IMPACT OF NEMATODE PEST MANAGEMENT STRATEGIES ON NEMATODE COMMUNITIES IN TOMATO PRODUCTION SYSTEMS IN ZIMBABWE

By

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ABSTRACT

An analysis of soil nematode communities can be a useful tool for assessing the quality of soils and for the development of biological monitoring systems due to their intimate relationship of nematodes with their surrounding environment. In this study, soil sampling surveys were carried out in Chinamhora Communal Lands in Goromonzi District, the Botanic Gardens in Harare, and Henderson Research Station in Mazowe District at 0 – 15 and 15 – 30 cm depth to explore the effects of the land management systems and recommended tomato cropping sequences on the soil nematode communities. Glasshouse and field experiments, laid in randomized complete block design also were conducted in the 200/72008 and 2008/2009 seasons to examine the effects of chicken manure, *Tagetes* spp., nematicides and inorganic fertilizers on nematode communities in soils planted to tomato (*Solanum lycopersicum* L.). Soil from the treatments were extracted using Baermann and wet-sieving techniques and nematodes from each sub-sample were identified into trophic groups i.e. bacterivores, fungivores, predators, plant-parasites and omnivores and then identified to genus and in the case of *Meloidogyne* spp. nematodes to species level. High abundance of nematode communities was recovered between 0 – 15 cm soil depth because it is the area of high biological activities. Soils at Henderson station had higher soil bulk density values that are not favourable for free-living nematodes. Predators and omnivores were more abundant in soils from the Botanic Gardens. Organic amendments were less consistent in the management of plant parasitic nematodes and they stimulated more populations of free living nematodes. Fenamiphos had long term negative effects on the abundances of fungivorous and omnivorous nematodes. Soybean cake showed higher reproduction factor for free-living nematodes and most plant parasitic nematodes reproduced more in the NPK fertilizer treatment. High structural SI and maturity MI index values were observed in less disturbed soils implying that the soils are fertile and well structured. Soil nematode communities responded to changes in agricultural management. This implies that nematodes and the indices derived from the analysis of their community structures have demonstrated that changes in soil management are either beneficial or deleterious to the soil ecology and are well suited to the role of bioindicators for soil health in agroecosystems.

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Finally, any personal sacrifice that was required during the period of this study has certainly been negated by the benefits of gaining new insights into farming challenges and the fringe benefits such as gaining new friends, and experience of welcoming nature of Zimbabweans.

DEDICATION

To my family, for being a source of great encouragement,

and

To my late parents, *baba* Raphael and *mama* Anna who did not live to see the light of this day!

ABBREVIATIONS

g	Gram
s	Second
N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
C:N	Carbon-Nitrogen ratio
G	Granule
^0C	Degree Celsius
WP	Wettable Powder
EC	Emulsifiable Concentrate
a.i.	Active ingredient
µm	Micron metre
ha	Hectare
km	Kilometer
cm^3	Cubic centimeter
ppm	Parts per millions
rpm	Revolution per minute
H_20	Water
EDB	Ethylene dibromide
USDA	United States Department of Agriculture
ANOVA	Analysis of Variance

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Agriculture in Zimbabwe

Zimbabwe is located in the tropics between 15^0 40'S and 22^0 30'S (latitude) and 25^0 12'E and 33^0 04'E (longitude). The country is divided into five Agro-ecological or Natural Regions (NR) (I-V) based mainly on rainfall and the type of farming system (Fig. 1.1). NR I is humid with comparatively low temperatures and an annual rainfall of more than 1000 mm per annum. It supports a specialized and diversified farming system with aforestation, fruit production, plantation crops and intensive livestock production. NR II with sub humid conditions receives a total annual rainfall of 800 – 1 000 mm confined mainly to summer months, November to March with occasional mid-season dry spells. NRs III and IV are semi-arid with annual rainfall of 650 – 800 and 400 – 650 mm respectively. NR III has infrequent much rains with high temperatures and experiences severe mid-season dry spells. These areas are suitable for fodder and livestock production. Crop production is marginal. NR IV is characterized by seasonal droughts and occasional dry spells during the rainy season. The farming system supports mainly livestock production and drought resistant crops such as sorghum and millets. NR V has a low erratic rainfall of less than 650 mm per annum. It is unreliable even for drought resistant crops and is only good for utilization of cattle or game ranching.

Agriculture plays a very important role in the economy of Zimbabwe, providing income for about 75 % of the population and contributing over 40 % of total national exports (Rukuni and Eicher, 1994). The agriculture community in Zimbabwe can be divided into two broad sectors; the small-scale subsistence and the large-scale commercial sectors. The small-scale farming sector encompasses most of the rural population which comprises at least 70 % of the national population (Mudhara, Anandajayasekeeram, Kupfuma and Mazhangara (1995).

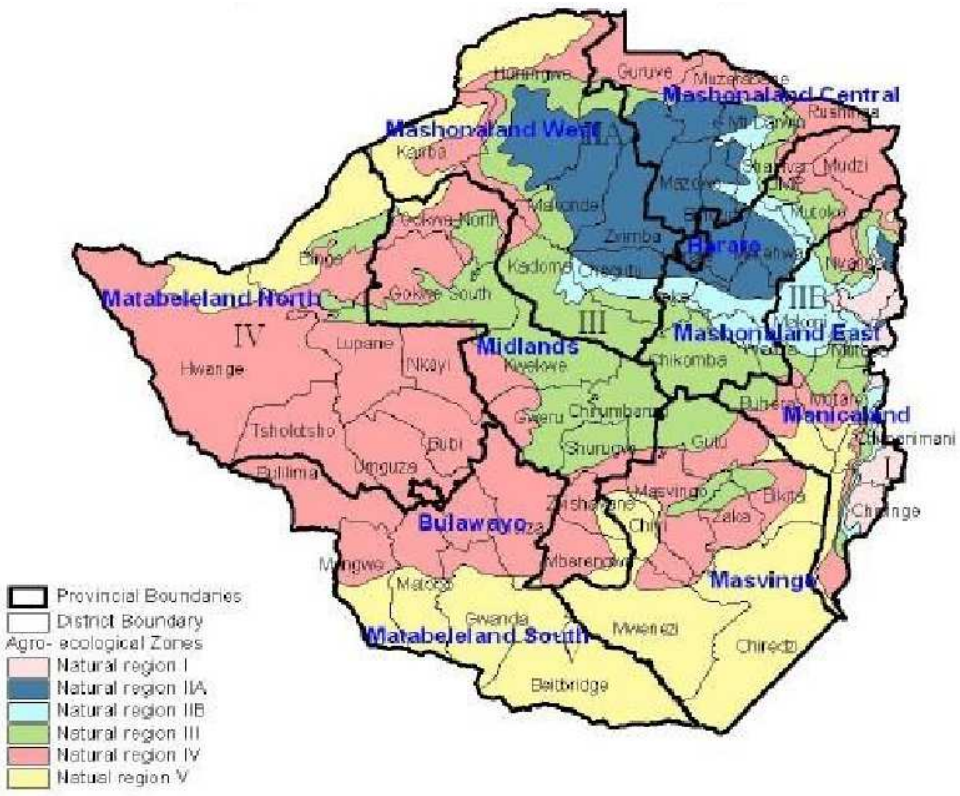

Fig. 1.1 Map of Zimbabwe showing the five Agro-ecological zones. Source: Food and Agriculture Organization, World Food Programme (2007)

The rural population is settled in NRs III, IV and V, whereas the majority of the commercial farms are on productive agricultural land in NRs I and II. The commercial farming sector grows tobacco, maize, soya beans and cotton. Communal family farms grow food for household consumption and the surplus is sold in the local market. Their major crops are maize, sorghum, millet and vegetables, mainly rape, tomato and cabbage. Vegetable tomato which is a core crop in this study is grown by both farming sectors, either for food or for cash.

1.2 Economic importance of tomato

Tomato (*Solanum lycopersicum* L.) plays a key role in Zimbabwe's horticultural industry and is among the most important vegetables grown by smallholder farmer in Zimbabwe

(Saunyama and Knapp, 2003). It is a vital component of diets, providing essential nutrients in raw or relish recipes to the diet of the majority of people living in rural and urban areas. It ranks either first or second to leaf vegetables depending on the farming area (Dobson, Cooper, Manyangarirwa, Karuma and Chiimba, 2002). The fruit contains 94% water, 1% protein, 0.1% fat, 4.3% carbohydrates and 25mg/100g ascorbic acid. It is also a good source of vitamin A, B_2, C, potassium, 0.6% dietary fibre, calcium, iron, thiamine, nicotinamide and magnesium (Kochhar, 1986). Tomato has also become an important raw material in processing industries, and for research on fundamental principles of growth and development in plants (Page, Mguni and Sithole, 1985).

1.3 Production and constraints

In the smallholder farming sector of Zimbabwe, tomato yields have remained very low due to poor crop management, especially pest control (Page, Mguni, and Sithole, 1985). Though the reliable estimates do not exists in Zimbabwe, tomato production losses in the tropics are estimated reach as high as 50 % and yield losses of 50 to 60 % have been reported in tomato crops in the main growing areas in east and southern Africa (Bourne, 1999). During a survey of selected districts in Zimbabwe conducted in 1984/85, 89 % of all soil samples collected were infested with root-knot nematodes, and severe damage symptoms were identified in many cases (Saka, 1985). However, the overall impact on tomato production is highly variable as there are other biotic and abiotic factors influencing production that may result in combined loss of 100 % in low input farming (Mwasha, 2000).

1.4 Root-knot nematode (RKN) pests and their management

Root-knot nematodes (RKNs) are included within the genus *Meloidogyne* (Göldi, 1892) (*Meloidogyne* = apple shaped female) and belong to a relatively small but important polyphagous group of highly adapted obligate plant pathogens. They are important pests of tomato worldwide (Barker and Koenning, 1998). RKNs parasitize many species of higher plant (Karssen and Moens, 2006). Four major species of economic importance that

have been reported in the tropics and sub-tropics are *Meloidogyne arenaria*, *M. hapla*, *M. incognita,* and *M. javanica*. These species cause galls or root-knots on infected plants. Other symptoms include stunted growth, wilting, and poor fruit yield. (Fortnum, Kasperbauer, Hunt, and Bridges, 1991).

Several control strategies, such as that of use of host plant resistance, rotation with non-hosts, sanitation and destruction of residual crop roots, nematicides, organic amendments, use of selected fungi and other biological control agents have been reported to effectively control root-knot nematodes (Fortnum *et al*., 1991). It should be recognized that no land management and cultural control practices are effective in controlling plant parasitic nematodes when applied alone. However, where practical, different nematode control practices are generally integrated into the cropping practices because it is the most viable option particularly for small-scale farmers with limited resources (Fortnum *et al*., 1991).

1.5 Impact of nematode management strategies on nematode communities

Nematodes are the most abundant multi-cellular organisms in terrestrial ecosystem and play a major role in decomposition and nutrient cycling in soil food webs (Bongers and Bongers, 1998). Nematodes can be grouped into five major trophic groups based on their feeding habits. The groups include bacterivores which is made up of nematodes such as cephalobids and rhabditids, fungivores which feed on fungi i.e. *Aphelenchus* spp. and *Iotonchium* spp., plant parasites including *Meloidogyne* spp. and *Pratylenchus* spp. that feed on vascular plants, predators, in the orders of Mononchida and Dorylaimida which feed on other nematodes and omnivores, encompassing nematodes such *Dorydorella* spp. which feed on algae, dead and living soil organisms (Yeates , Bongers, de Goede, Freckman and Georgieva (1993). Plant-parasitic nematodes are considered as primary consumers and they affect food web resources through direct herbivory (Ferris and Bongers, 2006). Bacterivore and fungivore nematodes graze on decomposer microbes, bacteria and fungi, and thus significantly contribute to nutrient mineralization (Ferris and Matute, 2003). Bacterivore nematodes also promote rhizosphere colonization of beneficial bacteria (Knox, Killham, Mullins and Wilson, 2003). Predatory and omnivory

nematodes regulate the food web by preying on other nematodes and invertebrates in the soil (Grewal, Ehlers and Shapiro-Ilan, 2005).

Disturbance of soils caused by application of strategies for management of RKNs results in tremendous shifts in soil microbial communities and soil food-web dynamics (Neher and Darby 2006). A previous study has shown that *Meloidogyne incognita* was reduced in soils amended with different organic substrates whilst the numbers of fungivorous nematodes, which feed on many different species of fungi including saprophytic and beneficial microbials, increased after application of organic amendments (Neher, Wu, Barbercheck and Anas, 2005). For example, essential oil and aqueous extracts from leaves of neem (*Azadirachta indica*) have been studied intensively in India and shown nematicidal properties against *Meloidogyne incognita* (Sikora and Fernandez, 2005) and increased the populations of bacterivorous and fungivorous nematodes in soils for up to 6 months after application (McSorley and Frederick, 1999).

As nematodes have different life spans and different reproductive and survival capacities, they have been used as an ecological bioindicator of soil process and quality. This has been reflected in changes in the population of nematode communities under different biotic and abiotic environments (Neher, 1999). In order to facilitate a significant interpretation of the relationship between the ecology of nematode communities and soil function, Bongers (1990) developed the Maturity Index (MI).The index is based on the proportion of colonizers (r-strategists) and persisters (K-strategists) where the attributed values represent their life history characteristics. The index value ranges from a colonizer (*c-p* = 1) to a persister (*c-p* = 5). Those with a *c-p* = 1 are *r* colonizers, with short generation times, large population fluctuations, and high fecundity. Those with a *c-p* = 5 are *K* persisters, produce few offspring, and generally appear later in succession (Bongers and Bongers, 1998). Small and large *c-p* weights correspond with taxa relatively tolerant and sensitive to ecological disturbance respectively.

1.6 Justification

Tomato continues to play a key agricultural role in Zimbabwe. It is grown from backyard Gardenss of almost every homestead up to large areas for fresh fruit consumption and is an important raw material in the processing industry. Improvement in tomato production will enhance agricultural productivity, alleviate poverty and facilitate food security (Page *et al*., 1985).

The average yields of tomato in main production areas have remained far below the crop's potential in the smallholder sector due to low level of agricultural inputs, poor management practices and incidence of pest and diseases that attack tomatoes (Valera and Seif, 2000). In the smallholder sector yield as low as 7 t/ha were reported in Tanzania, 10 t/ha in Uganda and 12 t/ha in Zimbabwe compared to yields of 100 t/ha in Zimbabwe in the commercial sector (Valera, Seif and Lohr, 2003). For many years, RKNs have been cited as a major limiting factor to yields and quality of both tomato and tobacco in Zimbabwe (Page *et al*., 1985). RKNs have a wide host range. Integrated cropping sequence is the most viable option been recommended particularly for small-scale farmers with limited resources. The management options that have been recommended include prevention, crop rotation, use of organic amendments, cultural and physical control, nematicides, host plant resistance and biological control strategies (Karssen and Moens, 2006).

Management of RKN pests can influence the densities of target and non-target organisms, potentially leading to a reduction in species richness and diversity in native communities. This may have negative or positive influences in the soil food web processes (Neher *et al*., 2005). Addition of organic amendments to the soil stimulates populations of bacterivorous and fungivorous nematodes. Fungivorous and bacterivorous nematodes feed on many different species of fungi and bacteria, including saprophytic, pathogenic and beneficial microbials, and that may alter plant decomposition and nutrient recycling (Wang, Mc Sorley and Gallaher, 2004). Plants such as *Crotalaria* spp. are good hosts of *Meloidogyne incognita* in crop rotation sequence, but *C. ochroleuca* and *C.*

incana are reported to increase the populations of *Rotylenchulus reniformis* and *Pratylenchus zeae* under field conditions (Desaeger and Rao, 2000). Other findings by Freckman and Caswell (1985) reported that the endoparasitic nematode, *Hoplolaimus columbus*, decreased populations of *M. incognita* and increased populations of *Scutellonema brachyurus* on cotton. Population of *Rotylenchulus* spp. increased during management of *M. incognita* under sweet potato fields.

To date, no research has been done on the RKN pest–ecosystems management in tomato production systems in Zimbabwe. Therefore, this study was intended to test Fenamiphos (nematicide), chicken manure and marigolds (organic amendments) to evaluate the management strategy good will hold promise for RKN pest management while incorporating aspects of sustainable agro-ecosystems such as (i) the enhancement of free living nematodes that are significantly involved in soil nutrient cycling; (ii) the suppression of RKNs; (iii) the enhancement of natural enemies of plant parasitic nematodes, and (iv) improvement of plant health. The overall objective of the study was therefore, to assess the impact of nematode pest management strategies on nematode communities in tomato production systems in Zimbabwe.

1.7 Objectives and Hypotheses

The overall objective of the study was to assess the impact of nematode pest management strategies on nematode communities in tomato production systems in Zimbabwe

1.7.1 Specific Objectives

The specific objectives were:

- To characterize nematodes in natural and agro ecosystems land management systems and explore the potential of using nematode communities as bioindicators of soil health.

- To monitor population dynamics of nematode communities in tomato production before and after application of a conventional nematicide, chicken manure and a botanical nematicide.
- To determine the effect of such management strategies on their distribution and interactions.
- To assess the influence of tomato cropping sequences on nematode communities in subsistence agriculture.
- To identify the potential of any emergent pest or pests as a consequence of deployed root-knot management strategies.

1.7.2 Hypotheses

The hypotheses tested were:

- Natural and agro ecosystems land management systems result in different nematode species and calculations of various indices obtained from such data can be used to assess the health status of the soil.
- Application of chicken manure, conventional and botanical nematicides in tomato for nematode pest management strategies affect the population dynamics of nematode communities and their distribution in the soil.
- Crop rotation sequences in tomato production in subsistence agriculture influence nematode communities thereby having serious implication on crops that can be rotated with it.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Tomato - Origin, importance and production challenges

2.1.1 Origin and growth patterns of tomato plants

The cultivated tomato plant belongs to the genus *Solanum*, which originated from the Andes region of South America (Massiaen, 1992). There is evidence to suggest that the plant was first introduced into Mexico where it was further domesticated and subjected to intensive artificial selection – leading to the development of most of the typical characteristics of the present-day cultivated tomato varieties (Jenkins, 1948). From Mexico, the tomato was then distributed to all parts of the world. The plant is largely considered to be autogamous implying that it is self fertilizing. Occasionally, however, cross fertilization facilitated by hymenopterous insects such as *Exomalopsis billotii*, can occur (Massiaen, 1992). The implications of such possibilities are that cultivars may not be able to maintain genetic purity in their progeny. Hence seeds 'saved' from the crop may show phenotypic features that significantly differ from those of the parents. For this reason, 'saved' seeds need to be used with caution or evaluated first before use.

George (1999) classified tomato plants into two types based on the plant growth pattern, namely determinate and indeterminate varieties. The determinate (or bush type) cultivars are now the most widely grown tomatoes worldwide and are suitable for both the fresh market and processing. The most distinguishing feature of tomatoes in this category is the limited branching (Dobson, Cooper, Manyangarirwa, Karuma and Chiimba, 2002). In terms of biomass, indeterminate cultivars are generally more productive than determinate varieties as they tend to produce excessive branching. It may not be wise, to use the criterion of biomass as a parameter to compare the effect of a factor (e.g. pathogen, pest, nutrient) on tomato plants belonging to these two distinct groups.

2.1.2 Importance of tomato

Almost every subsistence farming family cultivates a small vegetable garden, tomato inclusive. Tomatoes which are produced in these gardens provide important nutrients for a diet. According to Kochhar (1986) it is source of essential component of diets; the fruit contains 94% water, 1% protein, 0.1% fat, 4.3% carbohydrates and 25mg/100g ascorbic acid. It is also a good source of vitamin A, B_2, C, potassium, 0.6% dietary fibre, calcium, iron, thiamine, nicotinamide and magnesium. In order to prevent malnutrition, it is vital that people are encouraged to include tomato in their diet and not just cultivate the crop for sale.

2.1.3 Production challenges with particular reference to Root-knot nematodes

Root-knot nematodes are a serious and insidious agricultural production constraint in tomato. The pathology that nematodes cause is often inaccurately attributed to factors such as plant nutritional and/or water deficiencies or excesses, soil-inhabiting fungi, bacteria and insects, or undesirable soil structure, fertility or topography (Omat *et al*., 2001). Across major agricultural regions and crops of the world, the annual loss caused by plant-parasitic nematodes is 10-20%, an estimate that translates into hundreds of millions of dollars (Luc, Bridge and Sikora, 2005).

2.2 Behaviour and control of Root-knot nematodes (RKN)

Typically, RNKs are major limiting factors of tomato production (Mwasha, 2000). Species of economic importance that have been reported to infect tomatoes in the tropics and subtropics are *Meloidogyne incognita, M. javanica, M. arenaria* and *M. hapla*, the latter being commonly found in temperate regions (Sasser, 1979). Despite their relative importance, the biology and management of tomato root-knot nematodes have not been fully addressed in the region.

Typically, they reproduce and feed within plant roots and induce small to large galls or root knots. These nematodes affect crop yields directly through the alteration of the morphology of the root system that results from their invasion and feeding on root tissues. The most obvious symptoms of RNKs are galling on primary and secondary roots associated with stunted growth, wilting, and poor fruit yield (Fortnum *et al*., 1991). In intensive commercial production, where sequential cropping of one susceptible crop after another is practised, the lack of effective RNK management strategies has led to total crop failure (Sikora and Fernández, 2005).

2.2.1 Life cycle and behavior of RKNs (Meloidogyne spp.)

RKN nematode eggs are enclosed in gelatinous egg sacs that are usually deposited on the surface of galled roots or within the galls (Fig. 2.1). Following embryogenesis, the first moult occurs within the egg giving rise to the second-stage juvenile (J2) that is vermiform and is the only stage that is infective. *Meloidogyne* spp. are obligate parasites, and the J2 must find a host root to survive. Following root invasion, the juveniles migrate intercellularly through the aerenchymatous tissues of the cortex and establish a feeding site of specialized, giant cells and galls in the vascular system formed by the plant in response to secretion from the nematode (Bridge, Page and Jordan, 1982). They undergo several morphological changes and moult into third-stage juveniles (J3) and to the fourth-stage juveniles (J4) which, moult either to adult males or females. Many *Meloidogyne* spp., including those that are of major economic importance are parthenogenetic thus males are not necessary for egg fertilization. The vermiform male leaves the root while the developing female nematodes become sedentary in the root. It enlarges as it matures and eventually become pyriform, and will start producing eggs. The hatching of *Meloidogyne* spp. eggs is affected by temperature, host plants and nematode species. Each female may lay 30 – 50 eggs/day, it takes 21 – 28 days to complete a life cycle and may have more than 8 generations per year at 30 ^{0}C (Karssen and Moens, 2006).

