They have neither a respiratory nor a circulatory system. Their sexes are generally separate and fertilization occurs internally. The general nematode shape is vermiform (Hunt *et al*, 2005).

Plant parasitic nematodes suck and drain the fine hairlike roots and create knots in the smaller roots limiting the development of the root system. Galls appear all over the mass of the plant roots. The roots that are damaged can no longer take up water or fertilizer into the upper parts of the plant. Plants injured by nematodes are normally stunted or weak and somewhat chlorotic. Regeneration is slow and poor with little flowering so that the lifespan of a crop is diminished. Severe damage occurs in warm sunlit moist sandy soils.

The most important pathogenic nematodes include the widespread and highly pathogenic species like *Pratylenchus zeae* and *P. brachyurus* (Stirling and Blair, 1999). The common and highly pathogenic particularly on sandy soil include root-knot nematodes commonly *Meloidogyne javanica* and *M. incognita,* stubby root nematodes (*Xiphinema* spp.) and needle nematodes (*Paralongidorus* spp.). The widespread but moderately or weakly pathogenic include the stunt nematodes, *Tylenchorhynchus* spp. with *T. annulatus* the most widely distributed, spiral nematodes *Helicotylenchus* spp., *Scutellonema* spp. and *Rotylenchus* spp. with *H. dihystera* one of the most common species. The lance nematodes *Hoplolaimus* spp., ring nematodes, *Criconemella* spp., *Criconema* spp., *Hemicricomoides* spp. and *Ogma* spp., sheath nematodes, *Hemicychiophora* spp. and reniform nematodes *Rotylenchulus parus*.

Nematode diversity in sugarcane is greater than in most other cultivated crops, with more than 310 species belonging to 48 genera of endo- and ectoparasitic nematodes having been recorded from its roots and/or rhizosphere (Cadet and Spaull, 2005). Thus diseases caused by nematodes always involve a complex of species with different feeding habits and various degrees of pathogenicity. However much of the published information is based on limited surveys and the taxonomy at species level is often inadequate (Blair *et al.*, 1999). In Barbados, twenty genera have been named with the most abundant being *Aphelenchus*, *Helycotylenchus*, *Pratylenchus*, *Tylenchus*, *Rotylenchus*, *Criconemoides* and *Meloidogyne* species (Brathwaite, 1968). In Louisiana, *Tylenchorhynchus* and *Pratylenchus* were reported to be in large numbers. Other genera reported included *Xiphinema*, *Belonolaimus*, *Paratylenchus* and *Trichodorus* (Martin and Birchfield, 1955). Eight genera have been reported in Hawaii, out of which those believed to be of importance were *Meloidogyne*, *Pratytenchus* and *Helicotylenchus* (Jensen, 1953). Various reports of work in Puerto Rico (Steiner, 1959), Mauritius (Williams, 1962) and South Africa (Robbertse, 1979) have also indicated presence of various genera of plant parasitic nematodes in sugarcane. In Kenya work done has shown that *Pratylenchus* spp. is the most predominant parasitic nematode in the Nyanza Sugarbelt (Kariaga, 1988). Other genera occurring to varying degrees include *Trichodorus* spp., *Helicotylenchus* spp., *Rotylenchus* spp., *Telenchorhynchus* spp., *Criconemoides* spp., *Tylenchus* spp., *Longidorus* spp., *Aphlenchoides* spp. and *Hemicycliophora* spp.

2.2 Symptoms and diagnosis of diseases caused by nematodes on sugarcane

Damage by nematodes retards the development of shoots and reduces tillering. Because the canopy is slow to develop, nematodes-infested cane tends to have an open appearance. During periods when soil moisture is limiting, leaves may wilt and curl so that the plant has a spiky appearance. Severe infestation may reduce yield by 20-50% due to a reduction in the number and length of stalks (Stirling and Blair 1999). Nematodes also have subtle effects that are usually not recognized because non-infested crops are available for comparison. Such effects can only be observed by applying a nematicide and comparing growth in the nematicide-treated and untreated areas. Commonly, the treated crop will be taller and denser and will produce higher yields. Root symptoms tend to vary depending on nematode species present. Roo-knot nematode produces the most distinctive symptoms, with swellings and galls occurring on set roots and young shoots. Because galls often occur at root tips primary roots cease to elongate and root length can be substantially reduced. Lesions nematode is a migratory endoparasite that causes reddish- purple lesions on newly infested roots. These lesions become necrotic and turn purplish-black, causing the root system to darken in colour. As lesions expand roots are girdled, so that fine roots are destroyed and root mass is reduced. Ectoparasite nematodes feed on root tips, causing swelling and mal-formation of root tips and stunting of roots. Lateral roots produced behind the damaged root tip are also stunted, so that infested root system may have "stubby" appearance.

Root symptoms in the field are rarely specific enough to definitely diagnose a nematode problem. Galling caused by root knot nematode can be readily seen on roots of young plant cane, but because galls are small and discrete, they are not easily detected on older plant. Symptoms of other nematodes are relatively non-specific, so that lack of fine roots, swelling of root tip, proliferation of stunted lateral roots, root discoloration and presence of lesion may indicate a nematode problem. However the poor root growth that is typical of nematode damage can also be due to fungal pathogens, root-feeding arthropods, nutrient deficiencies (e.g. phosphorous) or toxicities (e.g. aluminium), soil compaction and poor aeration (Stirling and Blair 1999). Therefore to diagnose a nematode problem, soil and root samples must be collected and nematodes extracted, identified and quantified.

2.3 Factors influencing the population density and distribution of nematodes

A study in South Africa showed that the effect of soil type on the distribution of some of the nematodes is more than that of climate or topographic factors (Spaull and Cadet, 2003). The amount of sand and organic matter in soil appears to affect the distribution of nematodes associated with sugarcane (Spaull and Heyns, 1991; Hall and Irey, 1992). *Meloidogyne* are more frequently found in sandy soils than in clayey ones (Spaull, 1981; Blaire *et al.*, 1999a, b). The effect of soil texture on pathogenicity is partly due to the ease of movement of nematodes in sandy soils (Cadet and Spaull, 2005). Further, nematodes have been observed to have a greater impact in sandy soils due to a lower water holding capacity. Nematodes feed on roots so that the impact is felt more where there is water stress (Wallace, 1973).

Resistant varieties against a wide range of plant parasitic nematodes are not easily bred. The emphasis should be on selecting tolerant varieties that can grow well in spite of the damage caused by nematodes (Matsuoka, 1980). Varieties N12, N14 and NC0376 that dominate the South African sugar industry are tolerant to damage by nematodes (Spaull and Cadet, 2003). Sugarcane variety CP 70-321 that covers 20% of the cane grown in Lousiana and Texas appears to be tolerant to many parasitic nematodes (Koenning *et al*, 1999). In Kenya, minimal work on tolerance of sugarcane varieties to plant parasitic nematodes has been done. The old varieties include CO 421, CO 617 and CO 331 while recent direct introductions include CO 945 and N14. However, the Kenya Sugar Research Foundation (KESREF) has been running breeding programmes which to date has generated varieties such as EAK 70-76, EAK 70-97, KEN 82-216, KEN 82-247, KEN 82-808 and KEN 83-737.

Parasitism of sugarcane by nematodes is influenced by crop cycle. A study carried out in Burkina Faso showed increase in numbers of *Hoplolaimus* up to the third ratoon crop before declining. However, a similar study in West Africa showed that plant parasitic nematodes affected the plant crop but not following ratoon crops (Cadet, 1985). The work of Cadet and Debouzie (1990) in Cote d'ivoire showed the numbers of *Meoidogyne* was correlated with that of *Pratylenchus* and *Criconemella* and their absence with that of *Pratylenchus.*

Monoculture may favour high populations especially when the crop is undisturbed for many years. However, the continuous rise in numbers occurs for eight to ten years and thereafter a decline occurs (Jensen *et al*., 1959). Certain genera like *Tylenchus* spp. are known to be more numerous at a certain age of the crop, reaching its peak numbers at crop age of twelve to sixteen months (Zwaluwenburg, 1930). Intercropping can enhance multiplication of nematodes if the second crop is a susceptible host plant. For instance, *Tylenchorhynchus nannus* was found to be more disastrous if soya bean was used as an intercrop (Birchfield and Martin, 1956). Conversely, nematode numbers shall decline if crop rotation is practiced with non- host plant.

The communities of nematodes may be affected by both altitude and temperature. This was observed in a study in South Africa (Spaull *et al.*, 2003). It was observed that populations with larger communities of *P. zeae* and *X. elongatum* were common in lower altitudes of below 300m where average annual temperatures exceeded 20°C, the opposite occurred for communities with larger populations of *H. dishystera* and a species of *Rotylenchus*. It has been reported that *Tylenchus similis* decreases with increase in altitude. In fact, it is not found beyond 2000 feet asl. (Zwaluwenburg, 1930). *Criconemoides* spp. increases with increase in altitude. The Agro-ecological zones are also known to influence abundance and distribution of plant parasitic nematode. For example, Cadet and Spaull (2003) observed the presence of *M. javanica* at LM2 site but not LM1.

Plant parasitic nematodes are known to be reduced by organic amendments and the crops grown in amended soils are better able to tolerate attack by nematodes (Stirling, 1991). The crop residues generated from sugar factories primarily bagasse and filter press mud are organic and have been reported to suppress plant parasitic nematodes as well as increase yields in sugarcane (Estioko *et al.*, 1988; Albuquerque *et al.*, 2002). This happens because growth in the roots becomes more vigorous (Smith, 1956).

The composition of the soil communities too affects plant parasitic nematodes. *Phytophthora megesperma* in the presence of *Pratylenchus zeae* indicated a higher average number of nematodes recovered per gram of root (Khan, 1962). *Helicotylenchus nannus* and *Phythium graminicola* each had an independent reduction on yield (Martin *et al.*, 1959).

2.4 Management of plant parasitic nematodes

Losses due to plant parasitic nematodes have been on the increase in the tropics and sub-tropics (Netscher and Sikora, 1990). The overall average annual yield loss on the world's major crop due to damage caused by plant parasitic nematodes is 12.3% (Sasser and Freckman, 1987). It has been observed that nematode infestation causes yield loss of up to 50% in sugarcane (Stirling and Blair, 1999).

Management of plant parasitic nematodes involves the use of multiple control procedures aimed at reducing the numbers of the nematodes to non-injurious levels. Nematode management programmes employed are guided by the knowledge that plant parasitic nematodes have a wide host range and their dispersal is usually passive but may be active or aided by vectors. Their principal dispersal agents are water, man, wind and arthropods while their main reservoirs are soil, water and plant residues. While control methods employed should be more preventive rather than curative and aimed at preventing build-up of high population densities, sustainable management of plant parasitic nematodes requires that all viable strategies be combined into integrated pest management packages (Brown and Kerry, 1987). This may be achieved through integration of different tactics that include preventing introduction and spread of nematodes; cultural practices, particularly cropping systems, fallowing, resistant cultivars and organic amendments; physical agents especially heat; chemicals (nematicides); and biological control.

For example various strategies including nematicides, cultural practices, use of biological agents, organic amendments and resistant varieties have been developed for the management of root-knot nematodes (Sharma *et al.,* 1994; Bridge, 1996).

Cultural methods of control include preventive and direct killing. The preventive measures are use of quarantine regulations both at local and international level, crop rotation and ploughing-in that exposes nematodes to desiccation and lethal radiations. Others are weed control, which removes some weeds that also act as host plant and breeding for resistance. Direct killing measures include soil steaming and flooding.

The use of biological control involves parasitism, predation, competition and antibiosis (Sikora, 1992). This method involves the use of fungi against nematodes, nematodes against nematodes and bacteria against nematodes. Among the biological agents that have shown promising results in the control of nematodes is a fungus *Paecilomyces lilacinus* (Hafeez *et al.*, 2000).

Chemical control or the use of nematicides such as organophosphates and carbamates reduces nematode densities early in the season, when crops are most vulnerable to nematode damage. However, the high cost of nematicides usually limits their use in sandy soils, where species of *Pratylenchus, Meloidogyne, Paratrichodorus* and *Xiphinema* often cause heavy losses.

Results of nematicide trials in soil with a clay content of about 5% or less, show that nematicide treatment increased yields by 23-81% in plant crop and by 8-21% in the first ratoon (Spaull and Cadet, 1991) .In sandy loam soils with a clay content of about 10% yield responses were11-32%

(Spaull, 1995). However sandy soils generally constitute only a small proportion of the area under sugarcane, which would mean nematodes are perceived as unimportant in most of the world's sugarcane areas. Recent observations in Australia challenge that perception. When nematicides are applied to clay loam and clay soil in a manner that suppresses nematode populations for the whole growing season, root health improves primarily because feeder root density increase and yield responses of 5-20% are consistently obtained (Stirling *et al.*, 1999). This suggests that nematodes (particularly *Pratylenchus* spp.) are having insidious and widespread effects that are generally not recognized within the sugar industry. Most genera thrive better in known optimum pH 5.5 –5.9. Above pH 6.6 there is nematicidal effect (Morgan, 1962)

Concerns about the high mammalian toxicity of nematicides and their capacity to contaminate ground water are other limitations to chemical control. Cultivars with resistance to certain species of *Meloidogyne* can be used in situations where these species are the key pest (Spaull and Cadet, 1991). However, resistance cannot be used as a control strategy in most of the sugar industry, as sources of resistance to other important nematodes have not been identified.

CHAPTER THREE

3.0 ABUNDANCE AND DISTRIBUTION OF PLANT PARASITIC NEMATODES ASSOCIATED WITH SUGARCANE IN WESTERN KENYA

Abstract

The Kenya sugar industry has experienced a decline in overall sugarcane yields from an average of 90.86 tonnes per hectare (TCH) in 1996 to 71.46 TCH by 2005. This decline has been attributed to several factors among which are pests and diseases which include plant parasitic nematodes. A study was conducted in the four sugarcane-growing zones of western Kenya to determine the occurrence and distribution of plant parasitic nematodes associated with the crop. The zones were Nzoia, Mumias, West Kenya and Busia from which a total of 81 farms were selected. Moist soil samples were collected from the sampled plots by the traversing method.

The soil was collected from the rhizospheres at a depth of 5-20 cm, bulked and thoroughly mixed together to form a composite sample from which 500g was taken for analysis. Nematodes were identified up to the genus level following the keys described by Mai and Lyon and then counted. Data were subjected to General Linear Model and means separated by Duncan's Multiple Range Test.

Fifteen genera of plant parasitic nematodes associated with sugarcane were identified in western sugarcane zones of Nzoia, Mumias, West Kenya and Busia in Kenya. Three genera were found to be dominant namely *Pratylenchus*, *Scutellonema* and *Meloidogyne* with percentage densities of 21, 18 and 13, respectively. The least were *Longidorus* (0.04%), *Belonolaimus* (0.7%) and *Trichodorus* (0.9%). Most of the parasitic nematodes associated with sugarcane in these zones were found in Nzoia (55%) while the smallest number was in the West Kenya Sugarcane zone at only 4%.

Sandy clay soils were found to contain 40% more plant parasitic nematodes than clay or clay loam. All the varieties grown are susceptible to plant parasitic nematodes. Altitude and crop cycle each influenced the genera *Ditylenchus*, *Paratylenchus*, and *Tylenchus* whereas *Xiphinema* and *Aphelenchoides* were found to be influenced only by altitude. Use of cane tops as seed led to short cycles and subsequent reduction in number of plant parasitic nematodes. Use of organic substrates as manure significantly reduced plant parasitic nematodes associated with sugarcane. Numbers of plant parasitic nematodes was over 50 % higher in the upper midland (UM2 and UM3) compared to the lower midland (LM1 and LM2) agro-ecological zones.

3.1 Introduction

Sugarcane is an important cash crop in Kenya, earning farmers approximately KES. 8 billion annually. However, the yield has declined from an average of 90.86 tonnes per hectare in 1996 to 71.46 by 2005 (KSB, 2005). There are several factors causing the decline in yields and among them are plant pests and diseases (KSB, 2005). In sugarcane, it is relatively easier to identify diseases such as smut and ratoon stunting disease (RSD) as well as pests like termites, but the damage caused by nematodes is insidious and little about them is known.

The threat posed by plant parasitic nematodes may be serious especially because of continuous growing of the same crop year after year and poor knowledge about this pest. According to Sasser and Freckman (1987), the overall average annual yield loss on a worldwide scale due to damage caused by plant parasitic nematodes is 12.3%. In certain areas, nematode infestation causes yield loss of up to 50% in sugarcane (Stirling and Blair, 1999). Studies carried out in Pakistan, a tropical environment similar to Kenya showed that the damage caused by plant parasitic nematodes is more serious and complex than in temperate since the climate is suitable for nematode multiplication throughout the year (Maqbool, 1988). In Kenya, a survey carried out in the Nyanza sugar belt showed that *Pratylenchus* spp. are the most predominant nematodes (Kariaga, 1988). Nevertheless, no studies have been done to identify the nematode population and distribution in the western sugarcane zones of Kenya. In order to develop effective control measures, knowledge of the population and distribution of major plant parasitic nematodes associated with sugarcane is necessary. The objective of this study was therefore to determine the occurrence, abundance and distribution of plant parasitic nematodes associated with sugarcane in western sugarcane zones of Kenya.

3.2 Materials and methods

The study was conducted in the four sugarcane-growing zones of Western Province of the Republic of Kenya, namely Nzoia, Mumias, West Kenya and Busia (Figure 1). The survey area is within the longitudes $034^0$16E to $034^0$51E and latitudes $00^0$17N to $00^0$41N and has bimodal rainfall distribution. Long rains fall between March to May while the short rains come from September to November.

A total of 81 plots were selected by stratified random sampling from lists made available by the respective sugar companies in the zones. A questionnaire was used to collect information regarding to previous land use and other aspects (Appendix 7.4). Using a soil auger, eight soil sub-samples were collected from the rhizospheres at a depth of 5-20 cm, bulked and thoroughly mixed together to form a composite sample from which 500g was taken and placed in a polythene bag together with roots. The samples were then delivered to the University of Nairobi, Department of Plant Science and Crop Protection's Plant Pathology Laboratory and kept at 10^0C before analysis.

Nematodes were extracted from 200 cm^3 soil obtained from each of the samples using the modified Baermann funnel technique (Hooper, 1990). Nematodes from five gram root samples were extracted using the maceration/filtration technique described by Hooper (1990). The nematodes were killed using gentle heat in a water bath at 50–70^{0}C and fixed using the method described by Hooper (1990). Nematodes were identified up to the genus level following the key by Mai and Lyon (1975) and the counts recorded. From the preserved nematodes suspension, 2ml was drawn using a pipette, placed in a counting dish under a light microscope and nematodes counted thrice with the average recorded. Data were subjected to General Linear Model and means separated by Least Significant Difference test at $P \leq 0.05$ (Steel and Torrie, 1981) using SAS Release 8.1 for Windows (2000).

3.3 Results

Plant parasitic nematodes belonging to 15 different genera were identified in the sugarcane zones in western Kenya (Table 1). Distinct patterns of the distribution of the nematodes were evident in different zones. Overall, soils in Nzoia and Mumias were found to be more heavily infested compared to those in Busia and West Kenya. There were significant differences ($P \leq 0.05$) in the occurrence and distribution of plant parasitic nematodes among the four sugarcane zones of western Kenya (Table 2). The occurrence and distribution of twelve genera of plant parasitic nematodes were found to be significant, whereas three genera namely *Longidorus*, *Belonolaimus* and *Trichodorus* were not. The most prevalent genera were *Pratylenchus, Scutellonema* and *Meloidogyne* in decreasing order while the least were *Xiphinema*, *Ditylenchus* and *Hoplolaimus* (Plates 1-9).

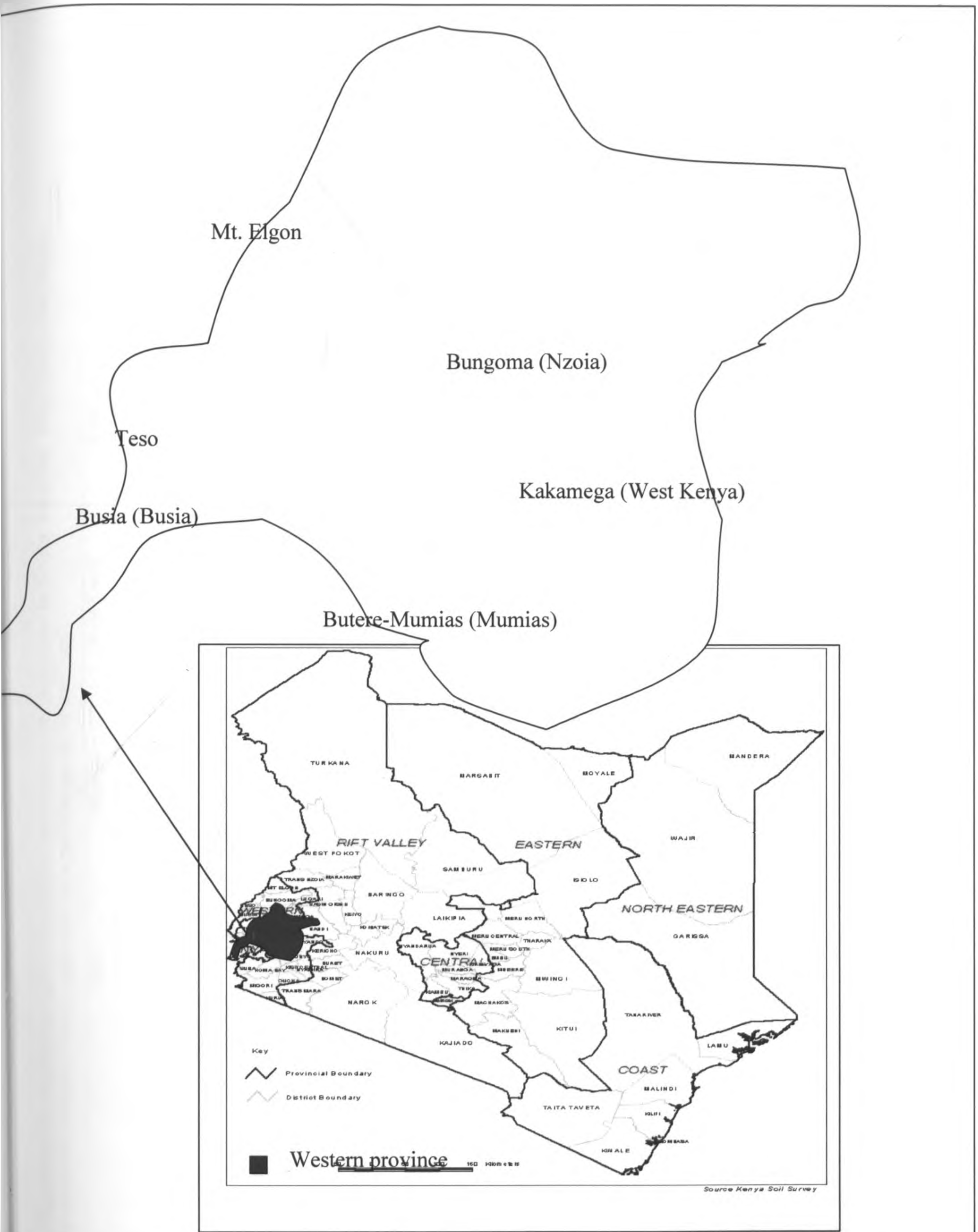

Figure 1. The location of the four sugarcane growing zones (in brackes) of western Kenya.

Table 1. Numbers (N) of plant parasitic nematodes associated with sugarcane in Nzoia, Mumias, West Kenya and Busia sugarcane zones of western Kenya expressed as a percentage in $200cm^3$ soil.

Nematode	Nzoia		Mumias		West Kenya		Busia		Total	
	N	%	N	%	N	%	N	%	N	%
Pratylenchus	2060	15.7	1805	26.1	80	7.9	980	34.4	4925	20.6
Scutellonema	2260	17.2	1400	20.3	0	0	700	24.6	4360	18.2
Meloidogyne	1955	14.9	980	14.2	0	0	205	7.2	3140	13.1
Rotylenchus	1065	8.1	670	9.7	590	58.4	50	1.8	2375	9.9
Aphelenchoides	1660	12.6	230	3.3	0	0	0	0	1890	7.9
Paratylenchus	845	6.4	250	3.6	310	30.7	395	13.9	1800	7.5
Tylenchus	1380	10.5	160	2.3	0	0	220	7.7	1760	7.4
Helicotylenchus	675	5.1	585	8.5	10	1	20	0.7	1290	5.4
Tylenchorhynchus	570	4.3	305	4.4	20	2	80	2.8	975	4.1
Xiphinema	135	1	90	1.3	0	0	110	3.9	335	1.4
Ditylenchus	100	0.8	225	3.6	0	0	0	0	325	1.4
Hoplolaimus	240	1.8	40	0.6	0	0	40	1.4	320	1.3
Belonolaimus	85	0.6	60	0.9	0	0	20	0.7	165	0.7
Trichodorus	95	0.7	100	1.4	0	0	30	1.1	225	0.9
Longidorus	0	0	10	0.1	0	0	0	0	10	0.04
*Percentage total		54.9		28.9		4.2		12		100

* Percentage of all the plant parasitic nematodes extracted from the samples collected

Table 2. Occurrence and distribution of plant parasitic nematodes in the four sugarcane zones of Western Kenya

Nematode genera	Nzoia	Mumias	West Kenya	Busia	Overall mean	F
Helicotylenchus	18ab	25a	1b	2b	16	**
Xiphinema	4b	4b	0b	9a	4	**
Ditylenchus	3ab	10a	0b	0b	4	**
Hoplolaimus	6a	2b	0b	3ab	4	*
Meloidogyne	52a	43a	0b	17b	39	**
Paratylenchus	23ab	11b	34a	33a	22	*
Rotylenchus	29b	29b	66a	4c	29	**
Tylenchorhynchus	15a	13ab	2b	7ab	12	**
Belonolaimus	2a	3a	0a	2a	2	ns
Trichodorus	3a	4a	0a	3a	3	ns
Scutellonema	61a	61a	0b	58a	54	**
Prutylenchus	56a	78a	9b	82a	61	**
Aphelenchoides	45a	10b	0b	0b	23	**
Tylenchus	37a	7ab	0b	18ab	22	**
Average	355a	300ab	112c	238b		

* Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$; ns=not significant
Data are means of 81 samples. Means followed by the same letter(s) along rows are not significantly different.