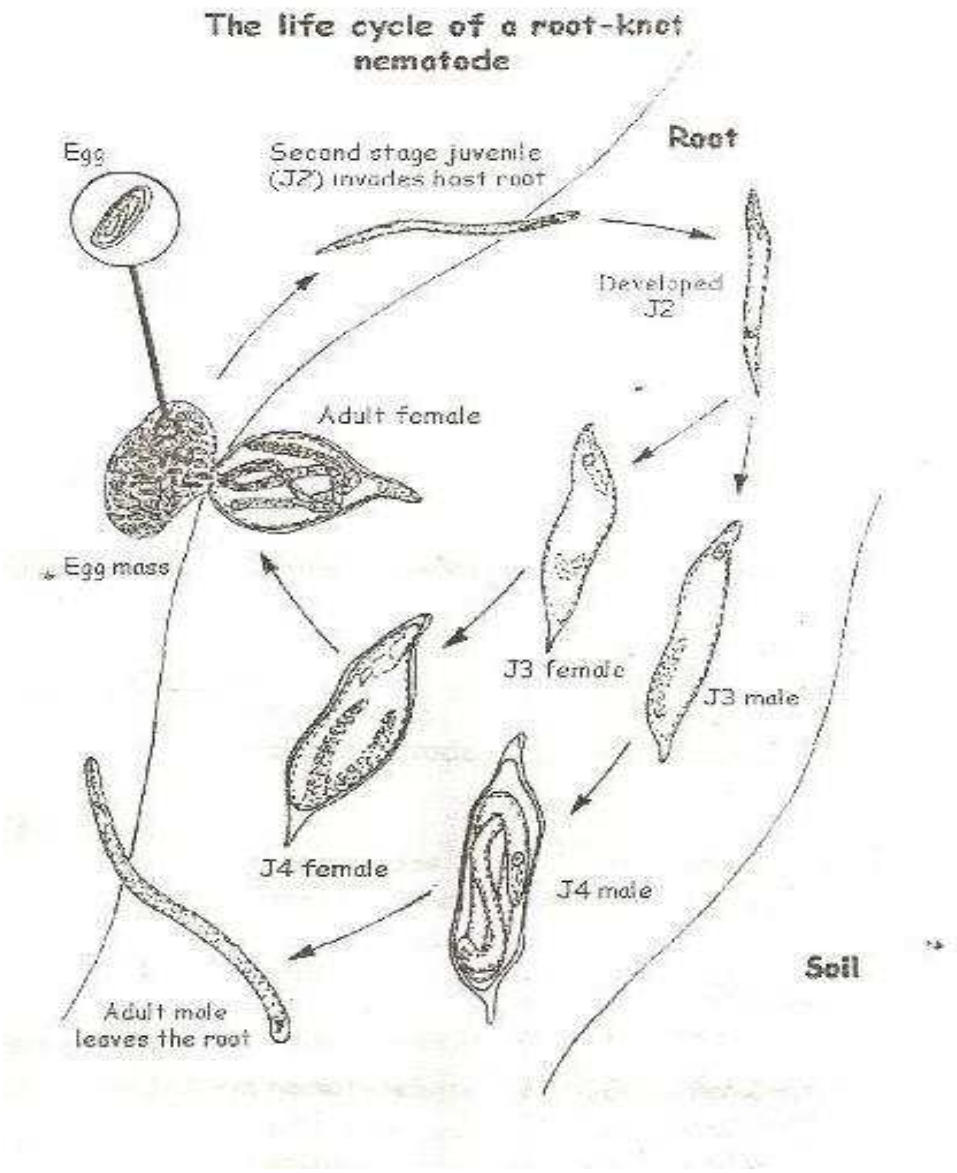

Fig. 2.1 The life cycle of a root-knot nematode. Source: (Pembroke and Gowen, 2005)

2.2.2 Effect of nematodes on plant growth and yield

Susceptible plants react to feeding by juveniles and undergo some morphological changes. Giant cells or feeding sites for the root-knot nematode are established in parenchyma tissue of the plant root. Plant development is suppressed by infections that inhibit root growth during moisture stress and thereby prevent the root system from

extending into moist soil. *Meloidogyne* spp. infection reduces root volume and, as a result leads to reduction in water uptake and decrease in the rate of photosynthesis (Sikora and Fernández, 2005).

2.2.3 Management strategies to control RKN

In conventional agricultural systems, synthetic fertilizers, pesticides and herbicides are important inputs and have been shown to impact on diversity and abundance of nematode trophic groups (Yeates and Bongers, 1999). Root-knot nematodes have a wide host range which makes them difficult to manage. Management practices that have been described in the literature include prevention, crop rotation, organic amendments, cultural and physical control, nematicides, host plant resistance and biological control strategies (Karssen and Moens, 2006). Such practices are more effective when several of these are employed in an integrated crop management programme (Fortnum *et al*., 1991).

2.2.3.1 Host Plant Resistance

Crop varieties with resistance to nematodes can be used, where available, to control nematode populations. Nematode resistance was defined by Steiner (1925) as the ability of plant roots to resist penetration by the pest. Host plant resistance to root-knot nematodes was first identified in the wild species of *Solanum peruvianum* (L.) Mill. (Ellis, 1943) and was later transferred into *Solanum lycopersicum* (L.). Some vegetable varieties are available which have natural resistance to root-knot nematodes e.g. tomato, pepper, sweet potato and bean (Sikora and Fernández, 2005). All currently available cultivars with root-knot nematode resistance are derived from these sources (Karssen and Moens, 2006).

Resistance is generally thought to be conferred by a single dominant gene designated *Mi*, (*Mi* representing *M. incognita*) (Roberts, 1982). This gene confers resistance in the heterozygous state, to the three most widespread species of root-knot nematodes, *M. incognita*, *M. javanica* and *M. arenaria* (Triantaphyllou, 1981). However, the resistance

conferred by *Mi* is broken down under high soil temperatures (Tzortzakaris and Gowen, 1995). It was reported by Sikora and Fernández (2005) that, although population densities of *Meloidogyne javanica* were reduced to low levels during the cropping season following either use of non-host or a resistant tomato cultivar, nematode population density rose to high levels at the end of the season.

In Zimbabwe, one resistant variety, Piersol, was available commercially until the late 1980s. However, this variety is no longer on the market, because it was not favoured by local seed companies. Currently, commercially available tomato varieties in Zimbabwe are Moneymaker, Heinz 1370, Floradade, Rodade and Roma VF and there are no reports concerning resistance in any of the varieties to root-knot nematodes. Previous studies with resistant tomato and pepper cultivars showed that host resistance alone is not adequate in managing nematodes. Integrating compatible and complementary tactics, such as host resistance/ tolerance and nematicides, should minimize potential problems associated with the appearance of nematode biotypes that attack resistant cultivars and negative effects on the environment if nematicides are not judiciously used. (Luc, Bridge and Sikora, 2005). Resistance can, however, be used in an integrated management strategy including chemical and non-chemical control measures (Noling, 1997).

2.2.3.2 Cultural control

Crop rotation

Crop rotation can be described as the sequence of crops grown in successive years or seasons on the same land. In a comparative study of crops grown in organic and conventional managed fields, nematode communities were influenced to a greater extent by crop species than by management systems (Neher *et al*., 2005). Rotating crops of different susceptibility can be useful in the reduction of RKNs damage (Sikora, 1992). However, the occurrence of nematode communities containing polyphagous species with wide host ranges, such as some species of *Meloidogyne* and *Pratylenchus*, limits potential use of non-host crops for the rotation.

Crotalaria species were recommended as an intercrop to control *Meloidogyne* spp. in pineapple. The intercrop produced an effective control of the root-knot nematodes but increased the population of *Pratylenchus brachyurus* to levels which were at least as harmful to the crop as *Meloidogyne* spp. (Luc *et al*., 2005). Rotation is difficult in intensive cropping, especially by farmers who have a shortage of land and when the susceptible crop is the main source of food and cash (Scurrah, Niere and Bridge, 2005). In agricultural land, crop rotation and regular tillage, both of which are associated with lack of permanent vegetative cover, are the two main kinds of soil disturbances. Neher *et al*. (2005) indicated that abundance and diversity of bacterivores, fungivores, omnivores and predatory nematodes are greater in less disturbed soil than with annual cultivation and cropping. Other studies by Sanchez-Moreno, Minoshima, Ferris and Jackson (2006) found that pore space distribution in soil due to management systems affects nematode composition. They frequently observed that disturbed soils have a higher bulk density and that nematode abundance is reduced as a consequence.

Organic amendments

This is a cultural practice that involves the addition of organic matter to the soil in the form of green manure cover crops and decomposed or partially decomposed animal wastes such as poultry or beef manure. Organic amendments have been shown to reduce soil bulk density and increase soil nitrogen and carbon supply (Bulluck III, Brosius, Evanylo and Ristaino, 2002a) Although various organic amendments can have differential effects on soil properties and nematode communities (Nahar, Grewal, Miller, Stinner, Stinner, Kleinhenz, Wszelaki and Doohan, 2006), all tend to increase availability of nutrients, such as nitrogen, microbial biomass and abundance of bacterivore and fungivore nematodes (Ferris, Venette and Lau, 1996). Amending soil with various sources of organic matter such as *Tagetes* species, neem leaves and seed cake, *Crotalaria* species and *Mucun*a species can offer an effective means of nematode management and soil fertility improvement (Viaene, Coyne and Kerry, 2006). Animal manure, bone meal and chitin have also been observed to reduce nematode pests. The activities of chicken manure, like chitin, depends on the release and build-up of nematoxic levels of ammonia

(Viaene *et al.*, 2006) and reduce the population of plant-parasitic nematodes (Bohlen and Edwards, 1994).

Sudan grass releases cyanogenic compounds that can be effective against plant-parasitic nematodes and have been associated with reduced populations of *Pratylenchus penetrans* on bean (Viaene and Abawi, 1998). Recently, chicken manure was identified to suppress *M. incognita* on cotton and *P. penetrans* on bean (Abawi and Widmer, 2000).

Addition of manure to soil is reported to increase numbers of bacterivorous and fungivorous nematodes and decrease numbers of plant-parasitic nematodes (Bohlen and Edwards, 1994). A study by Yeates, Bardgett, Cook, Hobbs, Bowling and Potter (1997) reported the relative abundance of Tylencholaimidae, Cephalobidae and Rhabditidae in organically compared to conventionally managed soils. Numbers of free-feeding nematodes play an important role in nitrogen mineralization (Ingham, Trofymow, Ingham and Coleman, 1985) and may increase suppression of plant diseases by adding sufficient nitrogen to the decomposing microorganisms and also to release for plant use (Agu, 2008). Although the use of organic amendments improves soil structure and water-holding capacity, limits weed growth, increases microbial biomass and hence enlarges the food base for free-living nematodes and reduces densities of plant parasitic nematodes, it is often limited by unavailability or inadequency as large quantities are needed.

2.2.3.3 Biological control

Biological control refers to the use of one living organism to control another, the latter being a pest (Kerry and Hominick, 2001). The prospects for controlling an economically important nematode by biological means and the selection of appropriate potential organisms are influenced by the population of the control agent (Atkinson and Kerry, 1988). According to their mode of parasitism, nematodes can be distinguished as sedentary or migratory, endo- or ecto-parasites of plants. To control migratory nematodes, parasitic natural enemies must develop adhesive spores, a trapping mechanism to immobilize the active host and enable infection to take place. Kerry and Hominick (2001) observed that sedentary nematodes are exposed to parasitism by a range

of relatively unspecialized bacteria and fungi. Six different taxonomic groups of organisms *i.e.* bacteria, fungi, nematodes, insects and mites and miscellaneous invertebrates can act as biological agents against plant-parasitic nematodes (Kerry and Hominick, 2001).

The nematophagous fungus *Pochonia chlamydosporia* (formally *Verticillium chlamydosporium*) is a facultative parasite of root-knot nematodes and in microplot trials has provided significant control of populations of *Meloidogyne* spp. (Bourne and Kerry, 1999). This nematophagous fungus secreted an alkaline protease which hydrolysed proteins in situ from the outer layer of the egg shell of the nematode. The mean number of colony forming units (CFU) of *P. chlamydosporia* for control of root-knot nematodes was greater in soils that are well aerated than those with poor aeration (Kerry, Kirkwood, De Leij, Barbar, Leijdens and Brookes, 1993).

Pasteuria penetrans (Thorne) Mankau is a prokaryotic, endoparasite and an obligate parasite of many species of plant-parasitic nematodes. *Meloidogyne* spp. are the most commonly reported hosts of *P. penetrans*, possibly because it is relatively easy to detect infection in mature female nematodes in root systems. The taxonomic status of the *Pasteria* species infecting other plant parasitic nematodes is still uncertain. Moreover, the females of *Meloidogyne* spp. Infected with *P. penetrans* produce few or no eggs compared to uninfected females (Gowen,[1] personal communication, 2006).

Mononchids, dorylaimids and diplogastrids are predatory nematodes that feed on plant parasitic nematodes (Stirling, 1981). The problem of predators is that they are not specific to plant parasitic nematodes; they also feed on other soil nematodes (Kerry, 1987). Moreover, it is difficult to produce them in large numbers and to apply them to the soil (Viaene *et al*., 2006). *Mononchoides fortidens*, a predator that belongs to the order Diplogastrida feeds on nematodes and bacteria and is generally found abundantly in

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decomposing organic manure. *M. fortidens* has been found to be effective in the management of RKNs in the soil (Bilgrami, Ahmed and Jairajpuri, 1989b).

Paecilomyces lilacinus is a naturally occurring fungus found in many kinds of soils that is capable of parasitizing nematode eggs, juveniles and females, and reducing soil populations of plant parasitic nematodes. It was first discovered in soil and observed to control root-knot nematodes on potato in Peru (Jatala, Kaltenbach and Bocangel, 1979). Subsequent tests on potted plants and field plots have shown the fungus to control a range of nematode species on a number of crops worldwide; its effectiveness was comparable to several chemical nematicides tested (Khan, 1979). While showing promise, their commercialization in South Africa has in the past been certainly lack of appreciation by farming communities at large of the economic significance of nematode infestation. The South African company, Biological Control Products (BCP) now has registration for the use of this biological agent sold under the brand name Pl Plus, for the control of nematodes in bananas, papinos, tomatoes, tobacco and citrus (Neethling, 2000).

2.2.3.4 Chemical control

Plant parasitic nematode problems commonly have been managed by chemical soil treatments. Nematicides have been used against plant parasitic nematodes with good results since the 1950s and are a suitable alternative for controlling pathogenic nematodes in order to grow a high yielding, good quality crop. They are effective and can give good economic returns on higher-valued crops. They can be classified into two categories: soil fumigants and non-fumigants. Although the practice generally improves crop yields, it rarely reduces nematode population densities for more than 2 – 3 months, and sometimes resulting in post harvest population densities greater than pre-plant densities (Van and Stanghellini, 2001).

The fumigants are rated to be approximately 50 – 90 % effective in reducing nematode populations. Total yield of tobacco in fields fumigated with ethylene dibromide were higher than unfumigated fields, and RKN activity in fumigated fields were significantly low (TIMB Progress Report, 2006). Non-fumigants may not kill nematodes at

recommended rates but they give the crop a “head start”, delaying nematode penetration at early sensitive stages of plant growth. Nematicides, therefore need repeated applications, making them less attractive economically (Sikora and Fernandez, 2005). They have been used extensively for root-knot nematode control in the production of many fruit, vegetable and nursery crops (Noling, 1997).

Chemical contaminants dissolved in soil water enter the nematodes body directly through the cuticle, which is the most important route for exposing nematodes to toxins. Predatory mononchids show different sensitivity under different conditions, exhibiting high sensitivity to some heavy metals (Parmelee, Wentsel, Phillips, Simini and Checkai, 1993), but are tolerant to other metals (Yeates *et al*., 1997). They show early successional recolonization following fumigation with methyl bromide (Yeates, Bamforth, Ross, Tate and Sparling, 1994). Pesticides may remove some but not all species of the soil biota, thus permitting the remaining species to multiply vigorously. It is possible that they are able to exploit the niche after the removal of other taxa following deployment of certain management strategies.

In Zimbabwe, the majority of small-scale farmers use non-fumigant nematicides, such as aldicarb (Temik® 5 G), carbofuran (Furadan 10® G) and Fenamiphos (Fenamiphos® 10 G, 40 EC or 400 EC). These are often not as effective as fumigants in increasing yields because they do not have broad-spectrum activity and in most cases only inactivate nematodes for short periods (Sikora and Fernández, 2005). However, many non-fumigants are often less phytotoxic than fumigants, and are able to be applied at planting time and have great residual effect in the soil for nematode management (Luc *et al*., 2005).

Although effective nematicides are available to control nematodes, a number of factors such as high cost of the chemicals, environmental concern, the need for proper handling of the chemical and toxicity of the product, mean that the chemical is not normally recommended as the preferred method for smallholder farmers (Lamberti, Molinari, Moens and Brown, 2000). As suggested by Hassan, Chishti, Rasheed and Tak (2009),

nematicides may be effective in the management of plant parasitic nematodes as a part of an integrated management system, which incorporates other control measures that are suited for subsistence and smallholder farming.

2.3 Impact of pest management strategies on nematode communities

Nematodes are widely distributed in soil and their communities are made up of diverse species that, according to their feeding habits, can be classified into five major groups: plant parasites, bacterial and fungal feeders, predators and omnivores (Neher *et al*., 2005). The role of nematodes in a soil ecosystems is to recycle nutrients by feeding on plant tissue and microorganisms and liberating minerals for easy absorption by plant roots Sanchez-Moreno, Minoshima, Ferris and Jackson (2006) and control of plant pests and pathogens (Grewal, Ehlers, and Shapiro-Ilan, 2005). Due to different nematodes having different life spans and different reproductive and survival capacities, the nematode community has been used as an ecological bioindicator to reflect environmental changes (Neher *et al*., 2005). The abundance of each species in the community can be transformed into ecological indexes and parameters to measure community changes in diversity and trophic structure, and to assess soil disturbance levels and decomposition pathways (Ferris and Matute, 2003).

Application of any practice in a nematode management programme is regarded as soil disturbance on biological populations because different microbial species, nematodes included, respond differently to a number of environmental stressors. Soil factors influencing the population of nematode communities include nutritional enrichment, carbon conservation and physical changes to the soil structure caused by agricultural operations (Neilsen and Winding, 2002). Nutrient enriched soils show a reduced biodiversity. Under such conditions, the populations of short-lived *r*-strategists (bacterial feeding Rhabditidae and Diplogastridae) increase relative to other nematode groups (Ferris and Matute, 2003). Neher (1999) reported that additions of organic amendments to soil increases number of bacterivorous and fungivorous nematodes and decreases the

number of plant parasitic nematodes. Ingham, Trofymow, Ingham and Coleman (1985) reported that increasing trophic diversity of the soil nematode assemblage increases nutrient turn over and plant growth.

In agro-ecosystems, tillage is the major disturbance to the soil and causes the redistribution of plant residue and soil organic matter, subsequently changing microbial structure and nematode community structure (Ettema and Bongers, 1993). Because of their individual affinities for particular ecological niches, nematodes species in their environment can be highly specific (Boag and Yeates, 2004).

2.4 Spatial distribution of nematode communities

The assemblage of plant and soil nematode species occurring in a natural or a managed ecosystem constitutes the nematode communities. The distribution of nematodes in soil is imperative that there is information on horizontal and vertical distributions for population dynamics of these organisms to be fully understood. Some surveys demonstrated that the distribution of certain nematode species strongly correspond to that of soil type (Blair, Stirling and Whittle, 1999). This was the case with *Ditylenchus dipsaci* in the Netherlands. In contrast, spatial variability of phytoparasitic nematode distribution was recorded at a field scale with the same soil type and the same plants (Cadet, Masse and Thioulouse, 2005). The reason for the non-uniform distribution of nematodes in soils greatly depends on a number of biotic and abiotic factors but they may vary considerably depending on the nematode species (Boag and Yeates, 2004).

2.4.1 Vertical distribution of nematodes

The vertical distribution of nematodes has been studied in a number of habitats. Phytophagous nematodes are obligate parasites and their distribution is necessarily linked with the distribution of the host plants, particularly for species, which do not have a broad host spectrum (Cadet, Masse and Thioulouse, 2005). In contrast, Boag and Yeates (2004) found that the distribution of plant-parasitic nematodes belonging to the genus

Trichodorus was not correlated with vertical depth distribution of tree roots and concluded that there were significant differences between species. For example, *Trichodorus velatus* was more abundant between 0 and 29 cm and *T. primitivus* was more numerous between 30 and 49 cm, while in a raspberry plantation *Pratylenchus penetrans* were not correlated with root distribution (Forge, De Young and Vrain, 1998). Other factors affecting the vertical distribution of nematodes in soil are competition between species (Boag and Alphey, 1988), tillage regime and nematode migration (Boag and Yeates, 2004). Sohlenius and Sandor (1987) suggested that the differences they observed in distribution of nematodes in arable soils were that at greater depths the nematodes suffered from shortage of food while nematodes near the surface suffered greater predation pressure and dehydration.

2.4.2 Horizontal distribution of nematodes

The horizontal distribution of nematodes has received considerable attention since it is of ecological significance and may be species specific (Boag and Yeates 2004). In addition to its economical importance in determining sampling procedures, it is used for detecting and estimating the size of plant-parasitic populations (Been and Schomaker, 1996). For some nematodes, distribution is determined by the distance of the roots from the plant (Zhang and Schmitt, 1995), while other factors such as cultivation affect the distribution of nematodes when the roots of crops are more uniformly distributed. From different geographical areas and crops (Pen-Mouratov, Rakhimbacv and Steinberger, 2003) observed that plant parasitic nematodes activities tends to be synchronized with that of roots e.g. egg production of *Xiphinema* and *Longidorus* spp. was usually greatest when root growth occurred. However, while originally nematode distribution in the soil was considered to be random (Cotton, 1979), it is now commonly understood that the distribution of soil nematodes is usually aggregated and not randomly or uniformly distributed due to the relative proportion of total organic matter which reflects the biological decomposition and exploitation (Tita, Desrosiers, Vincx, Gagné and Locat, 2000).

2.5 Influence of abiotic and biotic factors on nematode communities

The activities of soil-inhabiting nematodes are influenced to some degree by each of the many biotic and abiotic factors in their complex environment.

2.5.1 Temperature

Temperature is particularly important, affecting movement, rate of growth and reproduction, sex determination, relative abundance of food, and expression of nematode damage to plants (Khanzada *et al*., 2008). Study by Hassan *et al*. (2009) on the seasonal population dynamics of *Tylenchulus semipenetrans* in citrus orchard observed that, the population of *T. semipenetrans* increased with the optimum temperature ranges between 23 – 30 ^{0}C and low rainfall. The trend of the population decreased at temperatures as low as 5 ^{0}C. Plant parasitic families seemed to be particularly sensitive to low temperature. However, the apparent temperature sensitivity may be mainly influenced with indirect effects, e.g. resource availability (Dabire and Mateille, 2004).

2.5.2 Soil moisture

Bakonyi and Nagy (2000) showed that, although temperature was more important for the structure of the soil nematode communities, moisture had a predominant effect on their abundance. The dry fallow conditions following harvest of a summer crop, bacterivore and fungivore nematodes decline in abundance due to lack of soil moisture and, perhaps, food. The decline was more evident in bacterivores than fungivores Ferris, Venette and Scow, 2004). On the other hand, Porazinska, Duncan, McSorley and Graham (1999) reported significant effects of irrigation and fertilization on only a limited number of nematode genera. As stated by Todd, Blair and Milliken (1999), nematodes developing under different soil moisture conditions, display differential responses to altered soil water conditions.

2.5.3 Soil texture

The importance of soil texture and other edaphic properties on biological properties has been demonstrated in several studies. Franzluebbers, Haney, Hons and Zuberer (1996) found increasing soil microbial activity in coarser textured soils. This finding is in agreement with the general recognition that organic matter decomposes more rapidly in sandy soils than in fine textured soils (Hassink, 1994). However, Avendaño, Schabenberger, Pierce and Melakeberhan (2004) found more rapid turnover of organic matter in clay-amended soils when the soils were adjusted for soil water potential. Robertson and Freckman (1995) found that sand and silt were positively correlated with bacterial and fungal-feeding nematode density, but not with abundance of omnivore/predators or plant parasites. However, Wyse-Pester, Wiles and Westra (2002) concluded that the effects of physical and chemical properties on biological populations were not consistent from field to field but within certain ranges, the variation in these properties can affect biological variation.

2.5.4 Soil pH

Nematode numbers have been reported to increase in response to manipulation of pH by liming, but in some other studies, the numbers have remained unchanged after liming (Mika, 2004). Higher population of fungivore and lower populations of plant parasitic nematodes were in chemical fertilizer-treated than in compost-treated plots. These revealed that fungivores are more resistant to acid environment that has been created by the mineralization of chemical fertilizer in the soil (Yingchun and Cheng, 2007).

2.5.5 Predation

Soil microorganisms may influence local nematode community structure and diversity by limiting overall nematode abundance and competitive pressure. Nematode abundance is significantly lowered by predators such as fungi Bouwman, Hoenderboom, van der Maas and de Ruiter (1993) and numerous other soil organisms (Yeates and Wardle, 1996).

Although many nematode predators are generalists, their primary victims may be among the dominant nematodes species because predation rates in soil are largely dependent on chance encounters (Yeates and Wardle, 1996). Similarly, Bilgrami (1993) found that several bacterial feeding species greatly suffered from predation of *Aporcelaimellus nivalis*, except *Rhabditis* species, which evaded predation by rapid undulatory movements. However, assuming that every nematode species is susceptible to some predators, and given that in soils many different predators species operate simultaneously, it is likely that predation often reduces overall crowding and generally enhances local nematode diversity (Ettema, 1998).

2.6 Indices of nematode communities

2.6.1 Community structural indices

The development of the maturity index (MI) based on the colonizer-persister (c-p) values of nematodes has helped in interpreting the values of biological and trophic status to infer the disturbance level of different habitats (Bongers 1990). The index is based on the proportion of colonizers (r-strategists) and persisters (K-strategists) where the attributed values represent their life history characteristics. The index value ranges from a colonizer (*c-p* = 1) to a persister (*c-p* = 5). Those with a *c-p* = 1 are *r* colonizers, with short generation times, large population fluctuations, and high fecundity. Those with a *c-p* = 5 are *K* persisters, produce few offspring, and generally appear later in succession (Bongers and Bongers, 1998). Small and large *c-p* weights correspond with taxa relatively tolerant and sensitive to ecological disturbance respectively.