Plate 1. *Pratylenchus* (×100): shows the slight ventral curve and the flat cephalic region.

Plate 2. *Scutellonema* (×100): shows the head with well-developed sclerotization & cup-shaped stylet knobs and annulations

Plate 3. *Meloidogyne* (×100): J2 juveniles showing arcuate shape, slender stylet and hyaline tail end.

Plate 4. *Aphelenchoides* (× 400): shows the tail mucron.

Plate 5. *Paratylenchus* (x400): shows the posterior vulva and conoid, ventrally hooked (arcuate) tail tip

Plate 6. *Tylenchus* (×100): shows its characteristic whip-like (filiform) tail.

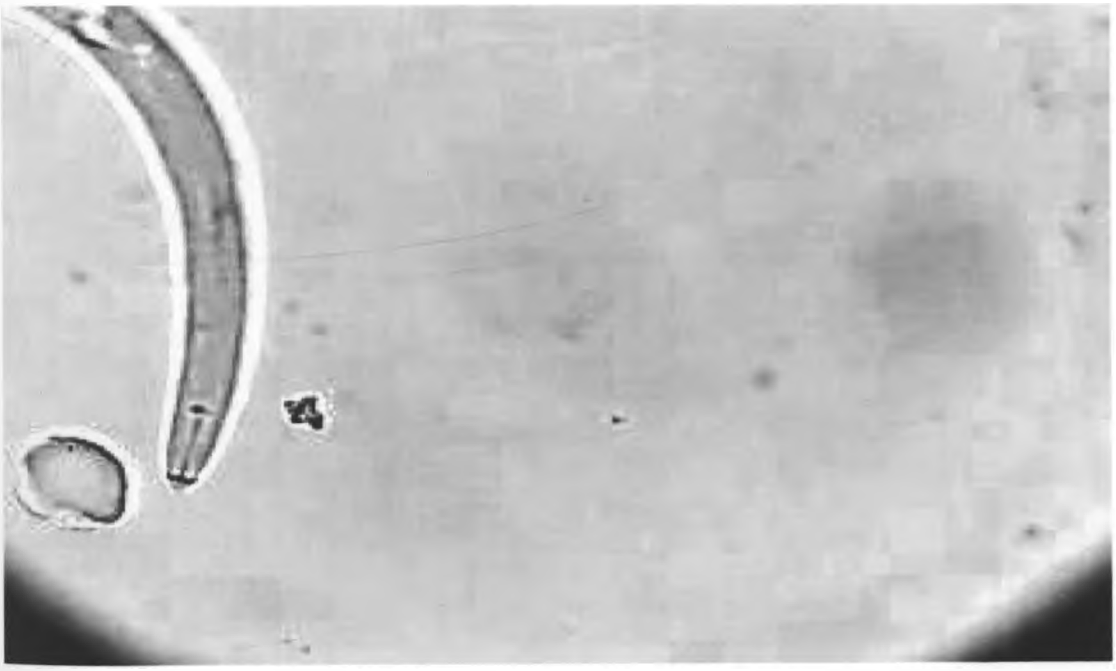

Plate 7. *Helicotylenchus* showing spiral shape (M, ×100) and head (N, ×400) shows the strong sclerotization and annulations of the lip region and round stylet knobs

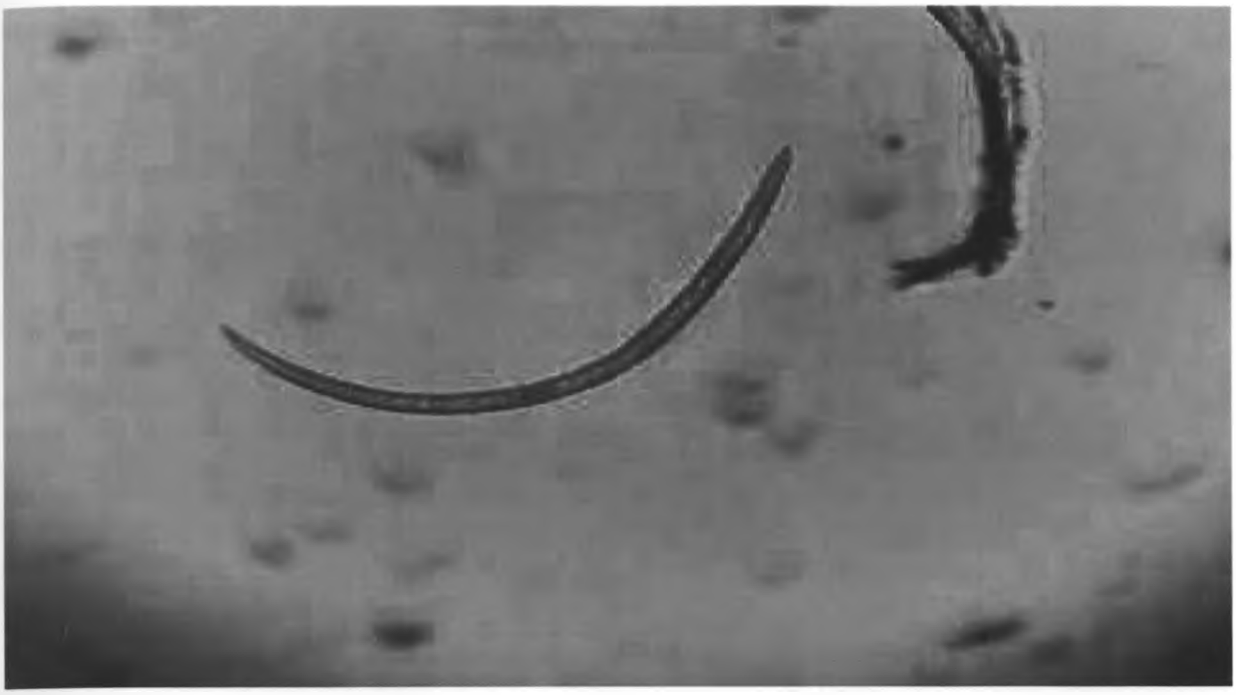

Plate 8. *Tylenchorhynchus* (×100): shows the open C-shape (ventrally arcuate) and the prominently annulated cuticle

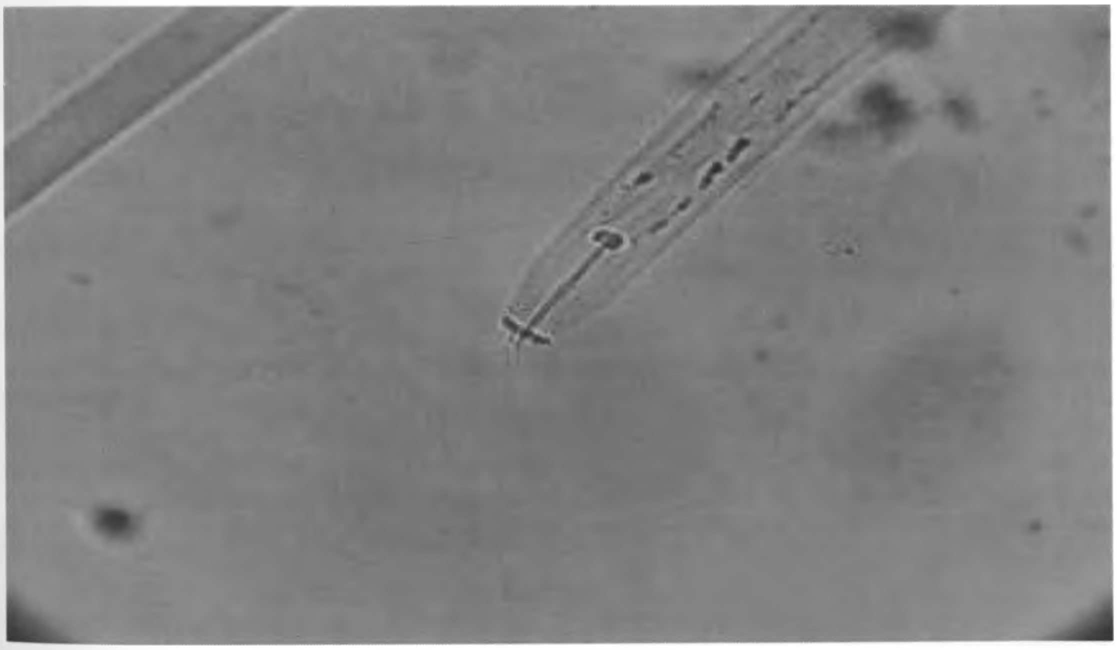

Plate 9. *Hoplolaimus* (×400): shows the massive tulip-shaped stylet knobs.

The influence of soil texture on the distribution of plant parasitic nematodes in the sugarcane zones was significant at $P \leq 0.05$ (Table 3). All the nematodes were significantly influenced by soil type except those in the genera *Helicotylenchus*, *Xiphinema*, *Meloidogyne* and *Aphelenchoides*. The highest population in sandy clay was *Pratylenchus*, in clay was *Rotylenchus* and in clay loam was *Meloidogyne*. Sandy clay harboured about 40% more nematodes than soils with more clay content.

Table 3. Effect of soil texture on the abundance of plant parasitic nematodes in Western Kenya

Nematode	Sandy clay	Clay loam	Clay	F
Helicotylenchus	19a	7a	12a	ns
Xiphinema	5a	7a	2a	ns
Ditylenchus	2b	4b	12a	**
Hoplolaimus	4ab	9a	0b	*
Meloidogyne	42a	42a	25a	ns
Paratylenchus	24ab	10b	27a	*
Rotylenchus	25b	18b	55a	*
Tylenchorhynchus	12ab	22a	4b	*
Scutellonema	70a	22b	25b	**
Pratylenchus	73a	37b	40b	*
Aphelenchoides	29a	28a	0a	ns
Tylenchus	33a	2b	0b	*
Average	342a	202b	211b	

*Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$; ns=not significant
Data are means of 81 samples. Means followed by the same letter(s) along rows are not significantly different.

Significant differences ($P \leq 0.05$) in the abundance of plant parasitic nematodes was observed between the lower midland (LM1, LM2) and upper midland (UM2, UM3) sugarcane growing Agro-ecological zones (AEZ) (Table 4). The nematodes were more abundant in the upper midland zones compared to the lower midland zones.

Table 4. Effect of Agro-ecological zones on the abundance of plant parasitic nematodes in Western Kenya.

Nematode genera	AEZ				F
	LM1	LM2	UM2	UM3	
Helicotylenchus	21ab	16b	7b	45a	**
Xiphinema	5a	0a	0a	8a	ns
Ditylenchus	8a	0a	0a	5a	ns
Hoplolaimus	6a	10a	0a	0a	ns
Meloidogyne	38b	68ab	110a	37b	*
Paratylenchus	15b	18b	10b	47a	*
Rotylenchus	24ab	27ab	10b	53a	*
Tylenchorhynchus	11ab	33a	0b	5b	*
Scutellonema	51b	2c	27bc	172a	**
Pratylenchus	63ab	30b	80ab	118a	*
Aphelenchoides	8c	73b	118a	3c	*
Tylenchus	4c	3c	177a	28b	**
Average	253b	222b	536a	538a	

* Significant at P=0.05; ** Significant at P=0.01; ns=not significant
Data are means of 24 samples. Means followed by the same letter(s) along rows are not significantly different.
LM=Lower midland, 1-Sugarcane zone and 2-Marginal sugarcane zone
UM=Upper midland, 2-Main coffee zone and 3-coffee/maize zone

Table 5. Effect of altitude on the abundance of plant parasitic nematodes in the sugarcane Western Kenya.

Nematode genera	1200-1299m	1300-1399m	1400-1499m	1500-1599m	≥1600m	F
Helicotylenchus	19ab	12ab	15ab	4b	23a	ns
Xiphinema	9a	4b	4b	0b	3b	**
Ditylenchus	0b	3ab	10a	0b	3ab	**
Hoplolaimus	3b	2b	10a	0b	1b	ns
Meloidogyne	26b	32b	46ab	58a	37ab	ns
Paratylenchus	35a	2b	21a	21a	33a	*
Rotylenchus	17b	20b	27b	36ab	48a	ns
Tylenchorhynchus	8b	13ab	24a	1b	3b	ns
Scutellonema	72b	48bc	21cd	0d	111a	ns
Pratylenchus	89a	69ab	40b	6c	80a	ns
Aphelenchoides	0b	13ab	33ab	21ab	40a	**
Tylenchus	15b	9b	2b	5b	72a	*
Average	303b	233bc	260bc	153c	455a	

* Significant at P=0.05; ** Significant at P=0.01; ns=not significant
Data are means of 81samples. Means followed by the same letter(s) along rows are not significantly different.

Significant (P≤0.05) differences were recorded on the influence of altitude on parasitic nematodes associated with sugarcane (Table 5). The most influenced genera were *Aphelenchoides, Ditylenchus* and *Xiphinema.* Seven genera remained unaffected. The highest concentration was in the high altitude of 1600m above sea level while the least was in the alttude range of 1500-1599m. But individual genera were affected differently by similar altitude. As an example, *Aphelenchoides* and *Tylenchus* thrived at high altitude whereas *Xiphinema* and *Ditylenchus* flourished in low and medium altitudes respectively.

General lack of a defined pattern for some nematodes notably *Helicotylenchus* and *Scutellonema* was observed.

Significant ($P\leq0.05$) difference was recorded on the influence of varieties only on the genus *Hoplolaimus* with EAK 70-76 being susceptible (Table 6). There was however no significant ($P\leq0.05$) difference in the total number of the nematodes across varieties.

Table 6. Effect of sugarcane variety on the abundance of plant parasitic nematodes in the Western Kenya.

Nematode genera	CO421	CO945	N14	EAK 70-76	KEN 83-737	F
Helicotylenchus	9a	25a	13a	10a	0a	ns
Xiphinema	5a	5a	3a	10a	0a	ns
Ditylenchus	0a	5a	6a	10a	0a	ns
Hoplolaimus	2b	5b	2b	35a	10b	**
Meloidogyne	31s	37s	47a	45a	40a	ns
Paratylenchus	23ab	27ab	16ab	38a	0b	ns
Rotylenchus	29a	29a	30a	20a	40a	ns
Tylenchorhynchus	6a	16a	13a	13a	0a	ns
Scutellonema	47a	69a	45a	25a	40a	ns
Pratylenchus	52a	72a	60a	5a	60a	ns
Aphelenchoides	30a	18a	25a	0a	30a	ns
Tylenchus	27a	11a	32a	0a	10a	ns
Average	262a	323a	298a	235a	230a	

* Significant at P=0.05; ** Significant at P=0.01; ns=not significant
Data are means of 81 samples. Means followed by the same letter(s) along rows are not significantly different.

The duration of sugarcane cultivation as reflected in the number of crop cycles significantly affected ($P \leq 0.05$) the abundance of *Ditylenchus, Tylenchorhynchus* and *Pratylenchus* (Table 7). Both *Ditylenchus* and *Pratylenchus* were more abundant in the second ratoon crop, while members of the genus *Tylenchorhynchus* were more prevalent in older ratoon crop. Generally, nematodes increased with increase in the duration a sugarcane crop was maintained up to the second ratoon before declining.

Table 7. Effect of duration of sugarcane cultivation on the abundance of plant parasitic nematodes in western Kenya.

Nematode genera	Plant Crop	Ratoon 1	Ratoon 2	Ratoon 3+	F
Ditylenchus	1b	2b	18a	4b	**
Tylenchorhynchus	4c	17ab	8bc	21a	*
Pratylenchus	62ab	65ab	81a	40b	*
Other phytonematodes	23a	26a	25a	21a	ns

* Significant at P=0.05; ** Significant at P=0.01; ns=not significant
Data are means of 81 samples. Means followed by the same letter(s) along rows are not significantly different.

The type of management led to significant differences ($P \leq 0.05$) in the distribution of plant parasitic nematodes with nematodes in eight genera being influenced while four were not (Table 8). Among the nematodes influenced by management type, *Pratylenchus* (P=0.01) and *Scutellonema* (P=0.01) were the most numerous while the least were *Hoplolaimus* (P=0.01) and *Aphelenchoides* (P=0.05). The crop managed by outgrowers had higher densities of plant parasitic nematodes compared to that managed by factories in their Nucleus estate farms.

Table 8. Effect of management type on abundance of plant parasitic nematodes in sugarcane.

Nematode genera	Company managed	Outgrowers	F
Helicotylenchus	10a	19a	ns
Xiphinema	5a	4a	ns
Ditylenchus	4a	4a	ns
Hoplolaimus	6a	3b	**
Meloidogyne	26b	45a	**
Paratylenchus	9b	28a	*
Rotylenchus	17b	35a	**
Tylenchorhynchus	17a	10a	ns
Scutellonema	36b	62a	**
Pratylenchus	47b	67a	**
Aphelenchoides	9a	3b	*
Tylenchus	6b	29a	*
Average	201b	337a	

*Significant at P=0.05; ** Significant at P=0.01; ns=not significant. Data are means of 81 samples. Means followed by the same letter(s) along rows are not significantly different.

3.4 Discussion

This study has clearly shown that plant parasitic nematodes associated with sugarcane are present in significant numbers in western Kenya. *Pratylenchus*, *Scutellonema* and *Meloidogyne* were found to be the most predominant genera, and this conforms with findings from previous studies elsewhere (Hollis, 1962; Kariaga, 1988; Cadet and Spaull, 2005). The total number of genera found associated with sugarcane in western Kenya was fifteen which comes close to similar studies worldwide; for instance twenty genera were associated with sugarcane in Barbados (Braithewaite, 1968) and eight in Hawaii (Jensen, 1953). In this study, twelve of the fifteen genera were found to be important.

It was noted that a high concentration of the nematodes were found in Nzoia and Mumias. Indeed over 50% of all the plant parasitic nematodes associated with sugarcane in these zones were found in Nzoia alone, while few were found in West Kenya and Busia. It has been observed that the major AEZ for sugarcane growing are LM1 and LM2 (Jaetzold and Schmidt, 1982). The entire Mumias Sugarcane Scheme lies within the ideal sugarcane AEZ, the LM1 and indeed it is this scheme that produces 60% of Kenya's sugar (KSB, 2005). On the other hand, Nzoia Sugarcane Scheme has incorporated non-traditional AEZs, the main coffee zone (UM2) and coffee-maize zone (UM3). UM2 and UM3 present temperate conditions that are favourable for multiplication of some particular nematodes. This could explain the high density of plant parasitic nematodes in Nzoia Sugarcane Scheme. Busia sugarcane zone is the latest of the four zones to be established. This probably explains the low population of plant parasitic nematodes in the zone because the crop has been grown for only as short as three years.

West Kenya Sugarcane zone exhibited the least number of plant parasitic nematodes. The diversity of nematodes was also the lowest at only five. The common practice in West Kenya zone is to establish sugarcane using cane tops. In this case, yields tend to deteriorate fast leading to ploughing out of the farm after only one ratoon crop, hence constant disruptions of the nematode reproduction cycles. Sugarcane in West Kenya and

Busia is wholly produced by outgrower farmers where the fallow periods between subsequent crops are long. This may also contribute to lower numbers of plant parasitic nematodes.

Plant parasitic nematodes associated with sugarcane are subject to variations due to soil type. Indeed a study in South Africa showed that the effect of soil type on the distribution of some of the nematodes is more than that of climatic or topographic factors (Spaull *et al.*, 2003). The amount of sand and organic matter in soil appears to be the main factors that affect the distribution of nematodes associated with sugarcane (Spaull and Heyns, 1991; Hall and Irey, 1992). This study showed that sandy-clay soils harboured the highest population of plant parasitic nematodes thus confirming previous findings (Hall and Irey, 1992; Cadet and Spaull, 2005).

Nematodes from four genera namely *Helicotylenchus, Xiphinema, Meloidogyne* and *Aphelenchoides* were not affected by soil type. This finding is similar to that of Spaull (1981) and Blair *et al.* (1999). *Pratylenchus* spp was found to be more numerous in sandy clay as opposed to a report by Hall and Irey (1992). It may mean that other local factors come into play in pathogenicity of plant parasitic nematodes in sugarcane. Similarly, *Scutellonema* was also predominant in sandy-clay soils. Sandy soils enable easy movement of nematodes thus increasing their pathogenicity (Cadet and Spaull, 2005). Sandy soils have a lower water holding capacity so that roots found there are restricted in growth, this coupled with destruction by nematodes makes their impact even worse (Wallace, 1973).

With the exception of variety EAK 70-76, the other four harboured low numbers of plant parasitic nematodes. Sugarcane variety N14 that is one of the main varieties grown in South Africa is known to be tolerant to damage by nematodes (Tew, 2003; Spaull and Cadet, 2003). This study has classified this variety along with three others grown in the western sugarcane zones of Kenya thus giving credence to the locally grown varieties as being resistant/tolerant to damage by plant parasitic nematodes.

Altitude influences plant parasitic nematodes as was observed in this study. Five genera were influenced three of them highly, of these, *Xiphinema* has been reported to be influenced by altitude in South Africa and Mauritius (Spaull *et al.*, 2003, Williams and Luc, 1977; Lamberti *et al.*, 1987). The four other genera found to be significantly influenced were *Ditylenchus, Paratychenchus, Aphelenchoides* and *Tylenchus*. *Xiphinema* was found to be restricted to altitudes below 1300m, while *Ditylenchus* thrived in the medium altitudes of between 1400–1500m above sea level (asl). *Paratylenchus* had a wider altitude range of 1400m onwards while *Aphelenchoides* and *Tylenchus* were restricted to the high altitudes of above 1600 m asl. Generally, a higher concentration of plant parasitic nematodes was observed at high altitudes and this was supported by observations on Agro-ecological zones. The upper midland zones had much higher numbers of plant parasitic nematodes compared to the lower zones.

This study showed three genera of plant parasitic nematodes namely *Ditylenchus, Tylenchus* and *Pratylenchus* to be influenced by duration of cultivation as reflected by the number of crop cycles. Similar observations were reported by Cadet (1985) and Bond *et al.*, (2000). Whereas in this study increase in crop cycles led to an increase in the number of nematodes up to the second ratoon crop, Cadet's work in Burkina Faso showed increase in numbers of *Hoplolaimus* up to the third ratoon crop before declining. In a related work by the same author in West Africa, plant parasitic nematodes were found to have a marked effect on the plant crop but little influence on the following ratoon crops. Thus it is not easy to come up with a trend that cuts across regions.

A higher concentration of plant parasitic nematodes was found in the out grower farms as compared to the nucleus estates. Only two genera were found in higher numbers in the nucleus estates than in the out grower farms namely *Hoplolaimus* and *Aphelenchoides*. The practice in the sugar factories is to spread filter press mud (scum) and baggase in their nucleus estate farms, thus increasing the organic matter level of the sugarcane plots. On the other hand, farmers lack the capacity to deliver the same to their farms due to prohibitive costs, hence rendering these farms less in organic matter. Filter press mud is known to suppress plant parasitic nematodes as well as increase yields (Estioko *et al.*, 1988; Albuquerque *et al.*, 2002).

3.4.1 Conclusion and recommendations

Fifteen genera of plant parasitic nematodes associated with sugarcane were identified in the western sugarcane zones of Nzoia, Mumias, West Kenya and Busia in Kenya. Of these, *Pratylenchus*, *Scutellonema* and *Meloidogyne* were predominant. Majority of the plant parasitic nematodes associated with sugarcane in these zones were found in Nzoia while the smallest number was in the West Kenya sugarcane zone.

Soils with higher contents of sand harbour more parasitic nematodes. Varieties of sugarcane grown in the western sugarcane zones of Kenya are generally tolerant to plant parasitic nematodes. Cane tops led to short cycles and subsequent reduction in number of plant parasitic nematodes. Three genera namely *Ditylenchus, Tylenchus* and *Pratylenchus* are influenced by duration of sugarcane cultivation.