It is routinely used as an ecological measure for assessing the status of soil food webs in terrestrial habitats (Neher *et al*., 2005). Plant parasitic index (PPI), which measures holding capacity of host plant to nematodes, is generally considered to be higher in the nutrient enriched conditions because it is affected by the host conditions (Bongers, van der Meulen and Korthals, 1997). PPI is calculated based on c-p value of plant-parasitic nematodes. The Shannon-Weiner Index to assess diversity (species richness and

evenness), ratio of bacterivore to fungivore nematodes, and trophic diversity have been used for the assessment the relative stability of the habitats (Freckman and Ettema, 1993).

2.6.2 Food web indices

In an attempt to improve the indicator capabilities of nematodes, Ferris, Bongers and de Geode (2001) assigned weights to indicator nematode guilds representing basal, enriched and structured conditions of the food web. This concept leads to the development of food web indices including enrichment index (EI), basal index (BI) and structure index (SI). EI is based on the expected responsiveness of the opportunistic guilds (bacterivore nematodes with c-p 1 to organic resources enrichment, and BI is an indicator of the prevalence of the general opportunistic nematodes that are tolerant to soil perturbation. Therefore, EI describes whether the soil environment is nutrient enriched (high EI) or depleted (low EI). The SI represents an aggregation of functional guilds with c-p values ranging from 3 – 5 and describes whether the soil ecosystem is structured with greater trophic links (high SI) or degraded (low SI) with fewer trophic links. A nematode channel ratio (NCR) provides information about the decomposition channels, a high NCR (> 50 %) indicates bacterial fungal decomposition channels whereas low NCR (< 50 %) suggests bacterial decomposition channels. Plotting of EI and SI provide a model framework of nematode faunal analysis as an indicator of the likely conditions of the soil food web (Fig. 2. 2). Use of these indices have provided critical information about below ground processes in distinct agroecosystems (Ferris and Matute, 2003; Neher *et al*., 2005).

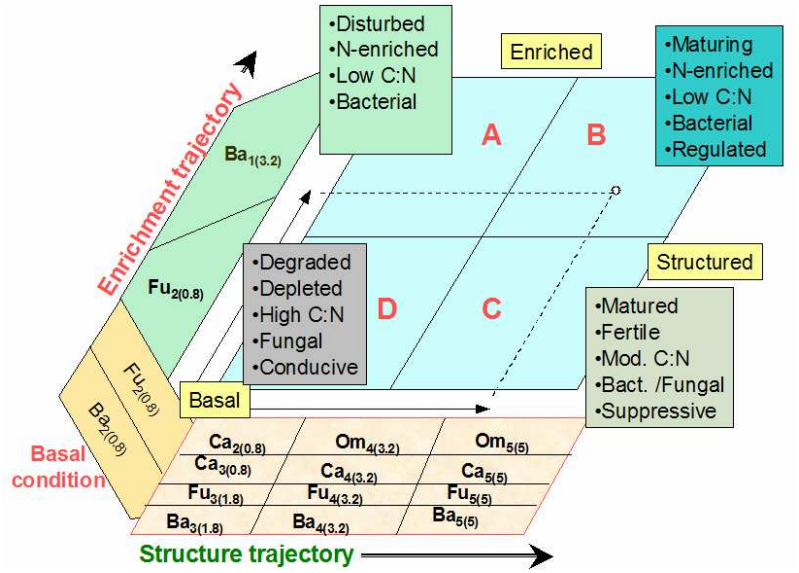


Fig. 2.2 Frame work of nematode faunal analysis as an indicator of the soil food web Conditions. Source: Ferris *et al.* (2001)

Functional guilds of soil nematodes characterized by feeding habit (trophic group) and by life history characteristics expressed along a colonizer-persister (cp) scale (cp scale proposed by Bongers and Bongers, 1998). Ba_x (bacterivores), Fu_x (fungivores), Ca_x (carnivores), Om_x (omnivores) (where value of x = 1-5 on the cp scale) represents various functional guilds. Indicator guilds of soil food web condition (basal, structured, enriched) are designated and weightings of the guilds along the structure and enrichment trajectories are provided, for determination of the enrichment index (EI).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Survey sites and experimental work

Soil sampling surveys were conducted between 2007 and 2008 at the following four sites:

(i) National Botanic Gardens in Harare (a natural ecosystem) and Henderson Research Station (a typical agro-ecosystem) that is located 36 km North-East of Harare in Mazowe Valley. The survey was aimed at identifying the effect of contrasting human interventions between the two sites as well as environment on nematode species composition, widely used as a bioindicator for monitoring the status of soils.

(ii) Chinamhora communal lands in Goromonzi district, the major tomato producing region in the country

(iii) Kutsaga Research Station (a tobacco research station) to enable use of tobacco as a model crop receiving intensive inputs, including soil fumigants.

To obtain a historical use of each location where soil samples were collected, a questionnaire (Appendix 4.1) was administered at each location.

(iv) Glasshouse and field experiments were carried out in the period between February 2007/2008 and August 2008/2009 at Plant Protection Research Institute (PPRI) in Harare. The objectives were: (i) To monitor population dynamics of nematode communities in tomato production before and after application of a conventional nematicide, chicken manure and a botanical nematicide and to identify the effect of such management strategies on their distribution in the soil and to identify any interactions among factors.

3.2 Nematode extraction and assay

3.2.1 Baermann funnel technique

Five soil sub hyphenate samples were thoroughly mixed before taking a 100 cm^3 subsample per sample for nematode extraction (Hopper, Hallmann and Subbotin, 2005). Nematodes were collected from trays at 24-hour intervals for 3 days. The nematode suspension was then passed through a 38 µm aperture sieve and nematodes on the sieve back washed into vials and collected in universal bottles for nematode assay.

3.2.2 The wet-sieving technique

Two hundred cubic centimeters (200 cm^3) of soil for extraction was added to 500 ml of water and stirred by hand to bring the nematodes into suspension. The mixture was allowed to settle for 30 – 60 seconds and decanted using a series of 710, 250 and 38 µm aperture sieves into plastic containers. This process was repeated 2 – 3 times to increase nematode recovery from the soil samples. The sievings were collected into centrifuge tubes with 32 cm rotor diameter, balanced and spun at 4000 rpm for 5 minutes. The supernatant was poured off and replaced by sugar solution (specific gravity 3.7). The tubes were balanced and spun for 30 seconds. The supernatant was poured through a sieve of 38 µm aperture before collecting the residues on the sieve into a universal bottle for nematode assays.

3.3 Killing and fixing nematodes

Nematodes were concentrated intoa small volume of water (30 ml) in a test tube. Triethanolamine, formaldehyde (TAF) and distilled water; normal strength = triethanolamine (2 ml) + 40 % formaldehyde (7 ml) + distilled water (91 ml) was heated to 99 ^{0}C and an equal volume quickly added to the nematode suspension. This killed and fixed the nematodes in one process.

3.4 Nematode identification and enumeration

Nematodes from each sub hyphenate sample were counted under a dissecting microscope at low magnification (x 40) and then 100 nematodes from each sub hyphenate sample were identified to genus and *Meloidogyne* spp. nematodes to species. Stylet length and robustness were used for male identification. The juveniles were identified by comparing tails and hyaline portions length. Nematodes were attributed to one of five trophic groups (Appendix 3.1 to 3.5). These are (i) bacterivores which involves species mainly feeding on bacteria and which includes nematodes such as cephalobids and rhabditids; (ii) fungivores which feed on fungi i.e. *Aphelenchus* spp. and *Iotonchium* spp.; (iii) predators, mainly in the orders Mononchida and Dorylaimida and which feed on other nematodes; (iv) plant-parasites, including *Meloidogyne* spp. and *Pratylenchus* spp. that feed on vascular plants and (v) omnivores, encompassing nematodes such *Dorydorella* spp. which feed on algae, dead and living soil organisms (Wang *et al*., 2004) and assigned to colonizer-persister (c-p) values as described by (Bongers, 1990). Abundance of nematodes was expressed as number of individuals per 100 cm^3 of soil.

3.5 Calculation of community and food web indices

The maturity index (MI) for free-living nematodes (all nematodes except plant parasitic nematodes) was calculated using the formula (Bongers, 1990):

$$MI = (\Sigma vifi)\ /n,$$

Where:

vi is the c-p value for the nematode genera *i*,

fi is the frequency of nematode genera *i*,

n is the total number of individual nematodes of the genera *i* in the sample.

The plant parasitic index (PPI) was calculated considering only plant parasitic nematodes (Bongers, 1990) as:

$$PPI = (\Sigma vifi)\ /n$$

Where:

vi is the c-p value for the plant-parasitic nematodes genera *i*

fi is the frequency of plant-parasitic nematodes genera *i*

n is the total number of individual nematodes of the genera *i* in the sample.

The Shannon diversity (*H'*), was calculated for nematode diversity, using the following formulae (Pielou, 1977):

$$Shannon\text{-}Weiner\ Index\ H' = -\Sigma Pi\ (ln\ Pi),$$

Where:

Pi is the proportion of genera *i* in the nematode community.

Enrichment (EI) and structure indices (SI) were calculated according to *Ferris et al*. (2001), with basal components (*b*) of the food web (fungal and bacterial feeders in the c-p 2 guild) calculated as:

$$b = \Sigma k_b n_b$$

Where:

k_b is the weighted constant for the guild

n is the number of nematodes in that guild.

Enrichment (*e*) and structure (*s*) components were similarly calculated, using nematode guilds indicative of enrichment (bacterivores in c-p 1, and fungivores of c-p 2), and guilds supporting structure (bacterivores in c-p 3-5, fungivores c-p 3-5, omnivores of c-p 3-5, and predatory nematodes of c-p =2-5).

Finally the calculations are EI was calculated as:

$$EI = 100 \times e/(e + b),$$

$$BI\ as\ 100 \times b/(b + e + s)$$

$$and\ the\ SI\ as\ 100 \times s/(s + b).$$

Where:

$b = (ba_2 + Fu_2) \times W_2$

$e = (Ba_1 + W_1) + (Fu_2 + W_2)$

$s = (Ba_n \times W_n + Fu_n \times W_n + Pr_n \times W_n)$

Ba_1 = bacteria feeding nematodes (guild 1)

$Ba_{2=}$ bacteria feeding nematodes (guild 2)

Fu_2 = fungal feeding nematodes (guild 2)

Pr = predatory nematodes

W = weighting assigned to nematodes in each functional guild

The nematode channel ratio (NCR) channel index (CI), which provides an index of the nature of decomposition, was calculated as (Tomar, Baniyamuddin and Ahmed, 2006):

bacterivores/(bacterivores + fungivores).

The SI and EI provide information about the structure and enrichment of the soil food web, respectively and NCR provides an index of the bacterial and fungal driven decomposition channels in the soil food web.

3.6 Data analysis

Data for community abundance was analysed using the JMP statistical program and plotting was aided by a Pivot table chart from the spread sheet. Where data were not normaly distributed they were transformed as ln(x+1) before carrying out ANOVA. Where there were statistically significant differences among treatment means these were separated by the Tukey-Kramer HSD test.

CHAPTER FOUR

NEMATODE COMMUNITIES AS BIOINDICATORS FOR SOIL HEALTH IN DIFFERENT LAND MANAGEMENT SYSTEMS

4.1 Introduction

Agricultural intensification is traditionally considered as essential to increase production of food, forage, fibre and fuel. Intense management practices that include application of pesticides and fertilizers, and frequent cultivation affect soil organisms, often altering community composition of soil fauna (Crossley, Mueller and Perdue, 1992). Tillage and cropping patterns cause profound changes in populations of soil organisms. Soil composition and physical properties (e.g. temperature, pH and water-holding capacity characteristics) and microbial composition are altered when Botanic Gardenss are converted to agro-ecosystems (Kladivko, 2001). Changes in these soil properties may be reflected in the distribution and diversity of soil mesofauna. Organisms adapted to high levels of physical disturbance become dominant within communities, thereby reducing richness and diversity of soil fauna (Neher and Barbercheck, 1999).

In a study of tillage effects on soil organisms, Wardle, Yeates, Watson and Nicholson (1995b) reported that bacterial-feeders were at least slightly stimulated by tillage in 65 % of the studies. However, in some studies, total nematode density was reduced after the first tillage, with bacterial feeders dominating in tilled plots and herbivores more abundant in no-till plots (Lenz and Eisenbeis, 2000). The maintenance of agricultural fields under bare fallow conditions usually leads to reduced abundance of plant parasitic nematodes (Cadet *et al*., 2005). When cropping is abandoned and fields allowed to settle into natural conditions, nematode diversity can increase significantly (Háněl, 2003).

Damage from root-knot nematodes (*Meloidogyne* spp.) can substantially limit yield in the production of many vegetables in Zimbabwe (Page *et al*., 1985). In the past, large scale tomato growers relied primarily on fumigation with methyl bromide to control the pests.

Inputs like nematicides are of limited use by subsistence farmers due to lack of cash besides methyl bromide has been implicated as a major ozone-depleting substance (Luc *et al*., 2005). Therefore, management of soil borne pests may require use of multiple tactics. These may include non-chemical alternatives such as rotation cropping systems, resistant crops and organic amendments (Challemi, 2002).

Crop rotation is widely used and very effective at reducing nematode multiplication and crop damage compared to continuous cultivation of susceptible crops (Widmer, Mitkowski and Abawi, 2002). Nematodes with a narrow host range can be controlled by infrequently growing host crop in rotation with non-host crops such as Pangola grass (*Digitaria eriantha*) (Chellami, 2002). Control using crop rotation is more difficult for nematodes with a wide range of hosts such as *Meloidogyne* species; where the choice of non host crops may be limited and not economically feasible; or where mixed populations of nematodes occur (McSorley and Dickson, 2001). Neither bare fallow nor growing non-host crops will eliminate root-knot nematodes from infested soil. Among the disadvantages of leaving land fallow include the loss of crop production, increased soil erosion and increased oxidation of soil organic matter (Whitehead, 1998). Continuous cropping is considered a poor production practice because of the possibility of increased soil borne pests and the expected reduction in marketable yields (Walker, Zhang and Martin, 2005). Some farmers in Chinamhora communal lands rotate their tomato crop with fallow and maize crops. The rationale of this study in these cropping sequences is to determine their effect on nematodes distribution and interaction.

Being abundant and functionally diverse, nematodes provide useful indicators of soil health conditions. They are the most abundant, multicellular group in soils, reaching a density of 10 million per m^{-2} (Bonger and Bongers, 1998). Nematodes directly influence soil processes and reflect the structure and function of many taxa within the soil food web (Ferris *et al*., 2001). Indices of community and food web structure and function based on characteristics of nematode assemblage give an insight on the effects of environmental stress, dominant decomposition channels, and soil suppressiveness to plant parasites and pathogens (Ferris and Matute, 2003). Currently, no scientific findings are available in

Zimbabwe on the impact of human activities in crop production how affects nematode communities in different ecosystems.

The metabolic footprint concept

Nematode diversity and functional indices that have been used by many ecologists to assess food web and ecosystem conditions do not provide information on the magnitude of ecosystem functions and services (Ferris, 2010). In the metabolic footprint concept, ecosystem enrichment is determined by the flow of carbon (C) and energy through activities of bacteria, fungi and herbivore channels reflecting on total biomass of bacterivore, fungivore and herbivore nematodes (Ferris and Bongers, 2009). Two components underlying the concept are production and respiration components. The production component is the life time amount of C partitioned into nematode growth and egg production and the respiration component assess C utilization in metabolic activities (Ferris, 2010). In the present study, nematode communities were extracted from soil following a survey conducted in the National Botanic Gardens, Harare (typical of a natural ecosystem), Henderson Research Station, Mazowe (typical of an agro ecosystem that had been under maize monocropping for more than 20 years) and at Chinamhora Communal Lands (an agro-ecosystem mainly under continuous tomato cropping). This study was designed: (i) To characterize nematodes in natural and agro ecoecosystem land management systems and explore the potential of using nematode communities as bioindicators to infer soil health. (ii) To assess the influence of tomato cropping sequences on nematode communities in subsistence agriculture.

The hypotheses tested were (i) Natural and agro ecosystem land management systems result in different nematode species and calculations of various indices obtained from such data can be used to assess the health status of the soil (ii) Tomato cropping sequences in subsistence agriculture influence nematode communities thereby having serious implication on crops that can be rotated with it.

4.2 Specific Materials and Methods

(a) Botanic Gardens and Henderson Research Station

4.2.1 Site description

As already mentioned above, surveys were carried out in the National Botanic Gardens and at Henderson Research Station (Fig. 4.1(a) and (b) respectively). The National Botanic Gardens are mapped under deciduous miombo savanna woodland by Wild and Barbosa (1968). Tree species that dominated the vegetation of the reserve land includes *Brachystegia spiciformis* and *Julbernardia globiflora*. The grass cover is more pronounced on the hill slopes, being largely comprised of *Hyperrhenia variabilis, Themeda triandra* and *Tristachya nodiglumis.* The Botanic Gardens is located (17^{o}47'55'' S and 31^{o}3'8" E) at an altitude of 1 200 meter above sea level (masl). The Henderson Research Station (17^{o}34 S and 30^{o}59 E) is located about 36 km North-East of Harare. Both sites lying in Mazowe valley receives a total annual rainfall of < 1 000 mm (Department of Meteorological Services – Harare, 2009). Henderson fields have been under continuous maize production for more than twenty years.

Fig 4.1(a): National Botanic Gardens

Fig 4.1(b): Henderson Research station

4.2.2 Soil sampling

Fifteen (15) composite soil samples from 0 – 15 and 15 – 30 cm depth were collected in a random pattern from the fields, each measuring about 10 hactares. Five sub-samples were mixed thoroughly to constitute a composite sample from which 500 g of soil was taken, placed in a plastic bag, sealed and then kept under cool conditions. The samples were transported to the laboratory in a cool box and stored at 10 ^{0}C for nematode assay and soil physical-chemical properties determination.

4.2.3 Parameters used for community analysis

Abundance: Number of nematode specimens of the genus counted in sample

Absolute frequency (AF): (Frequency divided by number of samples collected) x 100.

The production component of metabolic footprint

Nematode biomass was calculated following Andrássy (1956) formula:

$$W = (L * D)/(1.6 * 10^6)$$

where W is the fresh weight (µg) per individual,

L is the nematode length (µm)

D is the greatest body diameter (µm).

Nematodes in general have elongated cylindrical bodies tapering towards both ends with the anterior bluntly rounded and the posterior more acute. The simple shape is convenient for the calculation of volume and biomass. Nematode volume was calculated based on body diameter and length:

$$V = (L * D^2)/1.7$$

where 1.7 is an empirically-determined constant.

The respiration component of metabolic footprint

Nematode respiration rate is proportional to body size of the individual (Kleiber, 1932; West *et al*., 1997). The relation is described as:

$$R = cW^b$$

where R is the respiration rate

W is fresh weight of the individual

c and b are regression parameters, such that b is close to 0.75 (Atkinson, 1980; Klekowski, Wasilewska and Paplinska, 1974).

Thus calculation for expected respiration rate and the total rate of CO_2 evolution for all nematodes in the system can be carried out.

For each nematode species, the *c* values of the relationship $R = cW^b$

where b = 0.75, increases to a maximum at soil temperature between 20 and 30 ^{0}C and declines at higher temperatures.

The cumulative respiration rate is calculated as $\Sigma R = N_t W^{0.75}$

where N_t is the number of individuals in each of the t taxa of interest (Ferris et al., 1996).

4.2.4 Soil analysis

Soil physical and chemical analyses were carried out in the Soil and Chemistry Research Institute laboratory at the Harare Agricultural Research Centre. Available P was determined in the soil according to Watanabe and Olsen (1965) method in 0.5 M $NaHCO_3$ soultion buffered at pH 8.5. K was determined on a flame photometer. Ca and Mg were determined on atomic absorption spectrophotometer (AAS).

(b) Chinamhora Communal Lands (an agro-ecosystem mainly under continuous tomato cropping)

A survey was carried out during February, 2008 in Chinamhora Communal Lands, in Goromonzi district in Mashonaland Provinces (latitude 17.61^o; longitude 31.17^o), about 25 km East of Harare, at an elevation of 1637 masl. The area has unimodal rainfall pattern most of it falling between November and April. Results from a current survey carried out in Chinamhora (SAPP, 2009) show that the communal area is a major producer of horticultural produce for the Harare urban population.

During the survey, the sampled tomato fields represented different tomato cropping sequences, which were distributed as follows:

1. Fields that were under continuous tomato production, (five fields): more than 3 years
2. Tomato in rotation with maize, (six fields): more than 3 years
3. Tomato after natural fallow, (three fields): more than 3 years

To understand the history of each field where soil samples was collected during the survey, a questionnaire (Appendix 4.1) was administered to households to obtain the history use of land. Preferred crop varieties that were grown in the fields by the farming community in the survey area are tomato var. 'Rodade' and an early-maturing maize variety; SE 501.

4.2.5 Soil sampling and Nematode management

Fourteen fields, ranging from 0.5 to 1.5 ha were sampled to represent three different tomato cropping sequences. In each field, a trowel was used to collect soil from five randomly distributed spots from a depth of 0 – 30 cm. Random sampling was used because there was high homogenosity within the fields. The five sub-samples taken from each single field were then mixed throughly to constitute a composite sample. The soil clods in each composite sample were carefully broken up with the fingers and sieved gently through a coarse sieve to remove the debris without damaging fragile nematodes. Five hundred grammes (500 g) of soil were taken, placed in a plastic bag, sealed and then kept under cool conditions. The samples were transported to the laboratory in a cool box and stored at 10 ^{0}C for nematode assay. Soil samples were processed within 24 hours after the collection. Nematodes in the samples were extracted using the Baermann and wet-sieving techniques (as described in Sections 3.2.1 and 3.2.2). Nematode management was carried out (as described in Sections 3.3 to 3.6 of general materials and methods).

4.3 Results

4.3.1 Effects of land management systems and depth on nematode abundance and genera frequency

The total abundance of nematodes varied significantly ($p<0.05$) between the land management systems. At the 0 – 15 cm soil depth nematode abundance was significantly higher at Henderson station than in the Botanic Gardens and overall nematode abundance between sites was greater at this depth than at the 15 - 30 cm soil depth (Fig.4.2).

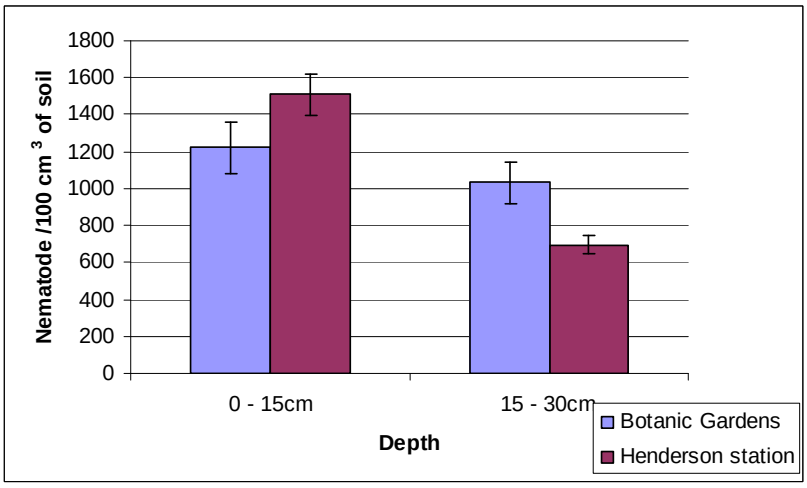


Fig. 4.2 Influence of land management systems and soil depth on nematode abundance
Bars represent standard error of the mean

A total of 16 genera and 6 families were recovered from both soil depths in the Botanic Gardens, while from Henderson station only 11 genera and 6 families were recovered from 0 – 15 cm depth (Table 4.1). *Hemicycliophora* spp. was not recovered from 15 – 30 cm depth in the agro-ecosystem. In the Botanic Gardens, among free-living nematodes, Rhabditidae, *Tylenchus* spp. and fungi dorylaims were the most prevalent at 0 – 15 cm depth with absolute frequencies above 93 %. The least frequent was *Filenchus* spp. with absolute frequency of 46 % at 0 – 15 cm depth. Rhabditidae, *Aphelenchus* spp. and fungi dorylaims were the most frequent at Henderson station with an absolute frequency of 100%. A higher absolute frequency of 100 % was observed for *Helicotylenchus* spp., *Scutellonema* spp. and *Pratylenchus* spp. across depths of the two land management systems. The least frequent parasitic genera at Henderson station were *Xiphinema* spp. with absolute frequency of 20 % at 0 – 15 cm depth. Although *Rotylenchulus* spp., *Meloidogyne* spp., *Trichodorus* spp. and *Hemicriconemoides* spp. were the least represented genera in the Botanic Gardens. They were, however, not detected at Henderson station.