The genera influenced by altitude are *Ditylenchus, Paratychenchus, Aphelenchoides, Tylenchus* and *Xiphinema.* Mumias sugarcane zone which lies in the best AEZ for sugarcane has relatively fewer parasitic nematodes associated with the crop. Use of organic products as manure reduces parasitic nematodes associated with sugarcane.

Measures of managing plant parasitic nematodes in western sugarcane zones should be geared towards the major nematodes namely *Pratylenchus*, *Scutellonema* and *Meloidogyne.* The centre of focus in management should be the heavily infested Nzoia Sugarcane Scheme. Efforts to prevent introduction of spread ought to be observed in the West Kenya zone which is least infested. Expansion into zones that are not typically meant for sugarcane should be done with care as the crop tends to suffer more from the parasites, such care entails pre-analysis of the soils to establish the level of infestation present already and thus carry out appropriate measures.

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CHAPTER FOUR

4.0 REACTION OF DIFFERENT SUGARCANE VARIETIES TO PLANT PARASITIC NEMATODES IN KENYA

Abstract

It has been observed over the last decade that overall sugarcane yields have been on a decline in the Kenyan sugar industry. Indeed the yields have dropped from an average of 90.86 tonnes per hectare (TCH) in 1996 to 71.46 TCH by 2005. Several factors have been thought to account for this decline amongst which are pests and diseases which include plant parasitic nematodes. Host resistance has been recommended as one of the strategies in the management of plant parasitic nematodes. However, for successful breeding programmes knowledge of resistance status of existing varieties is a prerequisite. Seven sugarcane varieties namely CO 421, CO 617, CO 945, EAK 70-97, KEN 83-737, KEN82-808 and KEN 82-216 were evaluated to determine their reaction to plant parasitic nematodes with N14 being used as the standard. The experiment was carried out in a glasshouse at University of Nairobi, Kabete. Soils collected from Nzoia sugarcane zone in western Kenya were mixed with sand at a ratio of 2:1 and divided in to two one of which was subjected to heat treatment at 60^{o}c for 30 minutes to kill the nematodes.

Seed sets were dipped in a solution of probineb to control fungal diseases. One-budded set was planted per pot. The experiment was arranged in a completely randomized design with three replications. Data on nematode populations and shoot length were collected at

0, 60 and 120 days after planting (DAP). Nematodes were extracted from 200 cm^3 soil obtained from a composite sample. At termination of the experiment at 120 DAP, data on root length and root weight were taken.

The numbers of nematodes from four genera namely *Pratylenchus, Scutellonema, Helicotylenchus* and *Hoplolaimus* were significantly influenced by the sugarcane varieties. The highest numbers of nematodes in all varieties were those of *Pratylenchus* at 188 per 200cm^3 while the lowest were those of *Hoplolaimus* at 92. Variety N14 was observed to harbour the highest number of plant parasitic nematodes (91) while KEN83-737 hosted the least at 55. All varieties tested showed a higher level of resistance against plant parasitic nematodes compared to N14.

4.1 Introduction

Sugarcane (*Saccharum officinarum*) is an important source of income to over 200,000 small-holder farmers in Western, Nyanza and parts of the Rift Valley provinces (KSB, 2005). However, sugarcane yields have been on the decline over the years due to a combination of factors which include pests and diseases, declining plot sizes and high cost of production (KESREF, 2003; KSB, 2005).

Plant parasitic nematodes are known to be one of the main pests of sugarcane, indeed their diversity in the crop is higher than in many of the other cultivated crops with more than 48 genera reported (Cadet and Spaull, 2005). But the effects of nematodes are not obvious especially to small scale growers because of their hidden nature. Many nematode management measures have been developed including cultural practices such as crop rotation, cover cropping, fallowing and intercropping. The use of nematicides and even biological methods are also in place with a view to managing nematodes. These methods are however limited in one way or another. Sugarcane production in particular poses extra challenge as it is semi-perennial that is produced under monoculture.

Host resistance offers the best option for managing the nematode problem not only in sugarcane production but also in all field crops (Sikora *et al.,* 2005a). Tolerant cultivars have been known to reduce damage caused by nematodes from about 47% to 15% (Matsuoka, 1980; Spaull and Cadet, 2003). Selection of resistant/tolerant cultivars that grow well in spite of nematode attack appears to be the way forward (Matsuoka, 1980). The reaction of sugarcane varieties to nematode infestation in Kenya is however yet to be documented. It is important to carry out a study to determine susceptibility, tolerance or resistance of the varieties of sugarcane grown in Kenya in order to manage the pest. In recent years, the Kenya Sugar Research Foundation (KESREF) has released new varieties whose reactions to nematode infestation in the field conditions are unknown. Thus the objective of this study was to determine the reaction of both the old and newly released sugarcane varieties to plant parasitic nematodes and thus classify them accordingly.

4.2 Materials and methods

This study was carried out in a glasshouse at the University of Nairobi, Kabete campus. Seven varieties were selected based on their relative importance to the Kenya Sugar Industry as reflected by the area each occupied as at December 2005 (KSB, 2005).

Under foreign direct introductions were CO 421, CO 617 and CO 945 while under locally-bred recently-released varieties were EAK 70-97, KEN 83-737, KEN82-808 and KEN 82-216. N14 was used as the standard due to its known tolerance status (Cadet and Spaull, 2005). Altogether, they occupied 70.1% of the total area under sugarcane. Seedcane was sourced from Kenya Sugar Research Foundation (KESREF) at Kibos.

Soil collected from sugarcane rhizospheres at Nzoia Sugar Scheme in western province was divided into two batches one of which was subjected to heat treatment at 60^{o}c for 30 minutes to kill the nematodes. The soil was then mixed with sand at a ratio of 2:1 to reduce soil compaction and improve aeration. The soil mixture was then put in 15cm-diameter polythene sleeves and 20g of N:P:K fertilizer (17:17:17) was added.

Seed sets were dipped in a solution of 50g of Antracol WP70 (a.i. probineb) in 20 litres of water for five minutes to control fungal diseases like pineapple disease of sugarcane caused by *Ceratocystis* spp. One-budded set was planted in each pot and the experiment arranged in a completely randomized design with three replications. Immediately after planting the pots were watered daily up to germination time, after which watering was done on alternate days. Top dressing was done using 20g of Urea (46%N) 40 days after planting.

Data on nematode populations and shoot length were collected at 0, 60 and 120 days after planting (DAP). Initial nematode populations were determined at zero days on the freshly composited soil. Soil samples were obtained at 60 and 120 DAP by pushing aside the top

5cm of soil then scooping out $50cm^3$ to a depth of 15cm from five pots. These were mixed to form a composite sample which was put in a polythene bag and taken to the laboratory. Nematodes were extracted from 200 cm^3 soil obtained from the composite sample using the modified Baermann funnel technique (Hooper, 1990). Data on shoot length was taken from three plants that were randomly selected and tagged. The plants were measured at 60 and 120 DAP using a tape measure.

On terminating the experiment at 120 DAP, data on root length and root weight were taken. The polythene sleeve was gently torn off and outer soil removed. The soil embedded in root was gently shaken off and collected in a container out of which $300cm^3$ was put in polythene bag and taken to the laboratory for analysis. Root lengths were measured and their weights recorded. Data were subjected to analysis of variance using Genstat release 4.24DE for Windows (2005) and means separated by Least Significant Difference (LSD) test (Steel and Torrie, 1981).

4.3 Results

Soil used in the greenhouse experiment was found to harbour fourteen different genera of plant parasitic nematodes associated with sugarcane. The most dominant genera were found to be *Pratylenchus* (17.7%), *Scutellonema* (11.5%), *Helicotylenchus* (10.6%) and *Paratylenchus* (9.6%) while the least was *Ditylenchus* at 0.2% (Table 9).

Table 9. Numbers of plant parasitic nematodes associated with sugarcane in 200cm^3 of soil used in the glasshouse experiment.

Nematode	Number	Percentage
Pratylenchus	2005	17.7
Scutellonema	1305	11.5
Helicotylenchus	1200	10.6
Paratylenchus	1090	9.6
Tylenchus	1000	8.8
Hoplolaimus	930	8.2
Rotylenchus	890	7.9
Tylenchorhynchus	640	5.6
Trichodorus	640	5.6
Belonolaimus	640	5.6
Aphelenchoides	480	4.2
Meloidogyne	320	2.8
Xiphinema	175	1.5
Ditylenchus	20	0.2

* Percentage of all the plant parasitic nematodes extracted from the samples collected

Significant differences ($P \leq 0.05$) were observed on the reaction of sugarcane varieties to nematode infestation (Table 10). The numbers of four genera namely *Pratylenchus, Scutellonema, Helicotylenchus* and *Hoplolaimus* were influenced by different sugarcane varieties. The highest numbers in all varieties were *Pratylenchus* while the lowest were *Hoplolaimus*. Variety N14 was observed to harbour the highest number of plant parasitic nematodes. The lowest number of nematodes was associated with variety KEN83-737.

Table 10. Effect of sugarcane varieties on nematode numbers in soils obtained from Western Kenya.

Nematode	Mean population density in 200cm^3 soil								Overall mean
	N14	CO945	CO421	KEN 82-808	KEN 82-216	EAK 70-79	CO617	KEN 83-737	
Helicotylenchus	17a	17a	14ab	12abc	17a	11bc	14ab	8c	13b
Hoplolaimus	23a	12bc	11bc	8c	8c	9bc	8c	13b	10b
Scutellonema	20a	15bc	18ab	15bc	13cd	15bc	13cd	10d	14b
Pratylenchus	31a	23b	21b	25ab	20b	22b	22b	24b	21a

Data are means of 18 samples. Means followed by the same letter(s) along rows are not significantly different.

Plate 10. Effect of plant parasitic nematodes on the roots of sugarcane (A-uninfested roots and B-infested roots)

There were significant differences ($P \leq 0.05$) in the numbers of plant parasitic nematodes associated with sugarcane following heat treatment. Treating soil led to significant differences in root and shoot lengths as well as weights of sugarcane (Figs. 2 and 3, Plates 10 and 11).

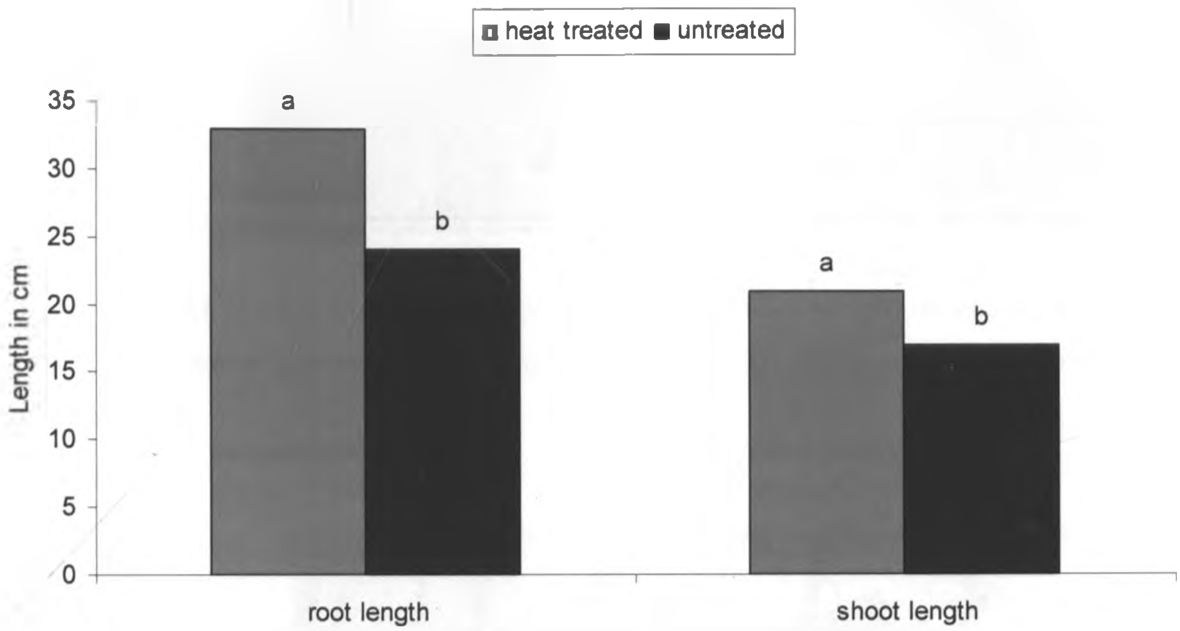

Figure 2. Effect of soil heat treatment on the root and shoot lengths of sugarcane.
Bars headed by different letter(s) are significantly ($P \leq 0.05$) different by least significant difference test.

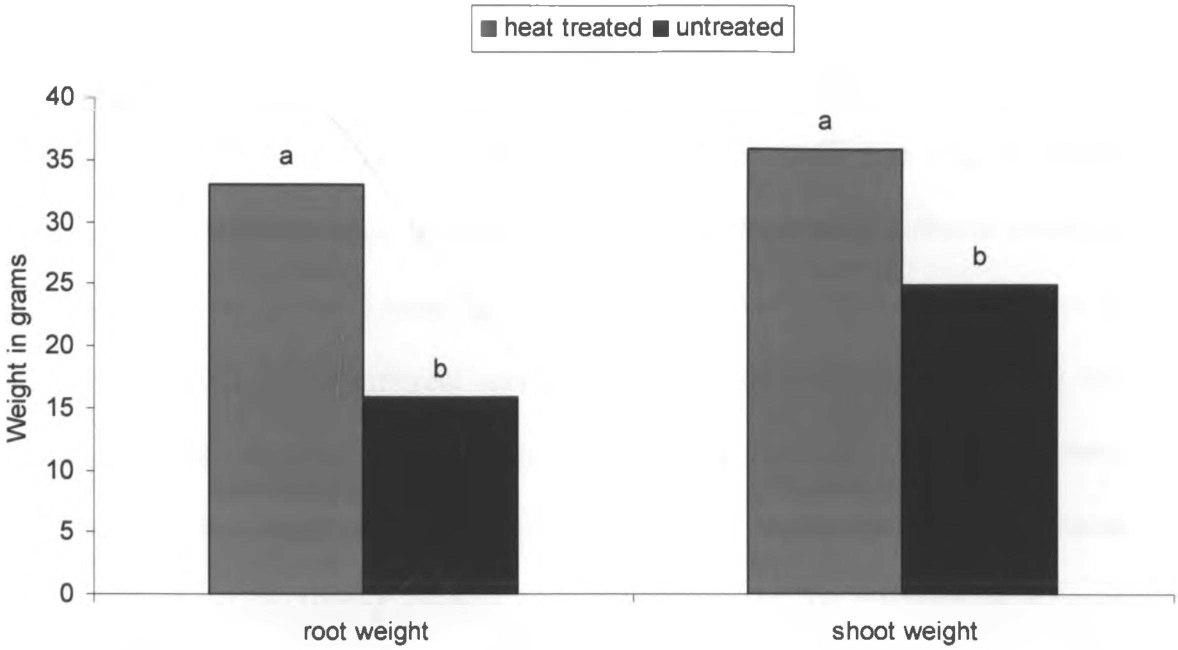

Figure 3. Effect of soil heat treatment on the root and shoot weight of sugarcane. Bars headed by the same letter(s) are not significantly ($P \leq 0.05$) different by least significant difference test.

Plate 11. Effect of soil heat treatment on shoot growth of Sugarcane (A-untreated and B-heat treated soil).

4.4 Discussion

This study has established that different sugarcane varieties supported varying numbers of plant parasitic nematodes. This indicates that the different genotypes may be having differing levels of host resistance. Similar works have been reported in different countries where sugarcane varieties have been observed to possess varying levels of resistance or tolerance when subjected to different species of plant parasitic nematodes. Mehta and Somasekhar (1998) reported resistance to species of *Pratylenchus* while Suwarno (1991) observed the same for *Meloidogyne* spp. Similar works by Dinardo-Miranda (1994) and Blair *et al.*(1999a) showed large differences in the numbers of *P. zeae* recovered from the rhizospheres of different varieties.

This study revealed that nematodes from four genera namely *Pratylenchus, Scutellonema, Helicotylenchus* and *Hoplolaimus* were influenced by varietal differences of sugarcane. Evidence is available on the influence of different sugarcane varieties on *Pratylenchus* which is clearly confirmed in the current study (Dinardo-Miranda, 1994; Mehta and Somasekhar, 1998). However, the influence of varieties on *Scutellonema, Helicotylenchus* and *Hoplolaimus* is seemingly a new finding of this study as little has been reported about them.

It was observed that the numbers of *Pratylenchus* was significantly higher in N14 than all other varieties except KEN82-808. Species of the genus *Pratylenchus* are known to be the most common plant parasitic nematodes associated with sugarcane worldwide (Lambart *et al.,* 1987; Blair *et al.,* 1999a,b; Bond *et al.*, 2000; Cadet and Spaull, 2005). In this study *Pratylenchus* spp were significantly ($P \leq 0.05$) higher than all the other nematodes.

The highest density of plant parasitic nematodes was found in sugarcane variety N14 which is a relatively recent introduction from South Africa, and is known to be tolerant to plant parasitic nematodes (Cadet and Spaull, 2005). This variety was used as the standard in the present study. It was observed that all the varieties tested haboured lower plant parasitic nematodes than the standard N14. This is a good indication of possession of resistance in sugarcane genotypes that are locally grown. This kind of information on potential sources of resistance to nematodes affecting sugarcane has not yet been documented in Kenya. This is unlike in Nigeria where attempts have been made to identify sources of resistance to *Heterodera sacchari* (Salawu, 1990).

Heat treatment of soil led to elimination of plant parasitic nematodes and subsequent increase in growth as measured using shoot and root length and weight. Valle-Lamboy and Ayala (1980) observed that plant parasitic nematodes lead to a reduction in shoot and root mass and stalk length, and this study has therefore confirmed the same.

The sugarcane varieties tested exhibited possible possession of resistant genotypes by having lower numbers of *Pratylenchus* spp compared to the standard N14, thus the study has for the first time established that locally grown sugarcane varieties are potentially resistant to plant parasitic nematodes.

4.4.1 Conclusion and recommendations

Different sugarcane varieties influence plant parasitic nematodes. This indicates that the different genotypes may be having differing levels of host resistance. Nematodes from four genera of plant parasitic nematodes namely *Pratylenchus, Scutellonema, Helicotylenchus* and *Hoplolaimus* were influenced by varietal differences of sugarcane. Number of nematodes of the genus *Pratylenchus* was significantly higher than the other nematodes. Plant parasitic nematodes led to an average of 20% reduction in shoot length of the sugarcane plant.

Numbers of *Pratylenchus* spp were significantly higher in N14 than all the tested locally grown sugarcane varieties except KEN82-808. Since the six varieties tested have shown potential for resistance/tolerance against plant parasitic nematodes, it is recommended that further studies be undertaken to determine yield loss due to the nematodes for each variety.

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CHAPTER FIVE

5.0 IMPACT OF DIFFERENT INTERCROPS ON THE POPULATION DYNAMICS OF PLANT PARASITIC NEMATODES ASSOCIATED WITH SUGARCANE IN KENYA

Abstract

Different crops are interplanted with sugarcane some of which are thought to aggravate the problem of plant parasitic nematodes associated with the crop in western Kenya. A study was therefore carried out to determine the effect of different intercrops on the numbers of plant parasitic nematodes associated with sugarcane at Kibos which is located in western Kenya. Five food crops namely bean (*Phaseolus vulgaris* L.) variety GLP2, soya bean (*Glycine max* L. Merr.) variety E.A.360, pigeon pea (*Cajanus cajan* L. Mill) variety 60/8, maize (*Zea mays* L.) variety WS502 and cowpea (*Vigna unguiculata* L. Walp aggreg.) variety K-80 were selected based on their popularity while four sugarcane varieties were selected based on their performance in the glasshouse study. Four sugarcane varieties namely CO421, CO617, KEN83-737 and N14 were used.

Sugarcane was planted at a spacing of 120cm between rows and diammonium phosphate fertilizer added at a rate of 100 kg per hectare. Intercrops were planted in single rows between the cane rows at recommended spacing. The experiment was laid down in split-plot design with variety as the main plot and intercrop as sub-plot. Data on nematode populations, shoot length and weight, root length and weight as well as tillering counts

were collected at 0, 60 and 120 days after planting (DAP). Nematodes were extracted from 200 cm^3 soil.

Pratylenchus, Aphelenchoides, Scutellonema and *Meloidogyne* with percentage densities of 21.7, 17.6, 15.2 and 13.3 respectively were the main plant parasitic nematodes associated with sugarcane. *Scutellonema* was the only nematode that was significantly influenced by different intercrops with the highest number (42) recorded when variety N14 was interplanted with beans. The least number (8) of the nematode occurred when variety CO421 was interplanted with beans. Significant differences were also observed when different sugarcane varieties were interplanted with soya beans. Intercropping resulted in reduction of numbers of plant parasitic nematodes with the exception of members of the genus *Scutellonema* whose numbers increased in sugarcane interplanted with common bean.

5.1 Introduction

Sugarcane yields have been on the decline in Kenya over the years, indeed it has declined by about 21% from 1996 to 2005 (KSB, 2005). The decline is attributed to several factors which include pests and diseases, declining plot sizes, high cost of production, monoculture and declining soil fertility (KESREF, 2002; KSB, 2005)

Plant parasitic nematodes associated with sugarcane are among the main pests causing up to 50% reduction in yield losses due to a reduction in the number and length of stalks (Stirling and Blair, 1999). Their diversity in sugarcane is greater than in most other cultivated crops, with more than 310 species of 48 genera of endo-and ectoparasitic nematodes having been recorded from its rhizosphere (Cadet and Spaull, 2005). The occurrence, abundance, distribution and pathogenicity of plant parasitic nematodes is influenced by soil, Agro-ecological Zone (AEZ), variety, altitude, crop cycle, age and cultural practices. One of the cultural practices that has been employed to manage plant parasitic nematodes is the proper use of multiple cropping.

Sugarcane is a monoculture crop with just a few months break between successive crops thus conditions are suitable for development of large populations of some species of plant parasitic nematodes (Cadet and Spaull, 2005). Intercropping may be used to break conditions that favour buildup of nematodes under monoculture conditions. Indeed multiple cropping is a common practice in subsistence agriculture systems such as those practiced in the Kenyan sugar industry. It has been demonstrated that row planting of crop mixtures, with sufficient spacing in between, could reduce nematode populations (Sikora *et al.,* 2005b). Thus, the focus of this study was to determine the impact of different intercrops on the population dynamics of plant parasitic nematodes associated with sugarcane in Kenya.

5.2 Materials and Methods

A field study was carried out at Kibos, Kisumu in western Kenya. Four locally grown sugarcane varieties were selected for this study based on their performance in the glasshouse study. The varieties selected were CO421, CO617 and KEN83-737 which had the lowest mean population of plant parasitic nematodes while N14 was maintained as a standard due to its known tolerance status (Spaull and Cadet, 2003). Five food crops namely common bean, soya bean, pigeon pea, maize and cowpea were selected based on their popularity with and potential for intercropping by the sugarcane farmers (Thuo, 2005).

Clean seedcane was obtained from the Kenya Sugar Research Foundation (KESREF). Certified seed of the intercrops were acquired from Kenya Seed Company Limited stores in Kisumu for bean variety GLP2, soya bean variety E.A.360 and cowpea variety K-80, Western Seed Company, Kisumu for maize variety WS502 while pigeon pea variety 60/8 was obtained from Kenya Agricultural Research Institute, Katumani.

Sugarcane was planted at a spacing of 120cm between rows and Diammonium Phosphate (18:46:0) fertilizer added at a rate of 100 kg per hectare. Intercrops were planted in single rows between the cane rows at recommended spacing. Recommended agronomic practices were observed for all the crops which were maintained up to harvesting (KESREF, 2002). The experiment was laid down in split-plot design with variety as the main plot and intercrop type as sub-plot measuring 8.4m × 6m with a net plot size of $24m^2$.

Data on nematode populations and shoot length were collected at 0, 60 and 120 days after planting (DAP). Initial nematode populations were determined on newly prepared seedbed by collecting soil samples using a soil auger. Eight soil sub-samples were collected at 60 and 120 DAP from the sugarcane rhizospheres at a depth of 5-20cm, mixed to form a composite sample which was put in a polythene bag and taken to the laboratory. Nematodes were extracted from 200 cm^3 soil obtained from the composite sample using the modified Baermann funnel technique (Hooper, 1990).

Six plants per sub-plot were randomly selected and tagged for determination of shoot length. The measurements were taken at 60 and 120 DAP using a tape measure. The experiment was terminated at 120 DAP when data on root length, root weight and tillering count were taken. Root lengths were measured while their weights were determined using a digital weighing balance. The numbers of tillers were physically counted. Data were subjected to analysis of variance using Genstat release 4.24DE for Windows (2005) and means separated using the Least Significant Difference (LSD) test (Steel and Torrie, 1981).