Table 4.1 Community structure of soil nematodes/ 100 cm^3 soil across depths at the Botanic Gardens and Henderson station (2008)

Trophic group/Genus	c-p[a] values	Botanic Reserve gardens depth (cm) [(15)]		Henderson Research station depth (cm) [(15)]	
		0 – 15	15 – 30	0 – 15	15 – 30
		AF (%)	AF (%)	AF (%)	AF (%)
Bacterivores					
Cephalobidae	2	73	46	46	20
Rhabditidae	1	100	93	100	60
Fungivores					
Aphelenchoides	2	53	40	46	66
Tylenchus	2	100	100	26	26
Aphelenchus	2	86	100	100	93
Filenchus	2	46	60	-	-
Fungi Dorylaimidae	3	100	100	100	100
Predators					
Mononchidae	4	100	100	-	-
Predatory Dorylaimidae	5	100	100	100	100
Omnivore					
Omnivore Dorylaimidae	4	100	100	86	100
Herbivores					
Helicotylenchus	3	100	100	100	100
Scutellonema	3	100	100	100	100
Criconemoides	3	86	93	100	100
Pratylenchus	3	100	100	100	100
Xiphinema	5	93	100	20	26
Tylenchorhynchus	2	53	46	46	-
Rotylenchulus	3	46	73	-	-
Hemicycliophora	3	40	53	40	-
M. javanica	3	86	93	-	-
M. incognita	3	53	33	-	-
Trichodorus	4	6	80	-	-
Hemicriconemoides	3	-	20	-	-

AF = Absolute Frequency

[a]The colonizer-persister (c-p) scale values (Bongers, 1990) . Nematode genera least sensitive to disturbance with value of 1 and 2 and genera most sensitive to disturbance with value of 5.

[(15)] Number of composite soil samples collected from each land management system

4.3.2 *Nematode taxa and trophic distribution in different land management systems*

A total of 10 free-living nematode groups were observed in both soils in the Botanic Gardens and at Henderson station, which composed of two bacterivorous families, four genera and one family belonging to fungivorous nematodes, two predatory families and an omnivoous family (Table 4.2). In terms of trophic abundance, higher abundance of free living nematodes was recovered from 0 - 15 cm depth in the Botanic Gardens (Fig. 4.3). Herbivores were abundant at both sites of the land *management* systems. *Rotylenchulus* spp., *M. javanica*, *M. incognita*, *Trichodorus* spp. and *Hemicriconemoides* spp. *Helicotylenchus* spp., *Scutellonema* spp. were abundant in the Botanic Gardens where as *Helicotylenchus*, *Scutellonema* and *Pratylenchus* were dominant herbivorous genera at Henderson station. Higher abundance of *Pratylenchus* spp. was recorded at both depths at Henderson station. Higher abundance of *Xiphinema* spp. was recorded at the Botanic Gardens, whereas higher abundance of *Criconemoides* spp. was recorded at Henderson station.

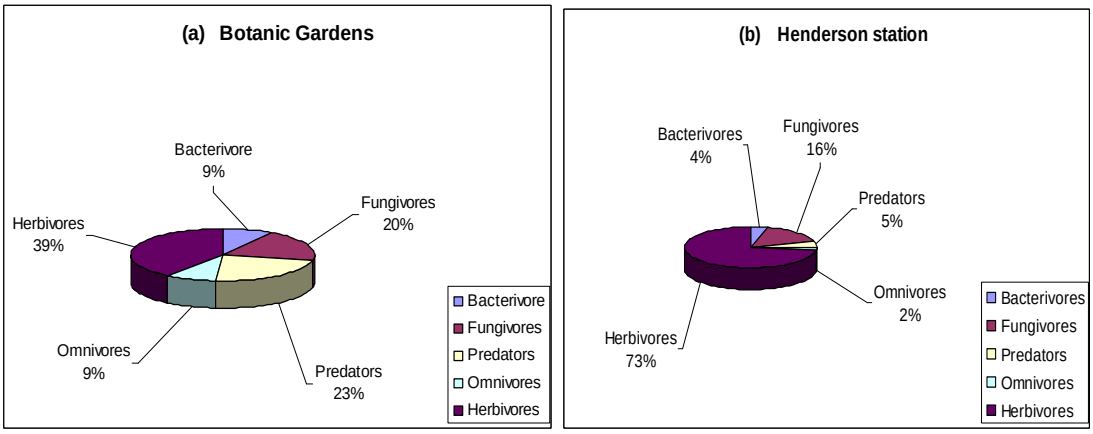


Fig. 4.3 Trophic structure of soil nematode communities at 0 – 15 cm depth at the Botanic Gardens and Henderson station

Table 4.2 Abundance of nematode genera/ 100 cm^3 soil across depths at the Botanic Gardens and Henderson station (2008)

Trophic group/Genus	Botanic Gardens[15] depth (cm) 0 – 15	15 – 30	Depth effect	Henderson Research station[15] depth (cm) 0 – 15	15 – 30	Depth effect	Depth effect across sites (0 - 15 cm)	Depth effect across sites (15 - 30 cm)
Bacterivores								
Cephalobidae	2.34	1.17	*	1.62	3.80	**	n.s.	**
Rhabditidae	4.26	3.18	**	3.61	2.67	*	**	**
Fungivores								
Aphelenchoides	3.67	3.08	*	1.56	0.57	ns	**	**
Tylenchus	3.32	2.70	*	0.95	1.64	ns	**	**
Aphelenchus	3.01	2.77	ns	3.96	1.50	**	*	*
Filenchus	1.57	1.61	ns	0	0.75	*	**	n.s.
Fungi Dorylaimidae	4.69	4.61	ns	4.95	2.88	**	n.s.	**
Predators								
Mononchidae	5.06	5.03	ns	0	0.25	ns	**	**
Predatory Dorylaimidae	4.58	4.35	ns	4.07	3.99	ns	**	n.s.
Omnivore								
Omnivore Dorylaimidae	4.59	4.53	ns	3.11	0.28	**	**	**
Herbivores								
Helicotylenchus	4.76	4.57	ns	5.29	3.35	**	**	**
Scutellonema	4.70	4.53	ns	5.71	3.16	**	**	**
Criconemoides	2.82	2.87	ns	3.56	4.45	*	n.s.	**
Pratylenchus	4.26	2.82	ns	6.24	4.97	**	**	n.s.
Xiphinema	3.22	3.40	ns	0.67	3.02	**	**	n.s.
Tylenchorynchus	1.43	1.03	ns	0.24	5.10	**	*	**
Rotylenchulus	1.31	1.42	ns	0.20	1.14	ns	*	n.s.
Hemicycliophora	0.97	1.92	ns	0.20	0	ns	n.s.	**
M. javanica	2.94	2.65	ns	0	0	**	**	**
M. incognita	0.17	0.86	ns	0	0	**	n.s.	n.s.
Trichodorus	1.11	2.43	*	0	0	ns	**	**
Hemicriconemoides	-	2.68	ns	0	0	ns	n.s.	n.s.

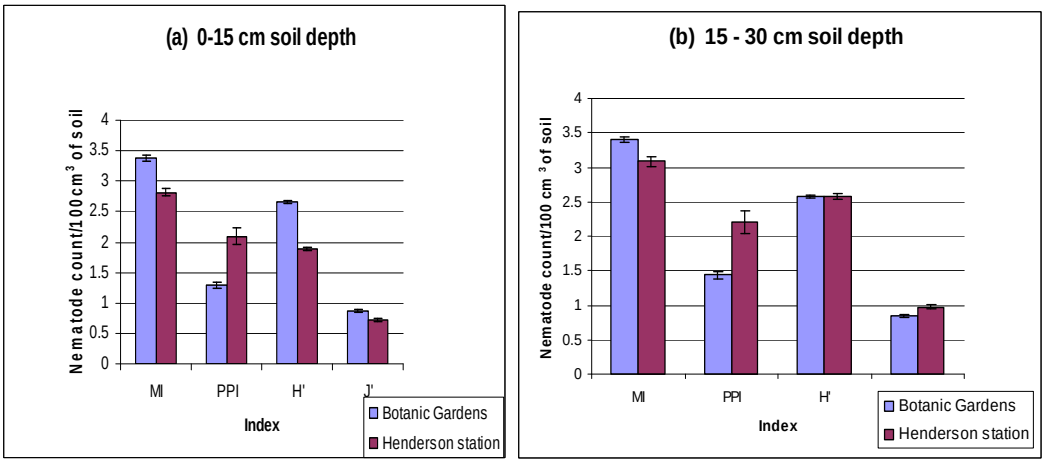
p-values are between factor effects. *:p< 0.05; **p< 0.01; ns.:p > 0. 05

[15] Number of composite soil samples collected from each land management system

4.3.3 Nematode ecological indices at different depths and land management systems

4.3.3.1 Community structural indices

Maturity indices (MI) were variable among land management systems studied (Fig. 4.4). The MI was significantly higher in the both soil depths in the Botanic Gardens than at Henderson station.



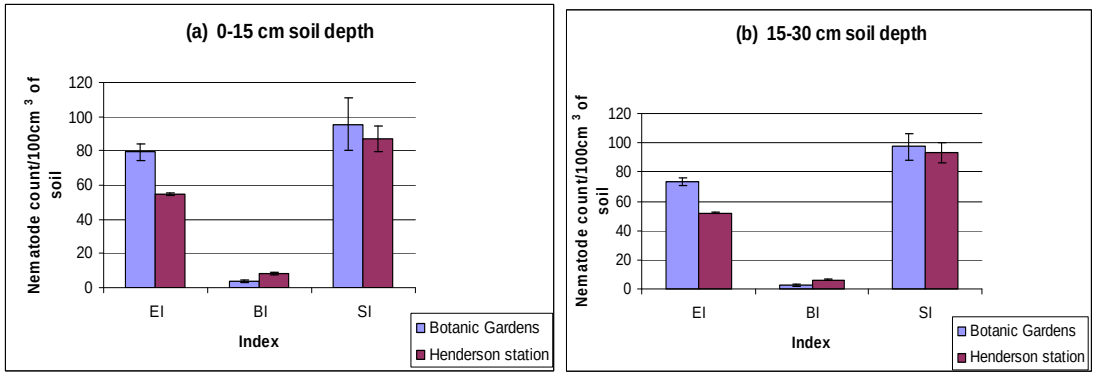
MI = Maturity index, PPI = Plant parasitic index , H' = Shannon diversity index, J' = Evenness index

Fig. 4.4 Community structural indices at 0 – 15 and 15 – 30 cm depth at the Botanic Gardens and Henderson station. Bars represent standard error of the mean

The values of plant parasitic index PPI at both depths were significantly higher at Henderson station than at the Botanic Gardens. Shannon diversity H' values were greater at Botanic Gardens and the significance was observed at 0 – 15 cm depth. The J' values were different in the soil depths across land management systems. The significantly higher values were observed at the Botanic Gardens at 0 – 15 cm depth and at Henderson station at 15 – 30 cm depth. Significantly ($p<0.05$) higher nematode channel ratio was observed at Henderson station (Fig. 4.6)

4.3.3.2 Food web indices

The structure SI, enrichment EI and basal indices BI were different between land management systems (Fig. 4.5). The enrichment and basal indices were significantly higher at both soil depths in the Botanic Gardens. At Henderson station, both soil depths recorded higher values of SI and BI. The Nematode Channel Ratio (NCR) was higher in the 0 – 15 cm depth at Henderson station. Lower values were observed in the Botanic Gardens at both depths.



EI = Enrichment index, SI = Structural index and BI = Basal index

Fig. 4.5 Food web indices at 0 – 15 and 15 – 30 cm depth at the Botanic Gardens and at Henderson station. Bars represent standard error of the mean

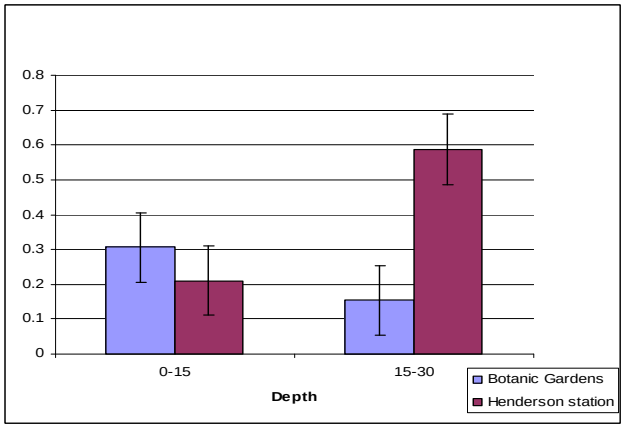


Fig. 4.6 Nematode channel ratio at 0 – 15 and 15 – 30 cm depth at the Botanic Gardens and at Henderson station. Bars represent standard error of the mean

4.3.3.3 Soil physico-chemical properties and nematode communities

Soil bulk density measured as an indicator of soil compaction was different between the land management systems (Table 4.3). Higher soil bulk density values were recorded at Henderson station. Soil mineral-N (NO_3^-) was higher in the Botanic Gardens than at Henderson station whereas soil available P_20_5 was higher at Henderson station. For exchangeable cations, more Ca and K were detected in the reserved land. Mg did not differ between the two land management systems.

Textural classes at Henderson station were courser grained than at the reserved land. The resource flow into the food web and intake from the food web by nematodes at the Botanic Gardens and at Henderson station have been presented in a pie chart with sub division indicating the proportion of resource (carbon and energy) flow through separate channels. Higher food web resource flow was contributed by herbivores at the Botanic Gardens at 0 - 15 cm depth (Fig. 4.7) and at Henderson at 15 - 30 cm depth (Fig. 4. 8), respectively.

Table 4.3 Soil physical and chemical properties at the Botanic Gardens and Henderson Research Station (2008)

Soil depth (cm)	pH (Cacl)	Ammonia + nitrate (ppm)	Extract P(ppm)	Exchangeable cations (mg $100g^{-1}$)			Soil texture ($g\ kg^{-1}$)	Bulk density ($g\ cm^{-3}$)
				K	Ca	Mg		
Botanic Gardens								
0-15	4.7	20	25	0.12	2.97	0.69	mgS	1.42
15-30	4.8	17	21	0.23	2.53	0.58	mgS	1.37
Henderson Research Station								
0-15	4.5	14	58	0.06	0.99	0.56	cgS	1.48
15-30	4.7	13	49	0.04	0.74	0.55	cgS	1.49

cm = centimeter; mg $100g^{-1}$ = milligram/100 gram; g kg^{-1} = gram/ kilogram and g cm^{-3} = gram/cubic centimeter; mgS = medium grained soil and cgS = courser grained soil

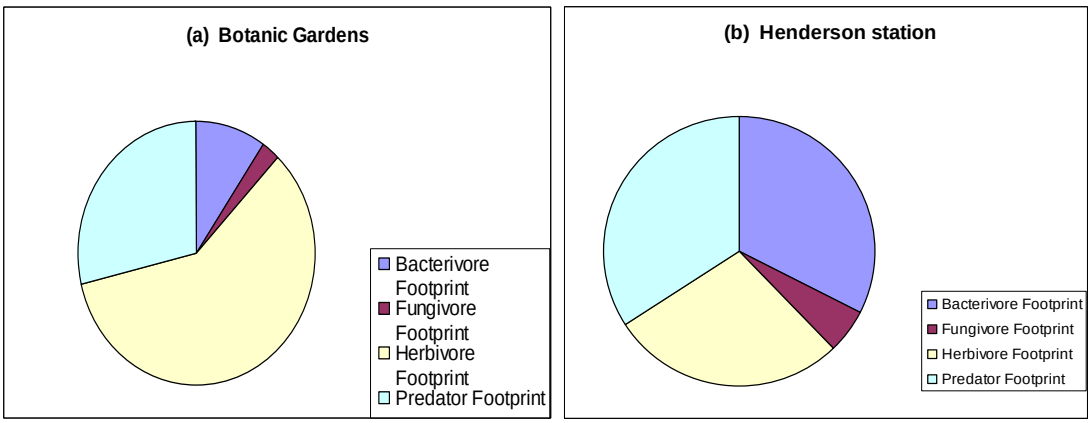


Fig 4.7: Food web – Resource Flow at 0 – 15 cm depth at the Botanic Gardens (a) and at Henderson station (b)

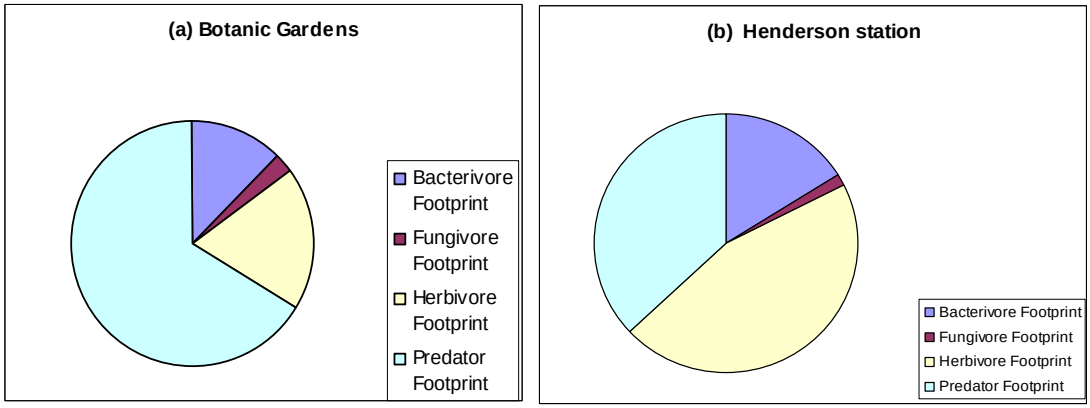


Fig 4.8 Food web – Resource Flow at 15 – 30 cm depth at the Botanic Gardens (a) and at Henderson station (b)

The food web resource intake charts for both land management systems (Fig. 4.9) shows that resource intake from the food web was consumed more by herbivores in the Botanic Gardens at 0 – 15 cm depth (Fig. 9) and at Henderson station at both depths (Fig. 4.10).

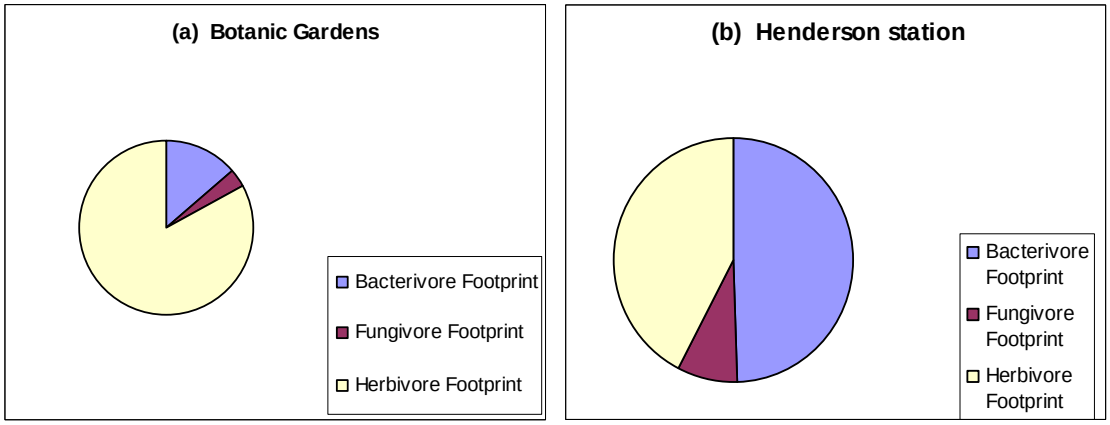


Fig 4.9 Food web – Resource Intake at 0 – 15 cm depth at the Botanic Gardens (a) and at Henderson station (b)

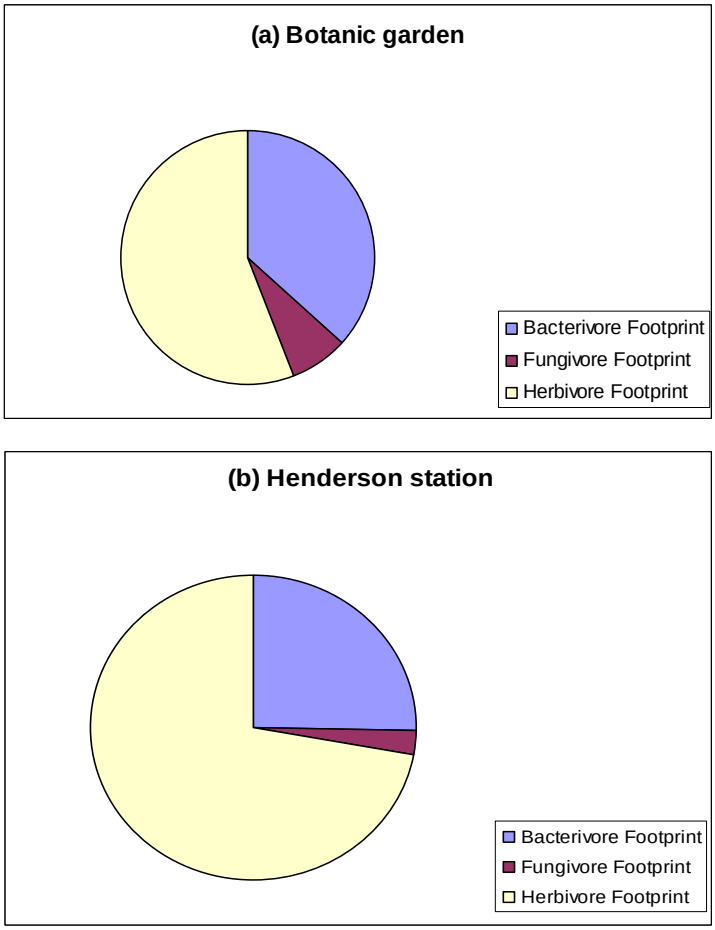


Fig 4.10 Food web – Resource Intake at 15 - 30 cm depth the (a) Botanic Gardens (a) and Henderson station (b)

In the the metabolic footprint (Fig. 4.11), a higher ratio of prey-predator was observed in the Botanic Gardens at 0 - 15 cm depth and at Henderson station at 15 - 30 cm depth (Fig 4.12). There were higher predator-prey ratio at the Botanic Gardens at 15 - 30 cm depth and Henderson station at 0 - 15 cm depth, respectively.