5.3 Results

Plant parasitic nematodes belonging to fifteen genera namely *Pratylenchus, Aphelenchoides, Scutellonema, Meloidogyne, Xiphinema, Tylenchus, Rotylenchus, Hoplolaimus, Helicotylenchus, Tylenchorhynchus, Trichodirus, Paratylenchus, Belonolaimus, Ditylenchus* and *Longidorus* were found associated with sugarcane in the experimental site at Kibos. The predominant nematodes were in the genera *Pratylenchus, Aphelenchoides, Scutellonema* and *Meloidogyne* with percentage densities of 21.7, 17.6, 15.2 and 13.3 respectively in soil samples obtained from rhizospheres of sugarcane (Table 11).

Table 11. Mean numbers of plant parasitic nematodes recovered from 200cm^3 soil obtained from the rhizosphere of sugarcane from the experimental field in Kibos.

Nematode genera	Number	Percentage
Pratylenchus	2400	21.7
Aphelenchoides	1985	17.6
Scutellonema	1695	15.2
Meloidogyne	1480	13.3
Xiphinema	610	5.5
Tylenchus	595	5.4
Rotylenchus	385	3.5
Hoplolaimus	285	2.6
Helicotylenchus	280	2.5
Tylenchorhynchus	200	1.8
Trichodorus	200	1.8
Paratylenchus	195	1.8
Belonolaimus	135	1.2
Ditylenchus	105	1.0
Longidorus	35	0.3

Significant differences ($P \leq 0.05$) in numbers of *Scutellonema* were observed when different varieties of sugarcane were intercropped with different crops (Fig. 4, Plate 12). The highest number of *Scutellonema* (42) was observed when variety N14 was interplanted with beans. The least number of the nematodes (8) occurred when sugarcane variety CO421 was interplanted with beans. Significant differences were also observed when different sugarcane varieties were interplanted with soya bean. Intercropping sugarcane with pigeon pea, maize and cowpea did not lead to any significant differences.

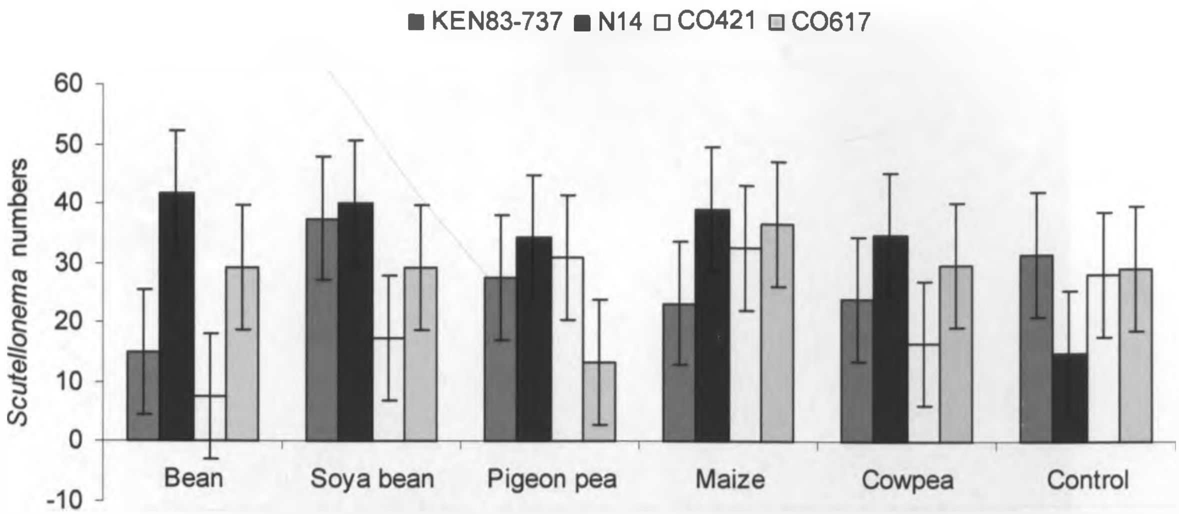

Figure 4. The influence of sugarcane varieties and intercrops on the numbers of *Scutellonema* in 200 cm^3 soil

Plant parasitic nematodes in the genera *Aphelenchoides* and *Pratylenchus* were significantly influenced by time and different types of intercrops (Table 12). The highest numbers of *Aphelenchoides* and *Pratylenchus* were observed in the varieties CO617 and CO421 in decreasing order. The least number of both nematodes was found in the variety KEN83-737. There were no significant differences in populations of these nematodes at 60 and 120 days after planting. The populations of nematodes in all genera decreased with time except for *Tylenchorhynchus*.

Plate 12. An intercrop of soya bean with sugarcane

The type of intercrop had a significant ($P \leq 0.05$) influence on growth of sugarcane (as indicated by changes in growth variables) (Table 13). Increases in root length and weight were most restricted in sugarcane-maize intercrop. The type of crop mixture did not influence shoot length. However, shoot weight increased under sugarcane-pigeon pea mixture.

Table 12. Effect of sugarcane varieties on numbers of *Aphelenchoides* and *Pratylenchus*.

Nematode	Sugarcane variety	Days after planting 0	60	120
Aphelenchoides	KEN83-737	20.8b	0.0a	0.0a
	N14	25.0b	0.0a	0.0a
	CO421	54.6a	0.0a	0.0a
	CO617	65.0a	0.0a	0.0a
Pratylenchus	KEN83-737	25.4c	9.2a	16.2a
	N14	45.8bc	10.0a	12.1a
	CO421	57.1ab	19.2a	10.0a
	CO617	71.7a	18.3a	11.7a

Data are means of eight samples. Means followed by same letter(s) along a column are not significantly different at $P \leq 0.05$.

Significant differences ($P \leq 0.05$) in number of tillers were observed when different types of intercrops were used with sugarcane (Figure 6). Sugarcane as a pure stand produced more tillers as compared to the interplanted crop. Intercropping sugarcane with maize and cowpea led to the least number of tillers. At 60 DAP soya bean and pigeon pea did not affect tillering in sugarcane, however, all intercrops tested reduced the number of tillers at 120 days.

Table 13. Effect of plant parasitic nematodes (PPN) on the roots and shoots of sugarcane grown with different intercrops.

Variable	Intercrop					
	Bean	Soya bean	Pigeon pea	Maize	Cowpea	Control
Total PPN	187a	168a	217a	198a	188a	178a
Root length	18.6a	18.6a	19.4a	13.7b	17.9a	17.8a
Shoot length	60a	31a	31a	32a	30a	31a
Root weight	7.2a	7.3a	6.2ab	4.2b	5.2ab	6.6a
Shoot weight	116.8ab	108.3ab	121.4a	99.5b	91.4b	112.7ab

Data for PPN are means of 24 samples and for growth variables 16. Means followed by similar letter(s) along rows are not significantly different at $P \leq 0.05$.

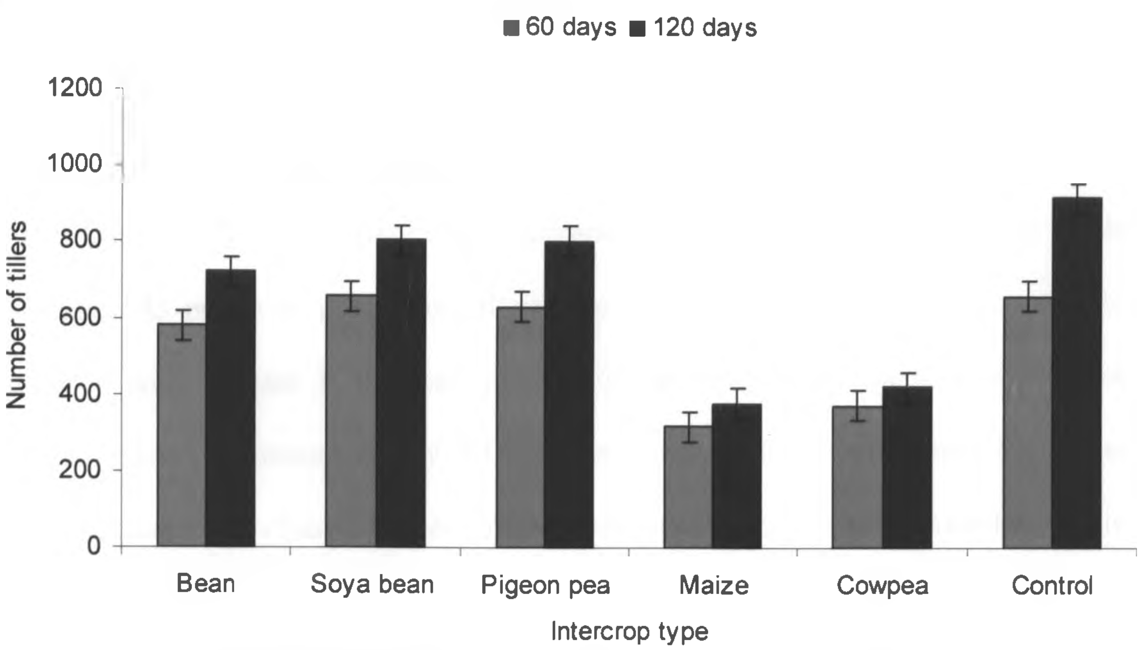

Figure 5. Effect of different intercrops on the tillering capacity of sugarcane

5.4 Discussion

The study has demonstrated that the main plant parasitic nematodes associated with sugarcane are in the genera *Pratylenchus, Aphelenchoides, Scutellonema* and *Meloidogyne*. Similar findings have been reported by other workers. Cadet and Spaull (2005) noted that species of *Pratylenchus* are the most common plant parasitic nematodes associated with sugarcane. But they also pointed out that nematode communities associated with sugarcane are not restricted to a few genera and may be as many as twelve. In this study, the total number of genera identified at Kibos in western Kenya was fifteen.

This study showed significant differences in numbers of nematodes in the genus *Scutellonema* associated with different varieties of sugarcane intercropped with different crops. Birchfield and Martin (1956) noted that intercropping can enhance multiplication of nematodes if the second crop is a susceptible host plant. For example, *Tylenchorhynchus nannus* is found to be more destructive with soya bean. In the present study, it was found that intercropping with bean increased the severity of *Scutellonema* thus confirming earlier findings (Kimenju *et al*, 1999). This study however, goes further to illustrate that different varieties of sugarcane are not affected the same way by the nematode, this points to possession of varying levels of host resistance among other factors. A point in case is the least number of the nematode *Scutellonema* that was observed when sugarcane variety CO421 was interplanted with beans. Significant differences were also observed when different sugarcane varieties were interplanted with soya bean.

This study has revealed that intercropping sugarcane with pigeon pea, maize and cowpea does not lead to increase or decrease of *Scutellonema* with any variety of sugarcane, at least in western Kenya sugarcane zones. These crops may therefore be recommended for intercropping with sugarcane. High numbers of *Aphelenchoides* and *Pratylenchus* were noted in varieties CO617 and CO421 at the initial stages but significant differences thereafter. These may therefore be ignored when it comes to formulating policies in this regard.

Cadet and Spaull (2005) observed that continuous monoculture that is widely practiced in sugarcane production tend to favour the development of relatively large populations of a few species. Thus intercropping can be used as a nematode control measure. Crops used to control nematodes in intercropping systems should possess resistance or even immunity. The mechanisms by which intercrops act against nematodes include acting as repellants, interfering with host-plant location by the pest, favouring of population build-up of nematode antagonists and improving plant resistance through better nutrient status (Palm, 1995; McIntyre *et al.*, 2001). But the present study has demonstrated that in a field of sugarcane, plant parasitic nematodes associated with the crop will initially tend to decrease before stabilizing. It appears that soon after planting, the parasites tend to be vulnerable following soil disturbance a practice which may be an option in managing the problem. Thus tillage coupled with intercropping can be incorporated in to an integrated management package for plant parasitic nematodes in sugarcane.

5.4.1 Conclusion and recommendations

The main plant parasitic nematodes associated with sugarcane are in the genera *Pratylenchus, Aphelenchoides, Scutellonema* and *Meloidogyne*. High numbers of *Scutellonema* were observed when variety N14 was interplanted with beans. It is important to take care when choosing a crop to be grown together with sugarcane.

Intercropping sugarcane with pigeon pea does not affect nematode population dynamics in the western Kenya sugarcane zones and may therefore be recommended as an intercrop. While intercropping sugarcane with either maize or cowpea does not affect nematode population dynamics, they have a negative effect on sugarcane tillering capacity and may therefore not be recommended as intercrops. It is thus recommended that a wider spectrum of both intercrops and sugarcane varieties be included in future studies.

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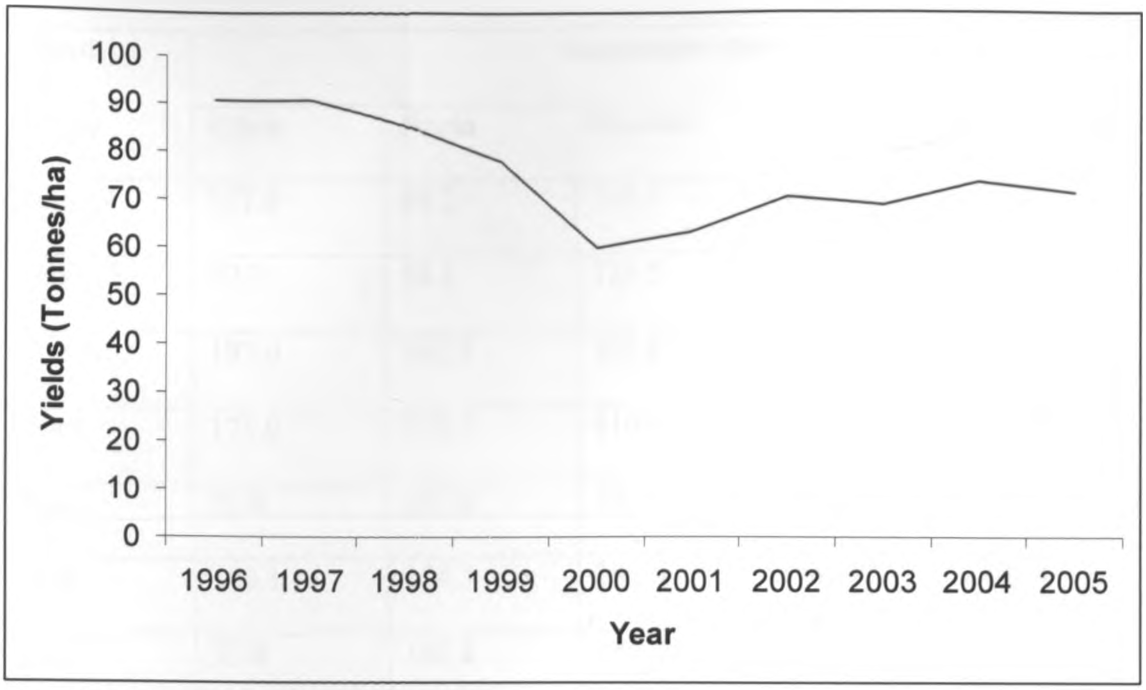
APPENDICES

Appendix 1a. Sugarcane production parameters in Kenya from 1996-2005.

Year	Area under Cane (ha)	Area harvested (ha)	Cane produced (tonnes)	Yields (tonnes/ha)
1996	131 130	39 249	3 870 479	90.86
1997	127 560	43 814	4 278 273	90.81
1998	117 657	50 111	4 661 361	85.51
1999	108 793	51 833	4 415 781	78.39
2000	107 985	57 243	3 941 524	60.52
2001	117 131	47 794	3 550 792	63.71
2002	126 826	54 010	4 501 363	70.67
2003	122 580	50 468	4 204 055	69.17
2004	131 507	54 191	4 660 995	73.81
2005	144 765	56 537	4 800 820	71.46

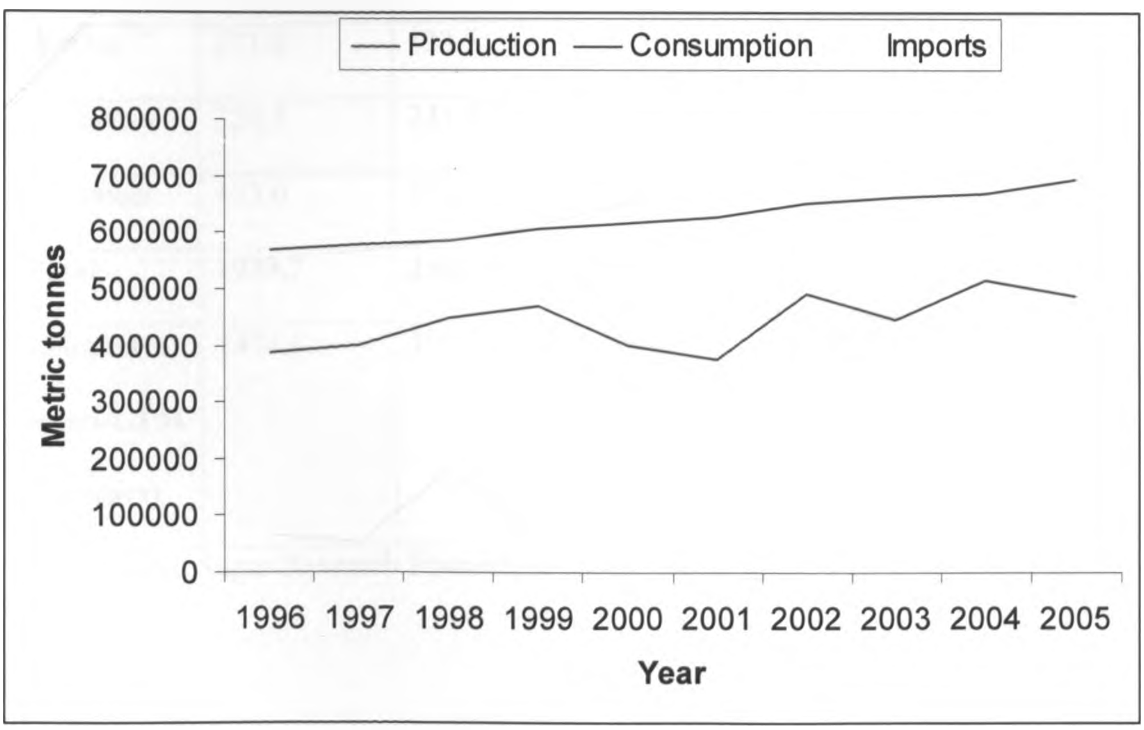
From KSB Yearbook of statistics 2005

Appendix 1b. Sugarcane yields trend over the past decade in Kenya



From KSB Yearbook of statistics 2005

Appendix 2. Sugar production, consumption and imports in Kenya over the last decade.



From KSB Yearbook of statistics 2005

Appendix 3. Rainfall data in mm for Kibos and the four sugarcane growing zones of western Kenya

Month (2006)	Sugarcane zone				
	Kibos	Nzoia	Mumias	West Kenya	Busia
January	157.8	50.2	119.7	24.5	254.0
February	29.3	58.1	135.5	72.6	72.9
March	192.0	242.1	305.8	228.9	133.9
April	171.0	329.7	410.4	231.1	193.6
May	93.8	233.9	285.9	137.2	290.2
June	100.1	174.3	185.0	266.8	207.3
July	52.8	142.8	180.1	219.8	74.0
August	93.3	98.8	122.1	150.2	21.8
September	46.1	178.7	182.8	210.4	89.2
October	253.8	133.5	115.0	85.6	122.6
November	326.5	233.8	310.6	326.4	333.1
December	423.0	218.7	278.4	268.5	237.9
Total	**1939.7**	**2084.4**	**2631.3**	**2222.0**	**2030.5**
Long term mean-LTM (10 years)	**1474.6**	**1911.2**	**2004.7**	**1815.2**	**1909.7**

From Kenya Sugar Research Foundation annual report 2006

Appendix 4. Sample questionnaire used in the survey

MSc. RESEARCH PROJECT

FIELD SURVEY – ABUNDANCE AND DISTRIBUTION OF PLANT PARASITIC NEMATODES ASSOCIATED WITH SUGARCANE IN WESTERN KENYA

DISTRICT..DIVISION................................

LOCATION...SUB-LOCATION.......................

AGRO-ECOLOGICAL ZONE...

ALTITUDE (M)..

GPS Location N...
E...

---

1. **Farmer's name:...**
2. **Plot number:..**
3. **Surface (Ha):..**
4. **Variety:...**
5. **Age (months):...**
6. **Crop cycle:..**
7. **Soil type:...**
8. **History:...**

....

....

....

....

....

Appendix 5. Mean square values and levels of significance generated from GLM output of the survey work

Nematode genera	Source										
	Overall	Error	Zone	Type	Variety	Cycle	Age	Site	Soil	AEZ	Altitude
	DF=80	DF=50	DF=3	DF=1	DF=4	DF=3	DF=9	DF=1	DF=4	DF=1	DF=4
Helicotylenchus	1117.9**	501.4	2231.2**	7358.9**	741.7ns	211.2	358.0ns	1485.8ns	1497.7*	1787.8ns	849.5ns
Xiphinema	67.3*	34.4	155.9**	93.2ns	32.0ns	9.9ns	38.8ns	108.4ns	37.3ns	27.9ns	166.2**
Ditylenchus	371.8**	113.3	389.1*	389.1ns	147.1ns	640.7**	62.1ns	7.67ns	624.3**	77.6ns	986.7**
Hoplolaimus	175.1**	35.7	165.2**	313.0**	448.3**	41.1ns	196.1**	0.53ns	67.5ns	173.3*	79.7ns
Longidorus	1.2ns	1.2	1.0ns	2.8ns	0.3ns	0.9ns	0.1ns	0.4ns	3.2*	3.1ns	2.4ns
Meloidogyne	2939.5**	934.8	8944.4**	21487.7**	712.0ns	1201.4ns	1358.9ns	50.2ns	3515.5**	3110.5ns	989.9ns
Paratylenchus	800.8*	431.8	1898.4**	2687.1*	754.8ns	68.6ns	414.7ns	360.6ns	1010.0ns	118.3ns	1041.7ns
Rotylenchus	1562.3*	677.4	6473.6**	6343.1**	480.0ns	821.6ns	687.6ns	506.0ns	1538.7ns	101.4ns	942.1ns
Tylenchorhynchus	621.0**	264.2	555.8ns	369.8ns	518.1ns	747.9*	620.8*	1843.2*	616.8ns	385.8ns	497.9ns
Belonolaimus	66.3ns	52.0	16.3ns	40.8ns	80.4ns	31.6ns	23.0ns	80.7ns	101.0ns	139.6ns	162.8*
Trichodorus	39.1ns	45.6	42.9ns	159.4ns	42.6ns	53.3ns	39.1ns	55.4ns	13.9ns	6.4ns	21.2ns
Scutellonema	10246.4**	1484.4	9802.5**	30439.1**	955.3ns	1409.4ns	2430.2ns	13474.3**	48693.0**	1014.8ns	2091.0ns
Pratylenchus	4084.0**	1745.0	12545.8**	20957.8**	362.9ns	680.2ns	3370.1ns	2437.4ns	37967ns	91.5ns	3096.8ns
Aphelenchoides	5993.5**	1775.9	10891.9**	12327.6*	770.2ns	2766.9ns	2179.3ns	1196.5ns	15637.8**	9549.6*	7627.3**
Tylenchus	7127.8**	1898.5	6124.9*	9151.2*	1426.8ns	2976.2ns	6912.3**	224.1ns	21112.3**	97.4ns	6172.7*

DF-Degrees of freedom, *-significant at P≤0.05, **-significant at P≤0.01

Appendix 6. Analysis of variance (ANOVA) for the effect of plant parasitic nematodes on different sugarcane varieties

Variable	Source		
	DF	Mean square	Error
Helicotylenchus	7	114.0*	47.9
Hoplolaimus	7	322.3**	26.7
Pratylenchus	7	144.1**	38.54
Scutellonema	7	112.5*	36.46
Total	11		

DF-Degrees of freedom, *-significant at P≤0.05, **-significant at P≤0.01

Appendix 7. ANOVA for the effect of intercrops on plant parasitic nematodes associated with sugarcane and subsequent tillering

Treatment	Variable	Source			
		DF	MS	E1	E2
Period	Total PPN	2	6481**	18245	13646
Variety×Period	*Aphelenchoides*	6	1896.9**	1000.2	246.4
	Pratylenchus	6	1520.6**	849.3	409.2
Variety×Intercrop	*Scutellonema*	15	524.8*	587.5	234.7
Intercrop×Period	Tillers	10	104398**	32326	8720
Total		48			

DF-Degrees of freedom, *-significant at P≤0.05, **-significant at P≤0.01
PPN-Plant parasitic nematodes, MS- Mean square, E1-Error 1 (Main plot), E2-Error 2 (Sub-plot)

Appendix 8. ANOVA table for effect of intercrop type on numbers of plant parasitic nematodes and early growth of sugarcane

Variable	Source			
	DF	Mean square	Error 1	Error 2
Root length	5	103.1*	41.9	26.3
Root weight	5	36.3*	37.5	12.9
Shoot length	5	3296ns	3006	3561
Shoot weight	5	3025*	5635	1077
Total PPN	5	1267ns	26562	16733
Total	48			

DF-Degrees of freedom, *-significant at P≤0.05, **-significant at P≤0.01
PPN-Plant parasitic nematodes, E1-Error 1 (Main plot), E2-Error 2 (Sub-plot)