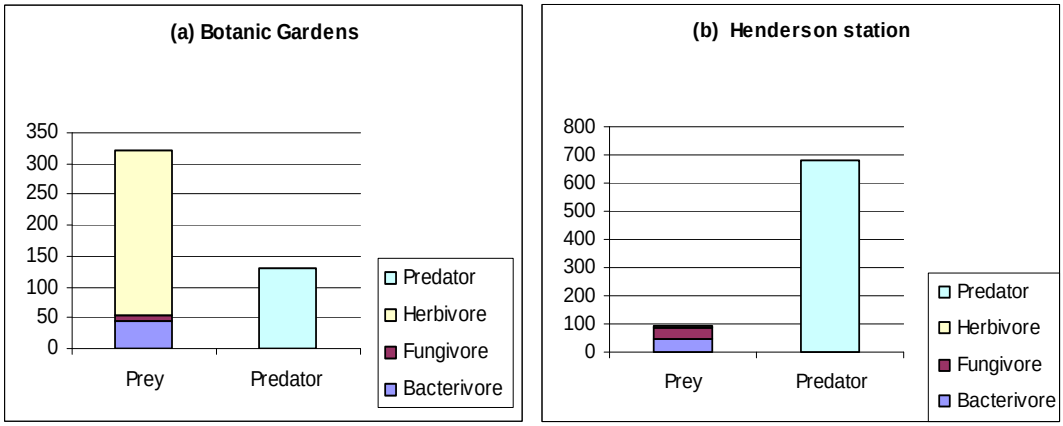


Fig 4.11 Metabolic Footprint at 0 – 15 cm depth at the Botanic Gardens (a) and at Henderson station (b)

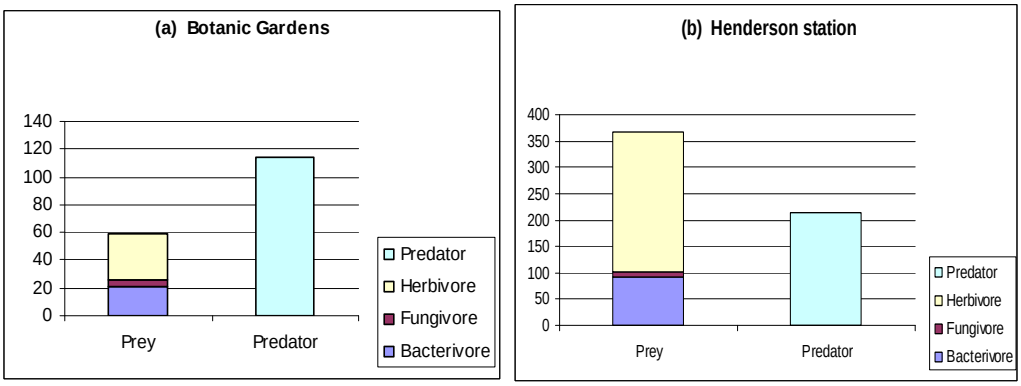


Fig 4.12 Metabolic Footprint at 15 – 30 cm depth at the Botanic Gardens (a) and at Henderson station (b)

4.4 Results for Chinamhora Communal Lands

4.4.1 Nematode abundance and trophic distribution

The abundance of nematode communities varied significantly between cropping sequences. The highest abundance was observed in tomato after tomato fields and natural fallows had lower abundance than the tomato after maize fields (Fig.4.13).

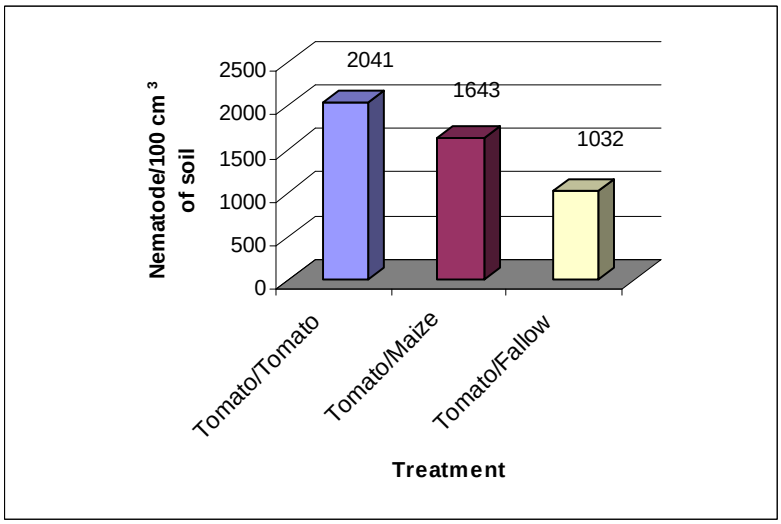


Fig.4.13 Effect of tomato cropping sequences on nematode abundance: Chinamhora Communal Lands (2008)

4.4. 2 Trophic structure and genera distribution

The nematodes communities were classified as herbivores, bacterivores, fungivores, omnivores and predators. Herbivores were the dominant in the agro ecosystem while fungivores and predatory nematodes dominated in the tomato after natural fallow fields (Fig. 4.14). The abundance of herbivorous nematodes was significantly higher in tomato after tomato fields.

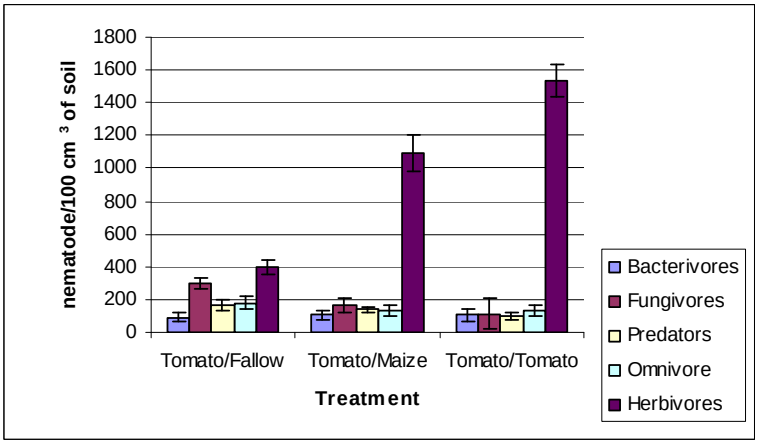


Fig. 4.14 Trophic distribution in different tomato cropping sequences: Chinamhora Communal Lands (2008). Bars represent standard error of the mean

In terms of individual nematodes groups, (Table 4.4) shows the list of different families and genera identified in the agro ecosystem. There was no significance difference in abundance of bacterivorous family among the cropping systems though Rhabditidae were more presented in each cropping sequence than Cephalobidae. Plant parasitic species abundance was affected by cropping sequences. Tomato after maize and tomato after natural fallow fields each had ten nematode taxa groups compared to seven taxa groups recorded in the tomato after tomato fields. Significantly ($p<0.05$) higher abundances of genera *Helicotylenchus*, *Scutellonema* and *Pratylenchus* were observed in tomato after maize fields. *Criconemoides* spp., *Xiphinema* spp., *Hemicycliophora* spp. and *Trichodorus* spp., most of them known for their proneness to environment disturbances, were more abundant in tomato after natural fallow fields. The significant abundance of *Meloidogyne incognita and M. javanica* was recorded from tomato after tomato fields.

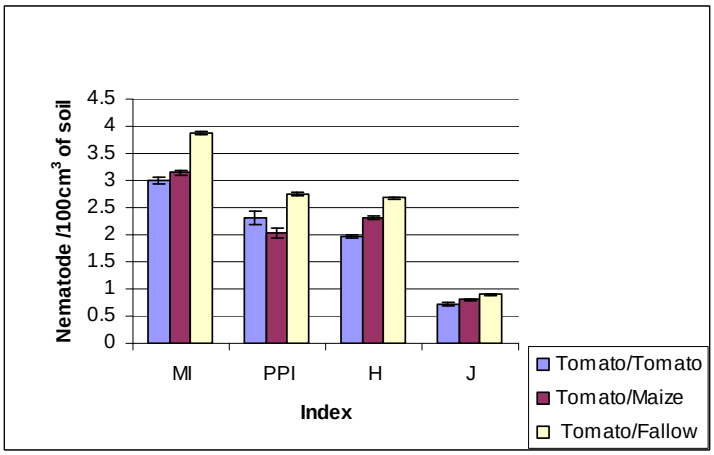
Table 4.4 Influence of cropping sequences on nematode genera abundance in tomato production: Chinamhora communal Lands (2008)

Genus/Family	Tomato (5)[a]	Fallow (6)	Maize (3)
Bacterivores			
Cephalobidae	1.23	1.82	1.63
Rhabditidae	4.21	3.17	4.40
Fungivores			
Aphelenchoides	0	0	0
Tylenchus	1.71	2.61	1.24
Aphelenchus	1.57**b**	3.74**a**	3.75**a**
Filenchus	0**ab**	1.50**a**	0**b**
Fungi Dorylaimidae	2.46**b**	5.15**a**	4.73**ab**
Predators			
Mononchidae	0**b**	4.29**a**	1.58**b**
Predatory			
Dorylaimidae	4.46	4.33	4.80
Omnivores			
Omnivore			
Dorylaimidae	4.91	4.68	4.74
Herbivores			
Helicotylenchus	5.68**a**	4.32**b**	5.57**a**
Scutellonema	5.36**ab**	4.72**b**	5.73**a**
Criconemoides	0**b**	3.95**a**	0.62**b**
Pratylenchus	0.73**b**	1.72**b**	5.68**a**
Xiphinema	0**b**	3.52**a**	1.05**b**
Tylenchorhynchus	0	2.36	1.27
Rotylenchulus	1.57	2.30	0
Hemicycliophora	0**b**	2.32**a**	0.61**ab**
M. javanica	6.42**a**	0**c**	4.52**b**
M. incognita	5.72**a**	0**b**	2.10**b**
Trichodorus	0.59**b**	3.09**a**	0.67**b**
Hemicriconemoids	0	0.54	0

NB: Levels not connected by same letter are significantly different
[a]Numbers in parentheses represent the total number of fields sampled for each cropping system.

4.4.3 Nematode community and food web indices

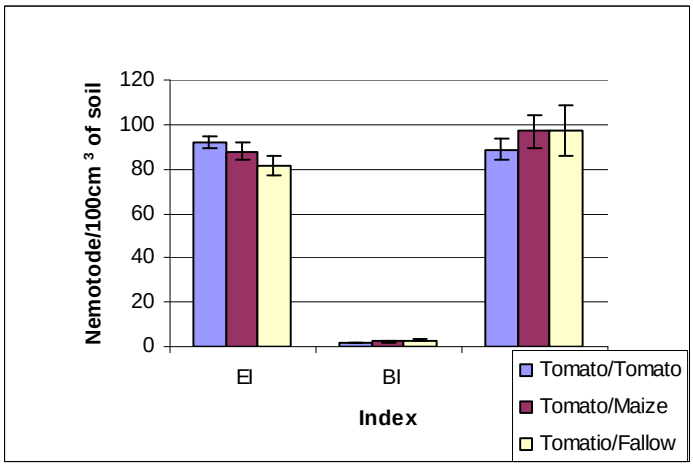
Maturity index (MI) and plant parasitic index (PPI) were significantly variable among the tomato cropping sequences (Fig. 4.15). The highest MI was recorded in the tomato after natural fallow while the lowest was tomato after tomato fields. The PPI was highest in tomato after natural fallow fields. The Shannon-Weiner diversity index (H) and evenness (J) were different among cropping sequences. The abundance and evenness of species were significantly higher in tomato after fallow and lowest in tomato after tomato fields.



MI = Maturity index, PPI = Plant parasitic index, H' = Shannon diversity index, J' = Evenness index

Fig. 4.15 Community structure indices in different tomato cropping sequencies at Chinamhora Communal Lands (2008). Bars represent standard error of the mean

Significantly higher enrichment index EI was observed in the tomato after tomato fields and tomato after natural fallow fields had significantly higher structural SI values (Fig. 4.16). The values of nematode channel ratio was low (below 50%) in both sequences under tomato production (Fig. 4.17).



EI = Enrichment index, SI = Structural index and BI = Basal index

Fig. 4.16 Food web indices in different tomato cropping sequences: Chinamhora Communal Lands (2008). Bars represent standard error of the mean

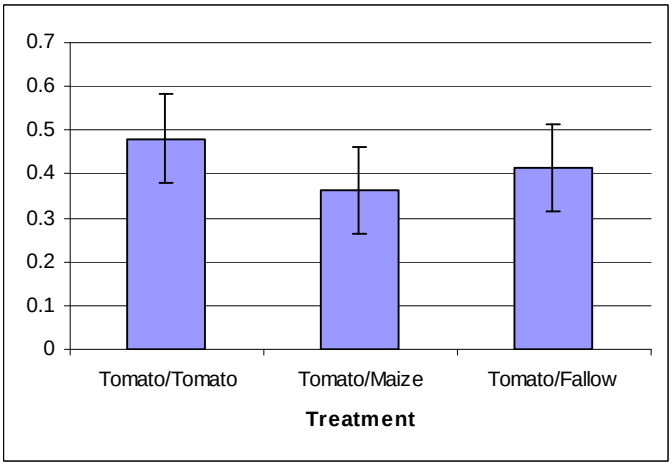


Fig. 4.17 Influence of cropping sequences on nematode channel ratio in tomato production: Chinamhora Communal Lands (2008). Bars represent standard error of the mean

4.5 Discussion

The findings of the study have revealed that the relationship between nematode communities and soil properties was influenced by land management systems and depth. The variability in nematode abundance and genera composition observed in the current study in the different land management systems and soil depth is an indication that land management practices have significant impact on soil ecosystems and this can be revealed through differences in nematode community structure and food web functioning. The Botanic Gardens had lower nematode abundance than Henderson station at 0 - 15 cm depth, with the opposite trend occurring at 15 - 30 cm depth. The nematode build up at Henderson station may be due to continuous maize planting that could relate with increased root biomass that increases biological activities in the soil. This observation agrees with findings by (McSorley, 1997) who reported most nematodes to occur in the upper 20 cm of the soil profile. Kimenju, Karanja, Mutua, Rimberia and Wachira (2009) observed the disturbance of the natural forest through felling of indigenous trees, followed by establishment of single species plantations resulted in an increase in nematode abundance with reduced species diversity and richness.

The variability in nematode abundance, trophic structure composition and genera diversity observed in the communal lands, indicates that different tomato cropping sequences have a significant impact on nematode communities. Higher nematode abundance was observed in fields that were planted tomato in consecutive seasons while the lowest abundances were recovered in the fields of tomato established on fields previously under natural fallow. Some species react positively to tillage due to enhanced incorporation of organic matter into the soil that gives rise to bacterial feeding nematodes if the proportion the materials are of low C:N ratio and fungi feeding nematodes for high lignin contents. The study by Liphardzi, Al-Khatib, Bensch, Stahlman, Dille, Todd, Rice, Horak and Head (2005) found general increase in nematode abundance in cultivated plots due to predominance of plant parasitic nematodes, fungal and bacterial feeders. According to McSorley and Gallaher (1996), fallow has been recognized as a means for reducing nematode population densities, but not much of it is practiced due increasing land use pressure. However, at this point greater emphasize would have to put on the species composition of the community in a particular agro-ecosystem before making firm conclusion.

Among free-living nematodes, predators and omnivores dominated in the Botanic Gardens. This observation suggests the absence of anthropogenic disturbance because these groups are known to be highly sensitive to perturbation. These taxa are assumed to play a regulating role both in the soil food web and in buffering outbreaks of soil-borne plant diseases (Bongers and Ferris, 1999). Their low populations in cultivated plots are indicating the degraded soil properties and a loss of fertility. In such conditions, plant parasitic nematodes may become a yield limiting factor since the crop is already weakened by inadequate growth conditions and inputs (Hillocks and Walter, 1997).

In Chinamhora, the abundance of Rhabditidae was relatively higher in the fields previously planted with tomato and maize respectively as they were stimulated by tillage. In some cases, total nematode abundance was reduced after tillage, with bacterial feeders dominating in tilled plots. Abundance of herbivores in samples from the Botanic Gardens suggests the presence of massive root biomass from the abundant grass and tree species

that support phytonematodes with broad host ranges. Generally, it is known that the population of fungivores are abundant in fallow fields, where there is no frequent fertilization of soils as normally practiced in soil under conventional tomato production. According to Wang *et al*. (2004), fungivorous nematodes are always negatively correlated with percentage organic matter in soils and become prominent as substrate with high lignin and cellulose accumulates in the habitat. This could partly explain the lower abundances of fungivorous nematodes observed in the fields managed conventionally in this study.

In both land management systems, nematode communities were dominated by the genera *Helicotylenchus*, *Scutellonema* and *Pratylenchus* spp., *Meloidogyne javanica* and *M. incognita*. Lesion nematodes; *Pratylenchus* spp. has been reported to be cosmopolitan in maize production system, and the most common in subtropical and tropical regions (Desaeger and Rao, 2000). The presence of genera *Helicotylenchus*, *Scutellonema*, and *Meloidogyne* in these land management systems was not unexpected. Higher abundance of *Criconemoides* spp. was observed at Henderson station than in the Botanic Gardens. This observation may be due to fact some species of plant parasitic nematodes are potentially more responsive to the host plant than to the soil management practices. However, these findings were contrary to Yeates (1996) who reported that, most of *Criconemoides* spp. are sedentary ectoparasites that are sensitive to environment disturbances such as plowing, and are found more in perennial plants and wild vegetation than disturbed environments.

Higher abundance of genera *Helicotylenchus*, *Scutellonema* and *Pratylenchus* observed in plots planted with tomato after maize, is an indication that these genera are major plant-parasitic nematode on maize. *Pratylenchus* spp. is widely spread and is well distributed across maize growing regions in Kenya (Kimenju, Waudo, Mwangombe, Sikora and Schuster, 1998), and are among the most common nematodes associated with maize in the tropics (De Waele and McDonald, 2000). The current study observations revealed that *Helicotylenchus* spp. is common in most agricultural management systems where soil fertilization occurs through agricultural intensification or other practices underpinned to

restore soil fertility. Abundances of *Meloidogyne javanica* and *M. incognita* were higher in fields planted with tomato for consecutive seasons. This suggests that for plant parasitic genera with more than one generation per year, their population can increase tremendously within short periods of time in the presence of suitable host like tomato.

The maturity index MI and structural index SI indicate the succession stage of communities, which in cultivated soils are normally in low values due to frequent disturbances and considered as premature (Berkelmans, Ferris, Tenuta and van Bruggen, 2003). In the study, the significant high MI values observed in the Botanic Gardens suggested a highly stable ecosystem. In cases where succession has been interrupted by common agricultural practices, such as cultivation and application of fertilizer and pesticides Neher *et al*. (2005), the successional status of a soil community may reflect the history of disturbance. Smaller index values are indicative of a more disturbed environment with higher abundance of colonizers (short life cycle, higher reproduction potential and tolerant to environment disturbances) and larger values may indicate a less disturbed environment (Freckman and Ettema, 1993). General opportunistic nematodes, that are tolerant to soil perturbation prevailed more in the Henderson station as indicated by having relatively higher BI values. Plant parasitic index PPI values were significantly higher at Henderson station. This implies high carrying capacity of the potential host crop to plant feeding nematodes in that management system. The current study observations contradicts the report by Neher and Campbell (1994) who reported higher PPI values occurring in soils from perennial crops or pastures than from annual crop fields. Lower PPI values observed at the Botanic Gardens suggest that there was a suppression of herbivore nematode populations in the system. This observation suggests that a fallow system may be a viable option in managing abundance of plant parasitic nematodes in agro ecosystems.

The higher maturity index MI and structural index SI values in the tomato after natural fallow fields suggest stable ecosystem associated with decreased soil. Both MI and SI increased with increasing contribution of predators and omnivorous nematodes, which are of high c-p value and prone to environment disturbances. The proportion of these

trophic groups in the nematode communities is always lower in cultivated soils (Ferris *et al*., 1996). The increase in Shannon-Weiner diversity and evenness indices observed in the tomato after fallow fields was consistent with the expectation of the study. Previous findings by Hànêl (2003) had reported the nematode diversity to increase significantly when cropping was abandoned and fields allowed to return to natural conditions. Fallow is characterized by reduced tillage, with increased soil fertility and species diversity (Bongers *et al*., 1997). Equally low nematode channel ratio NCR in both tomato cropping sequences reflects that organic matter decomposition and possibly nutrients and minerals cycling in most soils would choose fungal dominated decomposition pathways.

With regard to species diversity, the Shannon-Weiner diversity index (H) was higher in the Botanic Gardens. Diversity has been equated to reflect both on taxa richness and distribution evenness among nematode species (Shannon and Weiner, 1949). Higher index values suggest the favourable habitat for many genera to thrive. Lower values of nematode channel ratio NCR were recorded in both management systems with exception of 0 – 15 cm soil depth at Henderson station. This observation prompts one to speculate the presence of more fungal than bacterial feeders in the Botanic Gardens which influence the food web to select fungal dominated decomposition pathway. Supporting shift trends on decomposition of substrates among nematode trophic groups, Ruess and Ferris (2004) observed fungal/ bacterial dominated decomposition pathway when the soils were dominated with substrates low/ rich in labile nitrogen relative to available carbon. The higher NCR value observed in the lower depths Henderson station may reflect the abundance of mycorrhizal fungi. The lower NCR value in this region may be attributed to the lower pH (4.7 – 4.5) observed between two systems. Alexander (1997) found fungi more abundant at lower soil pH than bacteria, owing to the greater tolerance of acidity of the former and reduced competition with other micro-organisms.

Findings in this this study on the enrichment profile of the food web has identified different guilds contributing to the food web resource flow at different depths. Herbivore and predatory biomass at 0 – 15 cm depth were responsible for resource flow in the Botanic Gardens and at Henderson station. On the other hand, predator and herbivore

biomasses enriched the food web at 15 – 30 cm depth in the Botanic Gardens and at Henderson station. This observation suggests that at Henderson station at 0 – 15 cm depth, being a top layer of there was abundance of microbes of where predators could prey than in the lower layers of the soils. Higher diversity of plant and grass species at 0 – 15 cm depth in the Botanic Gardens supported higher herbivore biomass which contributed significantly to carbon and energy flowing into the food web.

Predator biomass contributed significantly to the food web enrichment at 15 – 30 cm depth in the Botanic Gardens. The lower layers of natural lands normally are associated with higher abundance of bacteria and fungi populations feeding on the decayed roots of the vegetations. These populations support enormous abundances of bacterivore and fungivore nematodes which contribute significantly to the food web enrichment in the presence of predators as it was observed in the Botanic Gardens at 15 – 30 cm depth. Bacterivore and fungivores were less presented at Henderson station due to diminishing food substrate with depth. Herbivores through their actions of feeding on plant root were likely to be dominant and active enrichment biomass at lower depths at Henderson station.

Resource intake from the food web appears to be mostly by herbivores in both land management systems, except at 0 – 15 cm depth in the Botanic Gardens where bacterivores dominated. Most of plant parasitic nematode genera identified in this study are of relatively low c-p values that are characterized with high high reproduction rates. It is likely they consume some nutrients from the ecosystem to support the faunal respiration component of their life cycles, which in turn influences the production component of the food web in Henderson station. The abundance of organisms in various functional guilds determines the magnitude of service to the food web (Ferris and Bongers, 2009). Higher prey-predator biomass observed in the Botanic Gardens at 0 – 15 cm suggests a state of metabolic footprint balance with possibility of “Top-down” regulation of opportunistic species, as there is sufficient intake resources to sustain the predators biomass, the ecosystem would be relatively stable (Ferris, 2010). Low predator biomass as presented in the Botanic Gardens at 15 – 30 cm depth and at Henderson

station at 0 – 15 cm depth reflects the constraints of resource inflow. The situation indicates an environmental contamination or disturbance constraint on nematodes of higher c-p classes.

The difference in the textural classes observed between the management systems and bulk density values implies that at Henderson station soils are more compacted, with low pore spaces. According to Edwards, Anderson, Coleman and Cole (2001), the magnitude of soil food web functions is positively related with pore space and water distribution, as these factors relate to habitable space and accessibility to food. High bulk density values at Henderson station may have discriminated larger nematodes, often predatory or omnivorous nematodes, that are slower to reproduce and characterized with long life cycle (K-strategists). This partly can explain to the low EI and SI values observed at Henderson station. *Helicotylenchus* spp. and *Scutellonema* spp. were dominant in both land management systems; this observation is partially supported by the report by Zoon, Troelstra and Mass (2000) who observed positive correlation of *Scutellonema* spp. with exchangeable acidity. Work of De Dye, Brody and Laughlin (2004) observed a strong dominance pattern of phytoparasitic nematodes in monoculture cropping and more diverse nematode communities in plots with higher plant diversity.

4.6 Conclusion

The natural and agroecosystem land management systems have shown to constitute different nematode communities and fauna indices derived from them assisted in the evaluation of health of the soils. It is suggested that soil disturbance is the major determinant of soil bulk density differences. The vertical distribution pattern of plant nematodes in soil was influenced by roots distribution as more nematodes were found at upper layers of soil. Differences in the vertical distribution of nematode genera may reflect the suitability in the various strata of factors such as temperature, moisture regime, and pore- size (Ilieva-Makulec, 2000).

Free-living nematodes were more prevalent in the Botanic Gardens. There was a decrease in nematode abundance in the Botanic Gardens than at Henderson station. Bacterivorous and herbivorous nematodes were the dominant genera. Bacterivorous nematodes are key microfaunal grazers that regulate ecological processes of decomposition and nutrient cycling, thereby indirectly affecting primary production. Thus, any change in land management that affects bacterivorous soil nematodes has the potential to influence critical ecological processes and are better bioindicators of the rate of decomposition of organic matter. In contrast Henderson station had significantly higher abundance of root lesion nematodes *Pratylenchus* spp. Migratory endoparasites like *Pratylenchus* spp. are considered harmful to the host plant as they cause cell death during feeding and migration through root tissue, and also predispose the cortex to attack by other plant pathogens. It can be concluded that transition from agro-ecosystem to Botanic Gardens can increase soil microbial biomass-N and populations of beneficial free-living nematodes.

Population densities of potential nematode pests such as *Meloidogyne* spp., *Pratylenchus* spp. were less abundant in tomato after fallowing sequence. However, according to observations by McSorley and Gallaher (1994) the benefit from nematode reduction may be outweighed by adverse effects of fertility and yield, which would probably limit wide-spread adoption of fallowing as an agronomic practice. However, only three (MI, H' and J') indices distinguished the difference of management regimes. They were higher in the Botanic Gardens than Henderson station.

CHAPTER FIVE

THE INFLUENCE OF SOIL AMMENDMENTS AND NEMATICIDE TREATMENTS ON DISTRIBUTION OF NEMATODES AT DIFFERENT DEPTHS

5.1 Introduction

Root-knot (*Meloidogyne* spp.) nematodes cause significant losses in horticultural crops in tropical and sub-tropical regions of east and southern Africa (Mwasha, 2000). Some tactics that have demonstrated significant improvement in nematode population management include rotations with non host crops, use of soil organic amendments, resistant varieties and fumigant and non fumigant nematicides (Kratochvil *et al*., 2004). A survey carried out in Zimbabwe (Page *et al*., 1985) determined RKNs as one of the major constraints of production in subsistence agriculture, where there is no ready access to inputs like host plant resistant cultivars and nematicides. Although each of the recommended practice alone improves yield of many crops, each has some undesirable features (Giller, Beare, Lavelle, Izac and Swift, 1997). According to Zasada and Ferris (2004), the application of organic amendments for reducing root-knot nematode populations has met with both successes and failures.

Marigold genus, *Tagetes* spp. has the ability to control certain plant parasitic nematodes. Incorporated *Tagetes* spp. plant residues (Siddiqui and Alam, 1987a) and root extracts (Topp, Miller, Bork and Welsh, 1998) are generally effective at suppressing populations of soil endo-parasitic nematodes such as *Pratylenchus penetrans* and *Meloidogyne* spp. *Tagetes* spp. root diffusate produces nematoxic compounds upon decomposition. The plant species is most effective in nematode control when used as green manure (Luc *et al*., 2005). Siddiqi and Alam (1988) reported that marigold roots inhibited hatching of second stage juvenile (J2) and were directly nematicidal to hatched juveniles.

Chicken manure has been shown to suppress population density of RKNs (Fortnum, 1995). In addition, chicken manure is a valuable source of plant nutrients because it contains significant quantities of N, P, K, Ca, Mg and micro plant nutrients (Sims, Velvis and Wolf, 1994). Besides low cost, safety and improved soil fertility, another advantage of including organic amendment in nematode control is their residual soil fertility effect, which chemical nematicides lack (Bulluck *et al*., 2002a).

Nematicides are used extensively as soil fumigants for controlling weeds, insects and soil borne fungi (Hamill and Dickson, 2005). Application of both fumigant and non fumigant nematicides increases the marketable yield of glasshouse grown tomatoes (Acosta, Vicente, Abreu and Medina-Gaud, (1987). However, if rainfall occurs shortly after Fenamiphos application, the nematicidal effect of the chemical might be reduced because of enhanced movement of the chemical (Johnson, Way and Barker, 2005). Registered fumigant and non fumigant nematicides for use in tobacco can be expensive and require specialized equipment that subsistence farmers cannot afford. Due to the ill-fate of these chemicals to human beings and the environment, the future of these chemicals is in question (Crow 2005). Cultural practice such as rotation is considered as an effective management tactic for suppression of *Meloidogyne* spp. for several reasons. Many potential rotational crops are either of relative low value compared to tobacco and reduce nematode densities by only about 20 % over one year. The relatively higher survival rate of the nematodes, and limited choice of rotation crops suggest that host resistance could play a more important role in successful management of root-knot nematodes (LaMondia and Taylor, 1987).

The vertical distribution of nematodes in soil is highly variable and may be influenced by many biotic and abiotic factors (Liang, Xiaore, Li, Jiang, Ou and Neher, 2005). Root distribution, height of water table, soil moisture, temperature, soil texture, rainfall, and depth of subsoil greatly influence vertical distribution patterns (Sohlenius and Sandor, 1987). Wallace (1963) suggested that root distribution is the chief factor in the vertical distribution of plant parasitic nematodes, and that physical factors play an important secondary role. Highest population densities of most plant-parasitic nematodes are

reported to occur in the upper 45 cm of soil, but specimens of some species have been found 400 cm deep. There appears to be some diversity in vertical distribution patterns among different species. *Trichodorus* species are reported to inhabit soil at greater depths than most nematodes (Francl, 1993).

Soil nematodes are important in nutrient cycling and serve to regulate many soil, chemical and biological processes (Tu, Ristainoand and Hu, 2005). Nematodes are ubiquitous and have diverse feeding behaviors and life strategies, ranging from colonizers to persisters. Some nematodes can survive harsh, polluted, or disturbed environments better than others, and some have short life cycles and respond to environmental changes rapidly. In general, nematodes are easy to sample and extract from the soil, their morphology reflects feeding behavior allowing easy functional classification, and nematode taxa are well classified (Bongers and Bongers, 1998; Neher, 2001). Because of these characteristics, nematode fauna can be used as bioindicators of soil health and provide insight into soil food web conditions (Yeates, 2010).

Sustainable agro ecosystem require cropping sequences and systems that incorporate desirable aspects of the subsistence agriculture that aims to suppress plant pests while enhancing agricultural productivity and activity of beneficial microflora and microfauna (Barker and Koenning, 1998). However, there are few ecological tools sensitive enough to detect changes in soil management. Soil nematodes and the indices derived from analysis of their community structure are well suited to the role of bioindicator of ecological health. It is because they are numerous and diverse with a wide range of trophic survival specialisms (Neher, 2001) and their intimate relationship with their surrounding environments (Neilson and Winding, 2002) are be able to demonstrate that changes in soil management are either beneficial or deleterious to the soil ecology. In Zimbabwe, tobacco could be used as the model field cash crop that has received intensive inputs including soil fumigants and cultural practices for the management of root-knot nematodes. The impact of application of a conventional nematicide, chicken manure and a botanical nematicide to nematode communities, however, have not been evaluated in

tomato cropping systems in Zimbabwe. It is this inadequacy that prompted the investigation with the following objectives.

- To monitor population dynamics of nematode communities in tomato production before and after application of a conventional nematicide, chicken manure and a botanical nematicide.
- To identify the effect of such management strategies on their distribution in the soil and to identify any interactions among factors.

The hypotheses tested were:

- Application of chicken manure, conventional and botanical nematicides in tomato for nematode pest management strategies affect the population dynamics of nematode communities and their distribution in the soil.

5.2 Specific Materials and Methods

5.2.1 Site description: Plant Protection Research Institute (PPRI)

Field experiments were carried out in the period between February 2007/2008 and August 2008/2009 cropping seasons at Plant Protection Research Institute (PPRI) in Harare; situated at an altitude of 1483 masl. The soil was categorized as medium grained clay with the following chemical characteristic: pH (H_2O) = 4.8, available P_20_5 = 205 ppm, exchangeable Ca = 6.25 Mg/100g, K = 0.8 Mg/100g, Mg = 1.65 Mg/100g. The rainfall pattern of the area is unimodal, generally most of it falling between November and April.

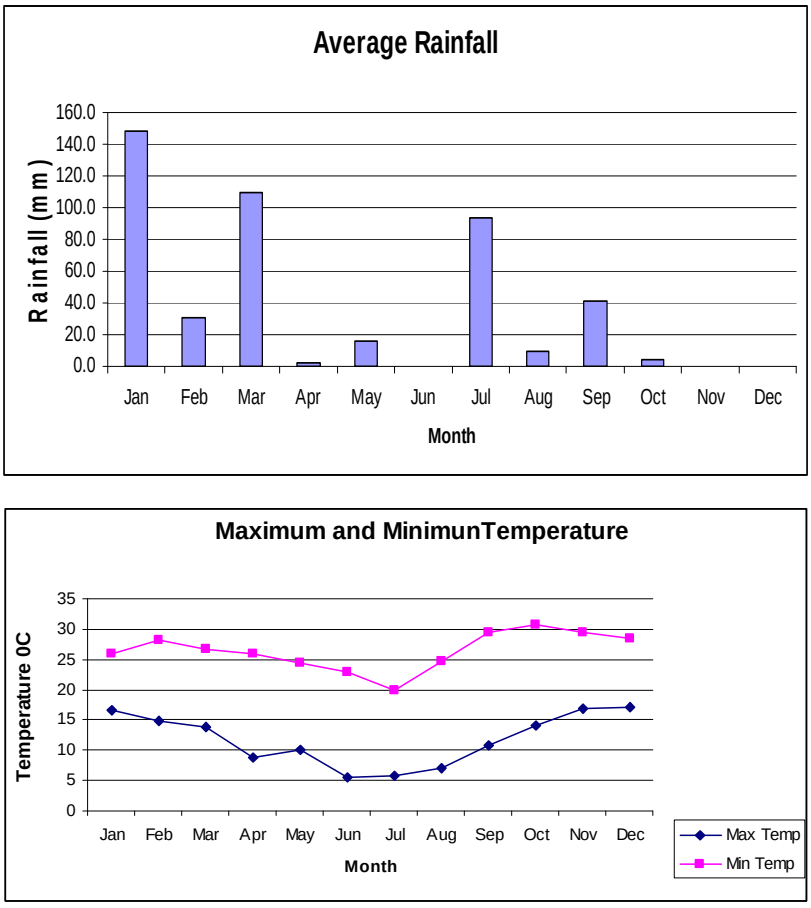


Fig. 5.1 Average rainfall, maximum and minimum temperature distribution for Harare Research Centre during the 2007/2008 and 2008/2009 seasons.

Source: Department of Meteorological Services – Harare (2009)

5.2.2 Treatments and experimental design at PPRI

Previously, the field site was planted to maize and had a natural infestation of nematodes. Black jack (*Bidens pilosa*) was the dominant weed in the study area. The trial was arranged in a randomized complete block design in three replications. During the first cropping season (2007/2008), three treatments were tested that included; Marigold (*Tagetes* spp.) var. Orangeade, chicken manure, Fenamiphos (Nemacur 400 EC) planted on 3m x 4m plots in the field. During the following cropping season (2008/2009) each plot that received a treatment in the previous season was halved to 1.5 m x 4 m plots. One portion received the same treatment and the other portion was left untreated to test for

possible residual effect of the previous treatment application. A total of six treatments were tested that included; (1) with and without Marigold, (2) with and without chicken manure and (3) with and without Fenamiphos.

Marigold were grown in respective plots and plowed-under at flowering stage two weeks before tomato transplanting. In each respective plot, before transplanting, Fenamiphos 400 EC was applied to the soil surface at the rate of 800 ml in 100 litres of water followed by incorporation in the soil using hand hoe to 20 cm depth. Chicken manure was applied at a rate of 1 kg/m^2. A day after irrigating the plots to field capacity, uniform 4-week-old 'Roma cultivar' tomato seedlings were singly transplanted at 0.75 m x 0.6 m inter- and intra-row spacing respectively. Carbaryl (Sevin 85 WP) at the rate of 27 g/13.5 litre of water was spayed for the control of cutworms and locusts. A basal dressing fertilizer, compound D (7 %N, 14 % P_20_5, 7 % K_20) was applied at transplanting at the rate of 300 Nkg/ha (i.e. 360 g/plot). Compound D is the recommended basal fertilizer dressing for tomato. Nematode assayes per 500 cm^3 of sub-soil samples collected at random pattern from the plot was determined and initial (Pi) nematode population established prio to treatments application. Nematode populations were monitored at monthyl intervals up to 120 days after planting when the final (Pf) nematode population was assessed. The rate of reproduction (R) of nematodes as Pf/Pi (final population/initial population and the juvenile/male (J/M) ratio were calculated.

5.2.3 Study area description: Kutsaga Research Station

A field study was conducted during the 2007/2008 cropping season at the Kutsaga Tobacco Research Station located $17^0$52 S; $31^0$02 E, near the Harare International Airport, Zimbabwe at an elevation of 1 500 masl. The soils at the research station are deeply weathered sandy loams derived from granite and classified as Udic Kandiustalf under the USDA system of soil classification (Nyamapfene, 1991). The area lies in NR II receiving rainfall ranging from 800 to 1 000 mm per annum (average 900 mm per annum) with a coefficient of variation of 19 %. The mean annual temperature is 21 ^{0}C

with insignificant frost occurrence in the months of June and July. The rainfall occurs during a single rainy season extending from November to April.

5.2.4 Treatments and experimental design

The experiment was split arranged in a randomized complete block design with continuous tobacco (CT) cultivation of the two tobacco varieties i.e. CT + Kutsaga Mammonth (no resistance to root-knot nematodes) and CT + Kutsaga RK26 (bred for resistance/tolerance) to *Meloidogyne javanica* infestation as the main factors. Each factor was evaluated with two nematicide levels i.e. 1.5 and 3.0 kg a.i./ha of ethylene dibromide (EDB) together with 2 years of rotation with Katambora Rhodes grass. Each treatment was replicated three times. Nematicide was injected into the soil by the aid of an injection gun to depth of 30 cm three weeks before a tobacco crop was planted. Tobacco seedlings were produced in the greenhouse in nematode freesoils before they were transplanted at 1.0 m x 0.45 m inter and intra row spacing, in respective plots. Basal fertilizer NPK (7 % N, 17 % P_20_5 and 7 % K_20) was applied to the soil at rate of 90 kg N/ha, 200 kg P/ha and 90 K/ha respectively. The experiment was under rain-fed conditions but irrigation was applied when necessary. Soil sampling for nematode communities assay was conducted at crop harvesting. Five (5) composite soil samples from 0-15 and 15-30 cm depth were collected in a random pattern from each plot. Five sub-samples were mixed homogeneously to constitute a composite sample from which 500 g of soil was taken, placed in a plastic bag, sealed and then kept under cool conditions. The samples were transported to the laboratory in a cool box and stored at 10^0C for nematode assay. Soil samples were processed within 24 hours after the collection.

5.3 Results

5.3.1 Results at Plant Protection Research Institute (PPRI)

5.3.1.1 Trend in nematode abundance during the course of the experiment

The trend for nematode abundance is presented in (Fig. 5.2). The abundance in the control and Fenamiphos treated plots at 0 - 15cm depth during the 2007/2008 season declined within 30 days after treatment incorporation and started rising. Maximum abundance across the treatments was achieved in the 60-day sampling, and thereafter the abundance declined steadily in both treatments towards the end of the experiment, 120-day. The Fenamiphos treated plots maintained lowest nematode abundances throughout the sampling period. In the 2008/2009 season, the trend for nematode abundance behaved as the previous season (Figure 5.3).

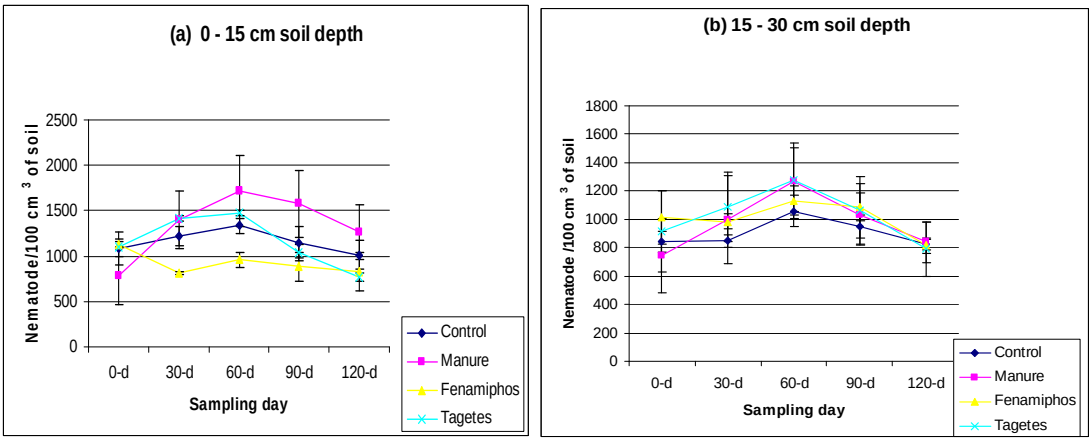
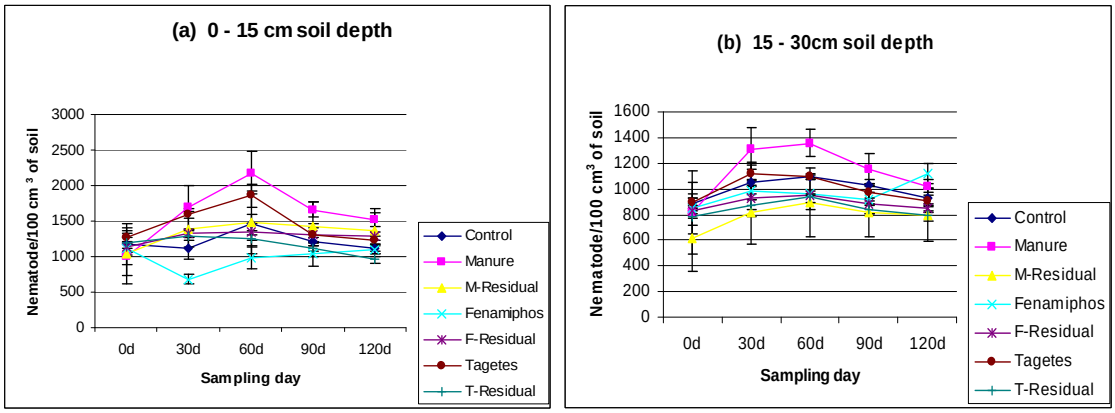


Fig. 5.2 Trend in nematode abundance: field experiment at PPRI (2008). Bars represent standard errors of the mean



M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

Fig. 5.3 Trend in nematode abundance: field experiment at PPRI (2009). Bars represent standard errors of the mean

5.3.1.2 Trophic structure and genera distribution

There was a general trend in reduction in abundance of bacterivores, omnivores and fungivore nematodes after treatment incorporation and an increase in the abundance over time in some treatments. At the final sampling during 2007/2008 season (120-day), abundance of herbivores was significantly ($p<0.05$) higher than other guilds in all treatments. Altogether, significantly ($p<0.05$) higher abundances of fungivores and omnivores were observed in the control and *Tagetes* treatments. *Tagetes* treatment recorded significantly ($p<0.05$) lower abundance of bacterivores at 0 - 15 cm depth (Fig.5.4).

The effects of treatment, time and soil depth on abundance of individual families and genera identified in the study during 2007/2008 season are shown in (Table 5.1 – 5.5). Bacterivorous nematodes identified were grouped into two families, the Rhabditidae and Cephalobidae. The abundances of Rhabditidae and Cephalobidae were significantly ($p<0.05$) higher in manure and Fenamiphos than in the control plots. After the treatment application, the abundance of fungivorous nematodes dropped in all treatments to low and stable levels during the course of the experiments, but begun to peak up in the plots amended with manure during the last sampling.

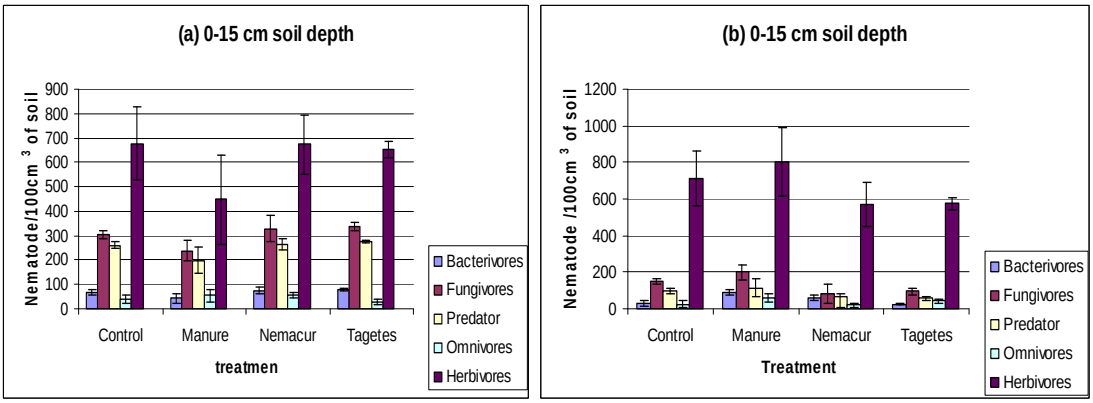


Fig. 5.4 Trophic distribution (a) before treatment application and (b) at the end of the experiment (120-day) at 0 – 15 cm soil depth: field experiment at PPRI (2008). Bars represent standard errors of the mean

Plant parasitic nematodes in the experiment consisted mainly of the genera, *Pratylenchus*, *Xiphinema*, and two species of *Meloidogyne*, *M. javanica*, and *M. incognita*. Occasionally present were *Criconemoides*, *Tylenchorhynchus*, *Hemicycliophora*, *Rotylenchulus*, *Trichodorus* and *Hemicriconemoides*. Neither of the treatments had a consistent effect on the abundance of most dominant plant-parasitic nematodes but abundance of some genera were influenced over time and depth. The genera *Helicotylenchus*, *Scutellonema*, and *Xiphinema* were more abundant at 15 – 30 cm depth while higher abundance of *Pratylenchus* spp. was recovered from 0 – 15 cm depth. Abundance of *Helicotylenchus* spp. and *Scutellonema* spp. was greatest in the control and manure treated plots. The abundance of *Xiphinema* spp. was higher in the control plots at 15 – 30 cm depth. Abundance of *Meloidogyne* spp. increased steadily in all treatments through the sampling time, at the final sampling the abundance of *Meloidogyne incognita* was significantly ($p<0.05$) higher in the control, manure and Fenamiphos plots than in *Tagetes* spp. plot at 15 – 30 cm depth.

Table 5.1 Effect of treatment and depth on abundance of nematode genera at (0-day): field experiment at PPRI (2008)

Genus	Control		Manure		Fenamiphos		Tagetes		Depth Effect
	Depth (cm)								
	0 - 15	15 – 30	0 - 15	15 - 0	0 - 15	15 - 30	0 - 15	15 - 30	
Bacterivores									
Cephalobidae	3.91	3.01	3.39	2.82	3.97	3.03	4.04	2.81	*
Rhabditidae	2.89	1.72	2.48	0.53	3.07	1.57	3.11	0.73	*
Fungivores									
Aphelenchoides	1.10	0	0.99	0	0	0	1.02	0	*
Tylenchus	1.92	1.92**b**	1.63	0**b**	3.21	2.95**a**	2.89	2.96**ab**	
Aphelenchus	3.32	2.58	2.83	2.72	3.37	2.39	3.76	1.12	
Filenchus	0.88	1.73	2.27	0.7	1.05	0.91	3.60	1.58	
Fungi Dorylaimidae	5.31	5.04	4.85	4.8	5.19	5.08	1.02	5.16	
Predators									
Mononchidae	0.95	2.45	1.80	0	2.11	1.08	5.12	4.00	
Predatory Dorylaimidae	3.66	4.03	3.46	3.68	3.82	3.78	0.80	3.48	
Omnivores									
Omnivore Dorylaimidae	3.62	3.75	3.69	3.45	3.97	4.24	3.37	5.15	
Herbivores									
Helicotylenchus	5.32	4.96	4.90	5.05	5.18	5.17	540	5’19	
Scutellonema	5.12	5.11	4.43	4.95	5.20	5.36	5.02	5.00	
Criconemoides	0	1.07	1.93	1.25	2.12	0	0	0.65	
Pratylenchus	5.37	4.79	4.88	4.51	5.20	5.09	5.30	0.85	
Xiphinema	0	1.07	0	1.91	1.89	1.95	0.80	0	
Tylenchorhynchus	0	0.79	0	0	0	0	0	0	
Rotylenchulus	1.05	1.73	0.86	0.91	0	1.95	1.60	1.55	
Hemicycliophora	0.74	0	0.73	0	2.01	0	0.80	2.10	
M. javanica	3.81	3.23	2.83	3.25	3.65	3.18	3.67	0.65	
M. incognita	3.10**a**	2.45	1.22**b**	1.44	3.39**a**	2.25	2.87**a**	0	*
Trichodorus	0	0	0	0	1.88	0.82	0	0	
Hemicriconemoides	0	1.07	0.81	0	2.12	0.70	0	0	

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 5.2 Effect of treatment and depth on abundance of nematode genera at (30-day): field experiment at PPRI (2008)

Genus	Control		Manure		Fenamiphos		Tagetes		Depth Effect
	Depth (cm)								
	0 - 15	15 – 30	0 - 15	15 - 30	0 - 15	15 - 30	0 - 15	15 - 30	
Bacterivores									
Cephalobidae	3.01	2.07	4.02	3.24	4.19	3.46	3.91	2.98	*
Rhabditidae	4.24**b**	3.82	5.66**a**	4.84	5.47**a**	5.13	5.81**a**	5.24	*
Fungivores									
Aphelenchoides	0.90	0	1.69	0	0.73	0	0	0	*
Tylenchus	3.27	1.73	4.30	3.49	2.02	2.46	4.31	3.86	
Aphelenchus	3.46	2.68**ab**	4.76	3.64**a**	2.02	0**b**	3.97	2.23	*
Filenchus	2.52	3.37	4.42	3.79	2.38	2.97	4.36	3.41	
Fungi Dorylaimidae	5.16**a**	4.53	4.96**ab**	4.60	4.28**b**	4.47	4.88**ab**	4.72	
Predators									
Mononchidae	1.73	2.07	1.36	2.16	0	0	0	0.96	
Predatory Dorylaimidae	4.54**ab**	4.09	4.82**a**	4.03	4.08**b**	4.48	4.77**a**	4.86	
Omnivores									
Omnivore Dorylaimidae	3.72	3.70	3.84	4.07	3.63	4.14	4.30	4.14	
Herbivores									
Helicotylenchus	5.37**a**	5,18	4.75**b**	5.25	4.62**b**	4.92	5.16**ab**	5.23	
Scutellonema	4.93	5.11	4.68	5.07	4.37	4.88	4.31	4.91	*
Criconemoides	0	1.51	1.00	0	0	0	0	0	
Pratylenchus	5.50**a**	4.44	4.86**b**	3.72	4.27**c**	3.95	4.95**b**	4.04	*
Xiphinema	0	0	0	0	0	0	0.90	1.83	
Tylenchorhynchus	0	0	0	0	0	0	0	0	
Rotylenchulus	0	0	0	0	0	0	0	0	
Hemicycliophora	0	0.99	0	0	0	0	0	0	
M. javanica	4.22**a**	3.40	3.13**b**	1.44	3.11**b**	2.97	2.93**b**	3.32	
M. incognita	2.40	3.31	2.30	1.05	2.43	2.59	4.25	2.23	
Trichodorus	0	0	0	0	0	0.71	0	0	
Hemicriconemoides	0	0.95	0	0	0	0	0	0	

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 5.3 Effect of treatment and depth on abundance of nematode genera at (60-day): field experiment at PPRI (2008)

Genus	Control		Manure		Fenamiphos		Tagetes		Depth Effect
	Depth (cm)								
	0 - 15	15 – 30	0 - 15	15 - 30	0 - 15	15 - 30	0 - 15	15 - 30	
Bacterivores									
Cephalobidae	1.99	1.64**b**	4.24	3.51**a**	3.97	3.53**a**	3.91	4.15**a**	
Rhabditidae	3.66**b**	3.36**b**	5.00**ab**	4.71**a**	5.14**ab**	4.90**a**	5.82**a**	5.46**a**	
Fungivores									
Aphelenchoides	0	0	0.13	0	0	0	0	0	
Tylenchus	2.21	1.21	4.33	3.95	2.92	2.26	4.31	4.35	
Aphelenchus	3.65**ab**	1.80	4.13**a**	3.51	2.90	1.23	3.79**ab**	3.42	*
Filenchus	3.67	1.86**b**	4.04	4.36**a**	3.18	3.18**ab**	4.36	4.31**ab**	
Fungi Dorylaimidae	3.60	3.87	4.75	4.99	4.53	4.30	4.88	4.68	
Predators									
Mononchidae	4.33	3.11	2.19	2.04	0	1.23	0	2.05	
Predatory Dorylaimidae	4.50	4.13	4.77	4.78	4.27	4.48	4.77	4.60	
Omnivores									
Omnivore Dorylaimidae	3.90	3.58	4.00	4.33	3.82	4.01	4.30	3.94	
Herbivores									
Helicotylenchus	5.57	5.67	5.37	5.40	5.14	5.68	5.16	5.33	
Scutellonema	5.44**a**	5.61	5.58**a**	5.24	4.46**b**	5.36	4.31**ab**	4.76	
Criconemoides	1.09	2.11	0	1.87	0	0	0	1.28	*
Pratylenchus	5.23	4.45	4.85	3.51	4.39	3.70	4.95	4.80	*
Xiphinema	1.07	1.93	0	2.05	0	1.23	0.90	1.15	
Tylenchorhynchus	0	0	0	0	0	0	0	0	
Rotylenchulus	0	2.02	0	0	0	0	0	0	
Hemicycliophora	3.8**a**	1.89	1.11**ab**	0	0**b**	0	0**b**	0	
M. javanica	4.76	4.11	4.13	3.03	4.07	3.82	2.93	4.43	*
M. incognita	3.88	3.46	4.66	3.67	4.00	3.83	4.25	4.69	*
Trichodorus	0	0	0	0	0.75	0	0	0	
Hemicriconemoides	1.27	0	0	0	0	0	0	0	

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 5.4 Effect of tr eatment and depth on abundance of nematode genera at (90-day): field experiment at PPRI (2008)

Genus	Control		Manure		Fenamiphos		Tagetes		Depth Effect
	Depth (cm)								
	0 - 15	15 – 30	0 - 15	15 - 30	0 - 15	15 - 30	0 - 15	15 - 30	
Bacterivores									
Cephalobidae	1.60	2.36	3.80	3.19	3.58	3.32	3.09	3.84	
Rhabditidae	3.38	3.02**b**	4.20	3.84**ab**	4.20	4.16**a**	4.12	3.29**ab**	
Fungivores									
Aphelenchoides	0**b**	0.74	3.01**a**	1.94	0**b**	0	0**b**	0	
Tylenchus	2.15	0	3.58	2.63**a**	2.27	1.08**ab**	3.22	2.63**a**	*
Aphelenchus	3.52**ab**	3.24**b**	4.16**a**	3.86	2.69**b**	3.30	3.66**ab**	3.68	
Filenchus	1.82	1.77	2.68	3.19	2.27	1.94	3.31	2.22	
Fungi Dorylaimidae	4.50	3.76	4.49	4.39	4.43	4.37	4.28	4.42	
Predators									
Mononchidae	2.95	0.74	2.33	3.78	0.89	2.95	2.87	2.15	
Predatory Dorylaimidae	4.52	4.31	4.89	4.44	4.46	4.56	4.47	4.71	
Omnivores									
Omnivore Dorylaimidae	3.78	3.72	4.12	4.20	4.01	3.84	3.81	4.18	
Herbivores									
Helicotylenchus	5.53	5.75	5.84	5.39	5.15	5.74	5.53**b**	5.62	
Scutellonema	5.47	5.39	5.21	5.02	4.62**b**	5.21	4.88	5.03	
Criconemoides	1.13**ab**	0	3.23**a**	2.97**a**	0	0**b**	0	0**b**	
Pratylenchus	4.41	3.91**b**	4.60	2.84**b**	4.13	4.05**a**	4.35	4.30**a**	*
Xiphinema	1.02	0.91	0.85	2.84	0	1.22	1.00	0.97	
Tylenchorhynchus	0	0.95	0	0	0	0	0	0	
Rotylenchulus	0	0	0	0.85	0	0	0	0	
Hemicycliophora	0	0	0	0	0	0	0	0	
M. javanica	4.76	4.06	4.84	4.17	4.29	4.29	4.38	3.94	*
M. incognita	4.11	3.69	4.81	3.93	4.04	3.60	4.22	3.55	*
Trichodorus	0	0	0	0	0	0	0	0	
Hemicriconemoides	0	0	0	0	0	0	0	0	

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 5.5 Effect of treatment and depth on abundance of nematode genera at (120-day): field experiment at PPRI (2008)

Genus	Control		Manure		Fenamiphos		Tagetes		Depth Effect
	Depth (cm)								
	0 - 15	15 – 30	0 - 15	15 - 30	0 - 15	15 - 30	0 - 15	15 - 30	
Bacterivores									
Cephalobidae	2.75	3.31	3.78	2.69	3.58	3.97	5.52	2.18	
Rhabditidae	2.06	2.03	3.29	3.11	3.10	2.79	2.60	2.37	
Fungivores									
Aphelenchoides	0.99	0.97	2.32	2.46	0.69	0.99	0	0	
Tylenchus	2.09	0.75	1.59	1.66	1.54	0	2.39	2.49	
Aphelenchus	2.85	3.31	3.88	2.81	2.19	3.45	3.07	3.24	
Filenchus	0.78**ab**	0.72	3.47**a**	1.67	0**b**	0	1.82**ab**	0.83	
Fungi Dorylaimidae	4.35	3.74	4.45	3.88	4.09	4.21	3.79	3.86	*
Predators									
Mononchidae	2.00	2.88	3.44	3.40	0	3.21	1.82	2.07	
Predatory Dorylaimidae	4.44	3.66	4.16	4.02	4.11	4.13	3.96	4.23	
Omnivores									
Omnivore Dorylaimidae	3.06	3.09	3.92	3.86	3.71	4.03	2.82	3.78	
Herbivores									
Helicotylenchus	5.54	5.48	5.55	5.52	5.14	5.29	5.26	5.42	
Scutellonema	5.06	4.97	5.29	5.32	4.77	4.83	4.79	4.89	
Criconemoides	0.78	0.93	2.32	1.88	0	0	0.95	0	*
Pratylenchus	4.18	3.94	3.85	2.15	4.51	3.82	4.48	3.81	
Xiphinema	0	2.03	0	1.66	0	0.96	1.69	1.19	
Tylenchorhynchus	0	0	0	0	0	0	0	0	
Rotylenchulus	0	0.97	0	0	0	0	0	0	

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

The reproduction factors i.e. final population to initial population (R=Pf/Pi) ratio is an indication of nematode multiplication. In treatments with manure, Fenamiphos and *Tagetes* there were significantly higher ($p<0.05$) reproduction factors for Cephalobidae at 0 - 15 cm depth during 2007/2008 (Table 5.6). Significantly ($p<0.05$) higher reproduction factors for *Aphelenchus* spp. were observed in the control, manure and *Tagetes* spp. plots. The genera *Aphelenchoides* and *Filenchus* had higher reproduction factors in manure plots. Treatments had no significant effect on the other guilds. Treatments did not affect the reproduction factor of most families and genera at 15 - 30 cm depth (Table 5.7).

However, the reproduction factor for *Pratylenchus* spp. was significantly ($p<0.05$) low in the control manure plots.

Table 5.6 Reproduction factors for nematode genera at 0 - 15 cm soil depth as influenced by treatments: field experiment at PPRI (2008)

Genus/Trophic group	Control	Manure	Fenamiphos	Tagetes
Bacterivores				
Cephalobidae	2.65**b**	3.84**a**	3.85**a**	3.54**a**
Rhabditidae	3.24	4.12	4.19	4.22
Fungivores				
Aphelenchoides	0.59**b**	2.26**a**	0.70**b**	0.57**b**
Tylenchus	2.32	3.08	2.39	3.60
Aphelenchus	3.54**a**	3.95**a**	2.64**b**	3.50**a**
Filenchus	1.92**ab**	3.37**a**	1.76**b**	2.96**ab**
Fungi	4.72	4.69	4.49	4.54
Dorylaimidae				
Predators				
Mononchidae	1.95**ab**	2.22**a**	0.60**b**	1.51**ab**
Predatory Dorylaimidae	4.33	4.42	4.15	4.36
Omnivores				
Omnivore Dorylaimidae	3.61	3.91	3.82	3.64
Herbivores				
Helicotylenchus	5.46**a**	5.28**ab**	5.04**b**	5.33**ab**
Scutellonema	5.20**a**	5.04**ab**	4.68**b**	4.79**ab**
Criconemoides	0.59	1.69	0.42	0.44
Pratylenchus	4.93	4.61	4.49	4.77
Xiphinema	0.41	0.17	0.37	1.11
Tylenchorhynchus	0	0	0	0
Rotylenchulus	0.21	0.17	0	0.32
Hemicycliophora	0.76	0.37	0.40	0.16
M. javanica	4.51	3.97	4.01	3.94
M. incognita	3.49	4.10	4.16	4.67
Trichodorus	0	0	0.70	0
Hemicriconemoides	0.25	0.16	0.42	0

NB: Row means followed by the same letter were not significantly different ($p=0.05$) according to the Tukey-Kramer HSD test

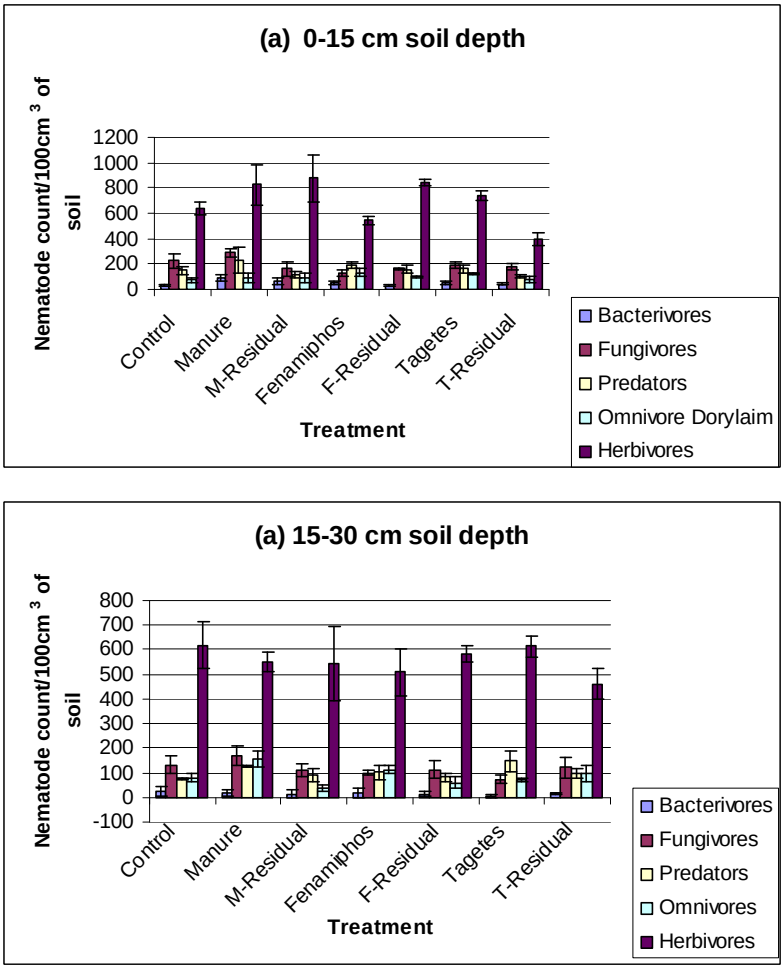
Table 5.7 Reproduction factors for nematode genera at 15 - 30 cm soil depth as influenced by treatments: field experiment at PPRI (2008)

Genus/Trophic group	Control	Manure	Fenamiphos	Tagetes
Bacterivores				
Cephalobidae	2.48**b**	3.08**ab**	3.56**a**	3.08**ab**
Rhabditidae	2.78	3.40	3.71	3.25
Fungivores				
Aphelenchoides	0.55	1.23	0.59	0.18
Tylenchus	0.77**b**	2.34**a**	1.75**ab**	2.87**a**
Aphelenchus	2.73	3.31	2.07	2.66
Filenchus	1.88	2.74	1.79	2.27
Fungi	4.18	4.53	4.48	4.51
Dorylaimidae				
Predators				
Mononchidae	2.24	2.27	1.69	1.90
Predatory				
Dorylaimidae	4.04	4.18	4.28	4.48
Omnivores				
Omnivore				
Dorylaimidae	3.56**b**	3.98**ab**	4.05**a**	3.96**ab**
Herbivores				
Helicotylenchus	5.40	5.32	5.35	5.42
Scutellonema	5.24	5.11	5.12	5.06
Criconemoides	1.12**ab**	1.58**a**	0**c**	0.13**bc**
Pratylenchus	4.30**a**	3.34**b**	4.12**a**	4.26**a**
Xiphinema	1.19	1.69	1.07	0.96
Tylenchorhynchus	0.16	0	0	0
Rotylenchulus	0.94	0.35	0.39	0
Hemicycliophora	1.09**a**	0**b**	0**b**	0.31**ab**
M. javanica	3.84	3.11	3.72	3.45
M. incognita	3.05	2.68	3.13	2.69
Trichodorus	0	0	0.52	0
Hemicriconemoides	0.40	0	0.14	0

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

During sampling prio to treatment application in 2008/2009 season, found significantly ($p<0.05$) higher abundance of herbivores and fungivores in all the treatments at both soil depths. The abundance of fungivores decreased after treatment application and increased later during the course of the experiment. However, the abundance of herbivores at 120-day sampling was significantly ($p<0.05$) higher than other guilds in all treatments. Significantly ($p<0.05$) higher abundance of fungivores and predators were observed in

the manure and *Tagetes* plots respectively. There was no significant difference on the guilds among the treatments (Fig. 5.5).



M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

Fig. 5.5 Trophic distribution (a) at 0 – 15 cm and (b) at 15 – 30 cm soil depth (120-day): field experiment at PPRI (2009). Bars represent standard errors of the mean

The reproduction factors of individual families and genera identified in the study at 0 – 15 cm and 15 – 30 cm depth are shown in treatments had no effect on the reproduction factors among the nematode families and genera (Table 5.8 and Table 5.9).

5.3.1.3 Nematode community and food web indices

During the 2007/2008 season, treatment had significant effect on the maturity index (MI) values. During the final sampling (120-day), significantly ($p<0.05$) higher and lower MI were observed in the control and Fenamiphos plots at 0 – 15 cm depth, respectively (Fig. 5.6). The PPI were not significantly different among the treatments. Significantly ($p<0.05$) high H' values were observed in the control followed by the *Tagetes* spp. plots. Significantly ($p<0.05$) lower H' values were in Fenamiphos plots. Nematode genera evenness (J') was significantly ($p<0.05$) higher in manure plots. There were no significant effects of treatments on the MI, PPI and J' values at the 15 – 30 cm depth. However, significantly ($p<0.05$) lower H' values were observed in the Fenamiphos plots and significantly ($p<0.05$) higher J' values in the control plots, respectively.

Table 5.8 Reproduction factor for nematode genera at 0 – 15 cm depth as influenced by treatments: field experiment at PPRI (2009)

Genus	Control	Manure	M-Residual	Fenamihos	F-Residual	Tagetes	T-Residual
Bacterivores							
Cephalobidae	2.37	3.16	2.64	2.19	3.01	3.34	3.39
Rhabditidae	3.27	3.56	4.04	3.87	3.39	3.82	3.03
Fungivores							
Aphelenchoides	0	0	0	0	0.18	0	0.56
Tylenchus	1.41**ab**	3.10**a**	1.31**ab**	1.23**b**	1.76**ab**	2.33**ab**	1.95**ab**
Aphelenchus	2.78**b**	4.44**a**	3.46**ab**	2.88**b**	2.75**b**	3.54**ab**	3.08**b**
Filenchus	2.01	2.94	1.60	2.29	2.65	2.65	1.80
Fungi Dorylaimidae	5.01**a**	5.11**a**	4.97**ab**	4.34**c**	4.52**bc**	5.02**a**	5.06**a**
Predators							
Mononchidae	3.04**a**	3.30**a**	2.54a**b**	1.34**b**	2.65**ab**	2.98**a**	2.57**ab**
Predatory Dorylaimidae	4.77	4.73	4.82	4.71	4.67	4.59	4.59
Omnivores							
Omnivore Dorylaimidae	4.52	4.48	3.39	4.47	4.69	4.49	4.52
Herbivores							
Helicotylenchus	5.37**ab**	5.61**a**	5.49**ab**	5.26**ab**	5.58**a**	5.55**a**	5.16**b**
Scutellonema	4.79	5.13	4.99	4.64	5.09	5.15	4.71
Criconemoides	2.01	1.59	1.65	0.98	2.32	2.15	2.42
Pratylenchus	4.08	3.82	3.59	3.51	3.59	3.67	4.06
Xiphinema	2.12	1.69	1.92	1.72	1.77	2.09	2.22
Tylenchorhynchus	2.05	2.33	1.73	1.03	2.25	1.47	2.11
Rotylenchulus	0	0.31	0.15	0	0	0.22	0.16
Hemicycliophora	1.32	1.07	0.74	0.63	0.91	0.57	0.61
M. javanica	4.91**ab**	5.07**ab**	8.75**ab**	2.19**b**	9.39**a**	4.63**ab**	4.13**ab**
M. incognita	6.82	2.76	2.88	2.95	2.69	3.28	3.54
Trichodorus	0	0	0	0	1.48	0	0
Hemicriconemoides	0	0	0.20	0	0.15	0	0

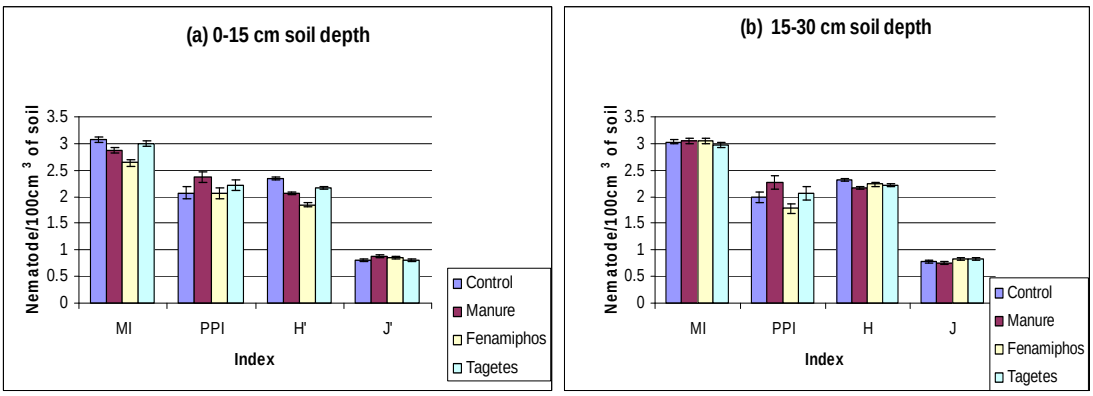
NB: Levels not connected by same letter are significantly different

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

Table 5.9 Reproduction factor for nematode genera at 15 – 30 cm depth as influenced by treatments: field experiment at PPRI (2009)

Genus	Control	Manure	M-Residual	Fenamiphos	F-Residual	Tagetes	T-Residual
Bacterivores							
Cephalobidae	1.57	1.55	1.60	1.77	2.21	1.79	2.39
Rhabditidae	2.14	2.10	2.81	3.22	2.31	2.62	1.82
Fungivores							
Aphelenchoides	0.20	0	0	0	0	0	0
Tylenchus	0.36**b**	1.81**a**	0.43**b**	1.37**ab**	1.00**ab**	0.52**ab**	1.15**ab**
Aphelenchus	3.12	2.78	2.64	2.07	3.19	2.73	2.94
Filenchus	0.82	1.53	0.49	1.21	0.72	1.17	0.35
Fungi Dorylaimidae	4.68**ab**	5.11**a**	4.59**b**	4.56**b**	4.38**b**	4.49**b**	4.28**b**
Predators							
Mononchidae	3.35**ab**	3.72**a**	2.80**abc**	1.88**c**	2.35**bc**	3.14**ab**	2.99**ab**
Predatory Dorylaimidae	4.10	4.35	3.92	4.27	4.03	4.15	4.12
Omnivores							
Omnivore Dorylaimidae	3.82**ab**	4.44**a**	3.61**b**	4.43**ab**	3.94**ab**	4.16**ab**	4.15**ab**
Herbivores							
Helicotylenchus	5.74**a**	5.56**ab**	5.29**b**	5.34**ab**	5.57**ab**	5.60**ab**	5.30**b**
Scutellonema	5.25**ab**	5.22**ab**	4.93**b**	5.01**ab**	5.21**ab**	5.42**a**	5.17**ab**
Criconemoides	2.02	2.52	1.85	1.08	1.91	2.56	2.23
Pratylenchus	2.75**ab**	1.47**b**	2.45**ab**	3.16**a**	2.47**ab**	2.74**ab**	2.84**ab**
Xiphinema	2.86	2.23	2.36	2.49	2.12	2.63	2.32
Tylenchorhynchus	2.65	2.12	2.32	2.20	2.31	2.49	2.80
Rotylenchulus	0	0.15	0	0.35	0.18	0.14	0.16
Hemicycliophora	1.13	1.79	1.41	1.53	1.35	1.81	1.86
M. javanica	3.46	2.79	2.75	2.82	3.39	2.86	2.78
M. incognita	1.47	1.94	1.54	1.44	1.57	0.60	1.56
Trichodorus	0	0	0	1.33	0	0.15	0

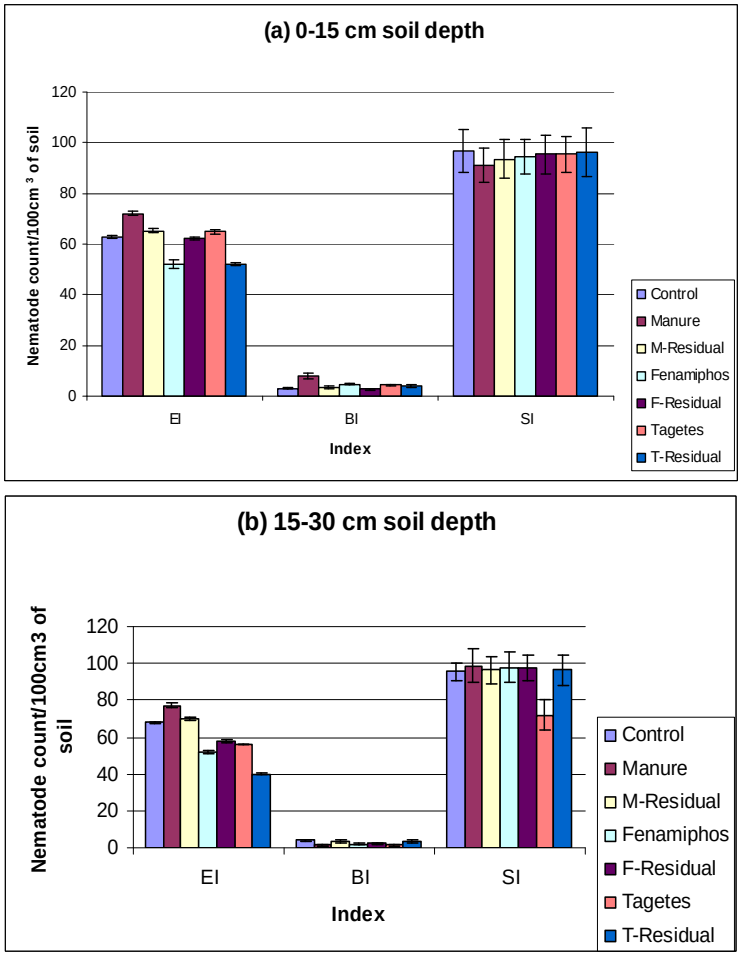
NB: Levels not connected by same letter are significantly different
M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual



MI = Maturity index, PPI = Plant parasitic index H' = Shannon diversity index, J' = Evenness index

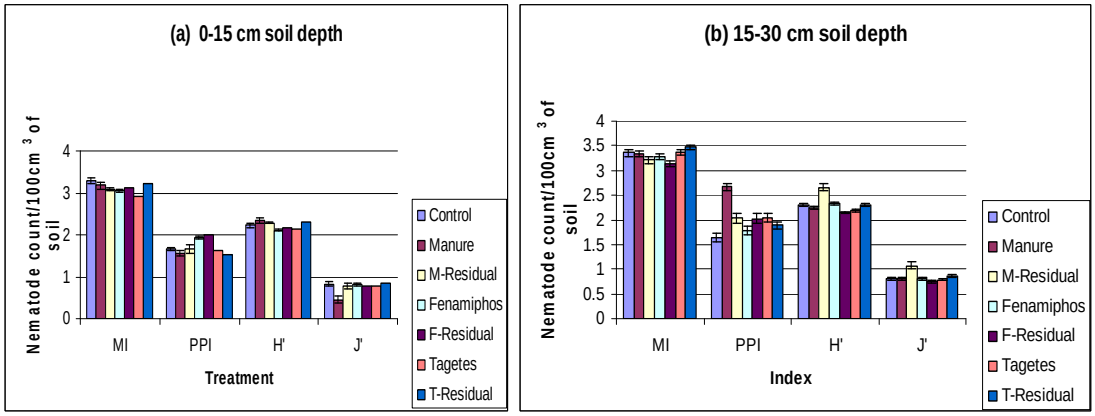
Fig. 5.6 Community structural indices at 0 - 15 and 15 - 30 cm soil depth at the end of experiment (120-day): field experiment at PPRI (2008). Bars represent standard errors of the mean

Manure treatment had significant high EI values at both depth, significantly ($p<0.05$) higher BI was recorded in the manure plots at 0 – 15 cm depth and significantly lower at manure at 15 – 30 cm depth (Fig. 5.7). Generally, the EI values were greater in plots amended with manure. Lower values were recorded in the Fenamiphos plots. At 15 – 30 cm depth, significantly ($p<0.05$) higher and lower EI were observed in the manure and Fenamiphos treatment respectively. Manure plots had significantly ($p<0.05$) lower BI values, whereas treatments had no significant effect on the SI values.



EI = Enrichment index, SI = Structural index and BI = Basal index, M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

Fig. 5.7 Food web indices at 0 – 15 and 15 – 30 cm soil depth at the end of experiment: (120-day): fieldexperiment at PPRI (2009). Bars represent standard errors of the mean

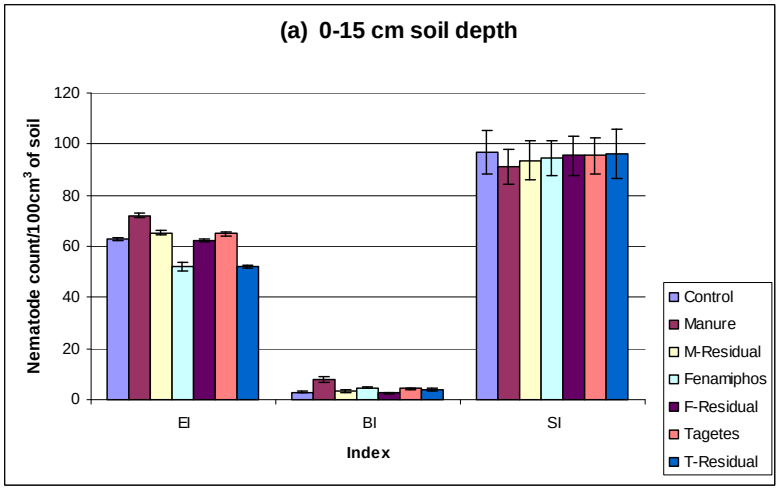


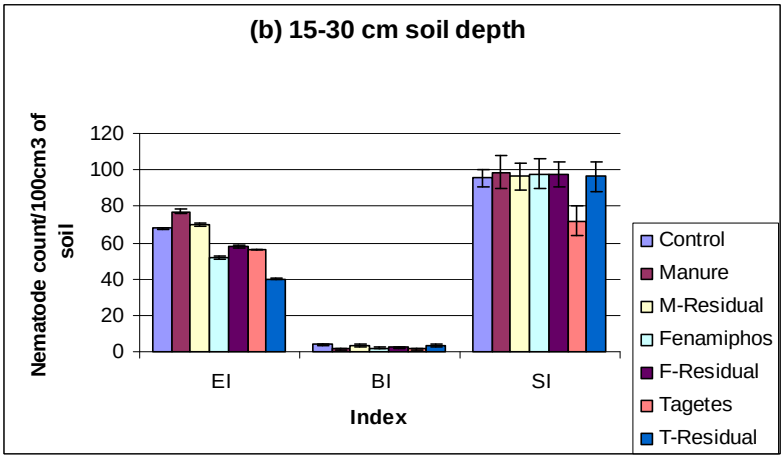
MI = Maturity index, PPI = Plant parasitic index H' = Shannon diversity index, J' = Evenness index, M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

Fig. 5.8 Community structural indices at 0 – 15 and 15 – 30 cm soil depth at the end of experiment (120-day): field experiment at PPRI (2009). Bars represent standard errors of the mean

Community structural indices at 0 – 15 and 15 – 30 cm depth during 2008/2009 season are shown in (Fig. 5.8). Plots with residual effect of *Tagetes* spp. had significant ($p<0.05$) higher MI values at both depths. PPI values were significantly ($p<0.05$) higher in the Fenamiphos residual plots, whereas significantly ($p<0.05$) lower J' values were recorded in the manure plots. At 15 – 30 cm depth, significantly ($p<0.05$) higher MI and PPI values were observed in the *Tagetes* residual and manure plots respectively. Plots with residual effect of manure recorded significantly ($p<0.05$) higher diversity (H') and evenness (J') of nematode genera.

The EI and BI values at 0 – 15 cm depth were significantly ($p<0.05$) higher in manure plots (Fig. 5.9). There were no significant differences among treatments on the SI values. At 15 – 30 cm depth, manure plots had significantly ($p<0.05$) higher EI values whereas significantly ($p<0.05$) lower SI values were observed in the *Tagetes* spp. plots. Treatments had no significant effect of BI values. The nematode channel ratio NCR values were lower in both treatments in both cropping seasons (Table 5.10).





M-Residual = Manure Residual; F-Residual = Fenamiphos Residual;
T-Residual = Tagetes Residual; EI = Enrichment index; BI = Basal index SI' = Structural

Fig. 5.9 Food web indices at 0 – 15 and 15 – 30 cm soil depth at the end of experiment (120-day): field experiment at PPRI (2009). Bars represent standard errors of the mean

Table 5.10 Influence of treatments on nematode channel ratio NCR: field experiment at PPRI (2008 and 2009)

Year	Depth (cm)	Control	Manure	M-Residual	Fenamiphos	F-Residual	*Tagetes*	T-Residual
2008	0 - 15	0.24	0.45	-	0.47	-	0.29	-
	15 - 30	0.34	0.28	-	0.39	-	0.23	-
2009	0 - 15	0.11	0.16	0.19	0.37	0.27	0.19	0.27
	15 - 30	0.10	0.04	0.21	0.24	0.17	0.21	0.35

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

5.3.1.4 Influence of treatment on Meloidogyne spp. sex ratio

The mean male-juvenile ratio of *Meloidogyne* spp. was significantly affected by treatments at the end of the experiments (120-day). During the 2007/2008 season, significantly ($p<0.05$) greater ratios of males were observed in the Fenamiphos plots at 0 – 15 cm (Table 5.11 (a) and 15 – 30 cm 5.11 (b)).

Table 5.11(a) Mean male-juvenile ratio at 120-day as influenced by treatments at the 0 – 15 cm soil depth: field experiment at PPRI (2008)

Genus	Control	Manure	Fenamiphos	Tagetes
M. javanica	0.16**b**	0.04**b**	1.61**a**	0.09**a**
M. incognita	0.12**b**	0**b**	1.12**a**	0.14**a**

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual;
T-Residual = Tagetes Residual

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 5.11(b) Mean male-juvenile ratio at 120-day as influenced by treatments at the 15 – 30 cm soil depth: field experiment at PPRI (2008)

Species	Control	Manure	Fenamiphos	Tagetes
M. javanica	0.12**b**	0.21**b**	1.10**a**	0.07**b**
M. incognita	0.05 **b**	0.05 **b**	0.67 **a**	0.07 **b**

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual;
T-Residual = Tagetes Residual

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

During the 2008/2009 season, significantly ($p<0.05$) higher abundance of juveniles were recovered from the control and residual Fenamiphos at 0 – 15 cm soil depth. Fenamiphos treatment at both depths recorded significantly ($p<0.05$) higher abundance of *M. javanica* males in the Fenamiphos treated plots (Table 5.12 (a) and 5.12 (b)).

Table 5.12(a) Mean male-juvenile ratio at 120-day as influenced by treatments at the 0 – 15 cm soil depth: field experiment (2009)

Species	Control	Manure	M-Residual	Fenamiphos	F-Residual	Tagetes	T-Residual
M. javanica	0.86**ab**	0.46**b**	0.57**ab**	1.36**a**	0.62**ab**	0.45**b**	0.65**ab**
M. incognita	0.11	0.21	0.29	0.41	0.06	0.15	0.31

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual
NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 5.12(b) Mean male-juvenile ratio at 120-day as influenced by treatments at the 15 – 30 cm soil depth: field experiment (2009)

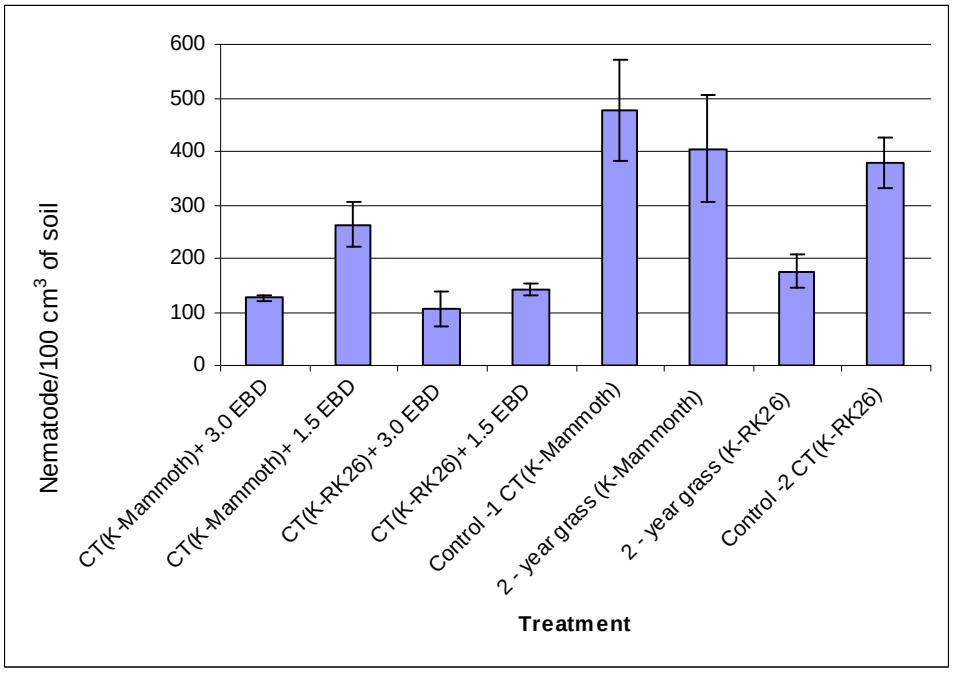
Species	Control	Manure	M-Residual	Fenamiphos	F-Residual	Tagetes	T-Residual
M. javanica	0.71**ab**	0.23**b**	0.23**ab**	1.16**a**	0.41**ab**	0.48**ab**	0.53**ab**
M. incognita	0.11	0.11	0.29	0.35	0	0	0.38

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual
NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

5.3.2 Result at Kutsaga Research Station

5.3.2.1 Impact of treatment on nematode abundance and trophic distribution

Abundance of nematodes varied significantly among treatments (Fig. 5.10). Both control plots under K-Mammonth and K-RK26 together with K-Mammonth after 2-year of Katambora Rhodes grass had significantly higher nematode abundance than the rest of treatments. Lowest nematode abundance was observed on K-Mammonth and K-RK26 both at the nematicide rate of 3.0 kg a.i./ha.

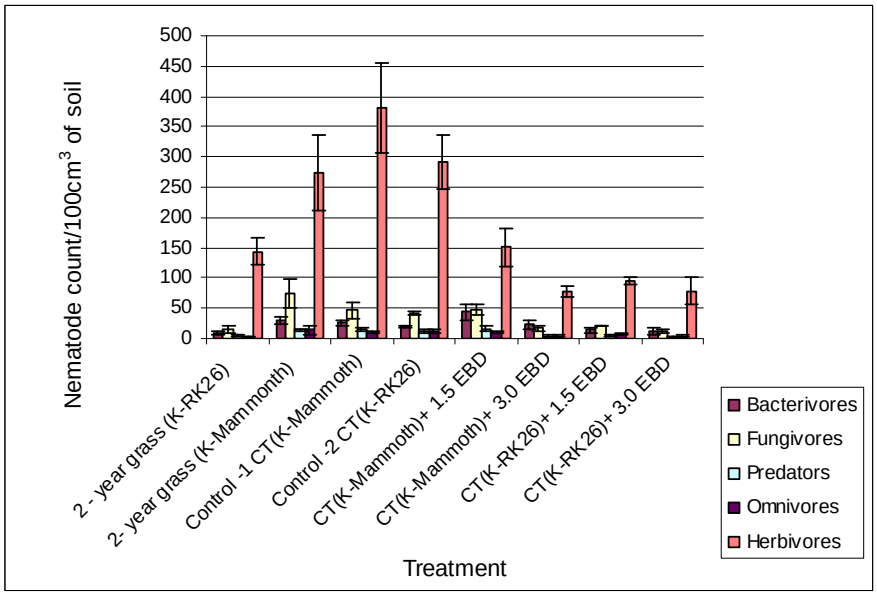


CT = Continuous Tobacco

Fig. 5.10 Influence of treatments on nematode abundance: tobacco experiment (2007). Bars represent standard errors of the mean

Bacterivores were significantly abundant in the K-Mammonth crop treated with EDB at 1.5 kg a.i./ha followed by the plots with K-Mammonth variety after 2-year rotation of Katambora Rhodes grass (Fig. 5.11). The higher abundance of fungivores was observed in the K-Mammonth variety after 2-year rotation with Katambora Rhodes grass and lowest abundance was observed in K-RK26 treated with EDB at 3.0 kg a.i./ha. The

populations of predators and omnivores were observed to be lower than other trophic groups across both treatments. The lowest abundance of fungivores was recovered in the 2-year rotation of K-RK26 variety with Katambora Rhodes grass and in the K-RK26 treated with EDB at 3.0 kg a.i./ha plots. Plant parasitic nematodes that were dominant in the both treatments, recorded significantly ($p<0.05$) higher abundance in the control plots of both the two tobacco varieties and in the K-Mammonth variety after 2-year rotation with Katambora Rhodes grass plots.



CT = Continuous Tobacco

Fig. 5.11 Influence of treatments on trophic group abundance: tobacco experiment (2007). Bars represent standard errors of the mean

5.3.2.2 Impact of treatment on nematode structure and distribution

The abundance of free-living nematodes (bacterivores, fungivores, predators and omnivores) were not affected by treatments. However, the abundance of *Rotylenchulus* spp. was significantly ($p<0.05$) high in the K-Mammonth production after a 2-year rotation with Katambora Rhodes grass plots. Some plant parasitic nematodes (herbivores) were significantly influenced by the treatments. The abundance of *Tylenchorhynchus* spp. was significantly ($p<0.05$) higher in the control plots of the K-Mammonth variety.

Table 5.13 Effect of variety, rotation and nematicide rates on nematode communities composition: tobacco experiment (2007)

Trophic group/Genus	2 yearr grass (K-RK26)	2 year grass (K-mammonth)	CT[a] – Kutsaga mammonth			CT[a] – Kutsaga RK26		
			1.5 EDB	3.0 EDB	Control	1.5 EDB	3.0 EDB	Control
Bacterivores								
Cephalobidae	1.87**b**	2.95**ab**	3.37**a**	2.78**ab**	2.80**ab**	2.42**ab**	2.16**ab**	2.68**ab**
Rhabditidae	1.16	2.42	2.41	1.86	2.33	1.30	1.16	1.50
Fungivores								
Aphelenchoides	1.80b**c**	3.13**a**	2.67**ab**	1.80**bc**	2.67**ab**	2.02**bc**	1.67**c**	2.68**ab**
Tylenchus	0.56**bc**	2.42**ab**	2.73**a**	1.28**abc**	1.28**abc**	0.28**c**	0.22**c**	2.47**ab**
Aphelenchus	0.28	1.59	0	0	0.99	0.43	0	0
Filenchus	0	0	0	0	0	0	0	0
Fungi Dorylaimidae	2.00**b**	3.33**a**	2.94**ab**	2.14**ab**	3.07**ab**	2.65**ab**	1.94**b**	2.89**ab**
Predators								
Mononchidae	0	0	0	0	0	0	0	0
Predatory Dorylaimidae	1.72**bc**	2.66**a**	2.78**a**	1.64**c**	2.71**a**	1.80**bc**	1.28**c**	2.47**ab**
Omnivore								
Omnivore Dorylaimidae	1.60**ab**	2.58**a**	2.38**ab**	1.40**b**	2.33**ab**	2.02**ab**	1.61**ab**	4.59**a**
Herbivores								
Helicotylenchus	3.34**bc**	4.26**ab**	3.43**abc**	2.94**c**	4.19**ab**	3.25**c**	3.08**c**	4.25**a**
Scutellonema	3.78**ab**	3.89**a**	3.87**a**	3.45**b**	4.44**a**	3.44**b**	3.33**b**	4.41**a**
Criconemoides	1.60**b**	2.70**c**	0**c**	0**c**	0**c**	0**c**	0**b**	0**c**
Pratylenchus	3.52**ab**	4.28**a**	3.65**ab**	3.04**b**	4.36**a**	3.15**b**	3.13**b**	4.34**a**
Xiphinema	1.30**ab**	2.46**b**	0**b**	0**b**	0b	0**b**	0**b**	0.56**b**
Tylenchorynchus	1.72**ab**	2.84**a**	0**c**	0**c**	3.13**a**	0**c**	0**c**	0.75**bc**
Rotylenchulus	0.84**b**	2.63**a**	0**b**	0**b**	3.02**a**	0**b**	0**b**	0.56**b**
Hemicycliophora	0.28	0	0	0	0	0	0	0
M. Javanica	2.08**abc**	1.49**a**	2.94**abc**	1.96**bc**	4.15**a**	2.10**abc**	1.36**c**	3.61**ab**
M. incognita	2.33**ab**	1.04**a**	2.59**ab**	0.51**c**	3.06**a**	2.04**abc**	0.49**c**	2.84**a**
Trichodorus	0	0.54	0	0	1.86	0	0	0

CT = Continuous Tobacco

NB: Levels not connected by same letter are significantly different

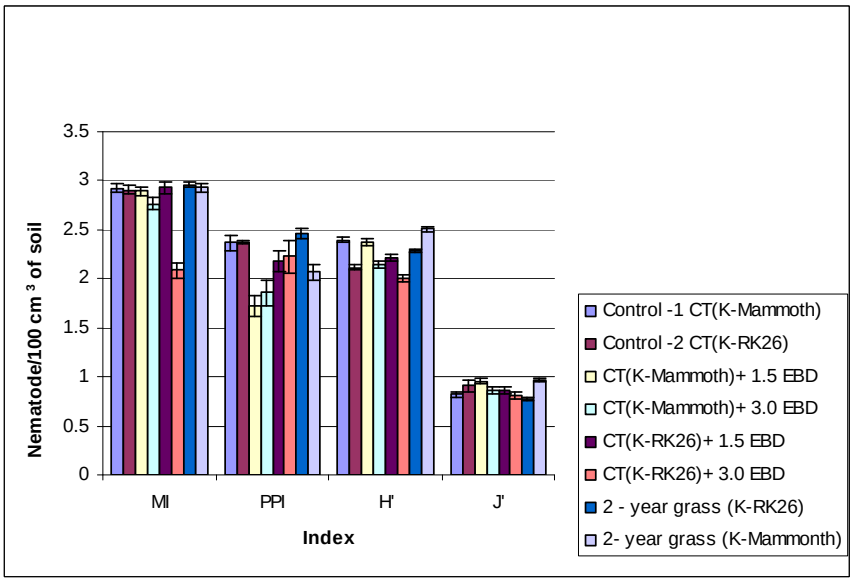
The K-Mammonth and K-RK26 varieties each after a 2-year rotation with Katambora Rhodes grass recorded significantly ($p<0.05$) higher abundance of *Criconemoides* spp.

A high abundance of *Scutellonema* spp. was observed in the control plots of K-Mammonth and K-Mammonth varieties treated with EDB at 1.5 kg a.i./ha. The Higher abundance of *Meloidogyne javanica* and *M. incognita* were recovered in the control plots

of K-Mammonth variety, whereas the lower abundances were recovered from the K-Mammonth variety production after a 2-year rotation with Katambora Rhodes grass.

5.3.2.3 Nematode community and food web indices

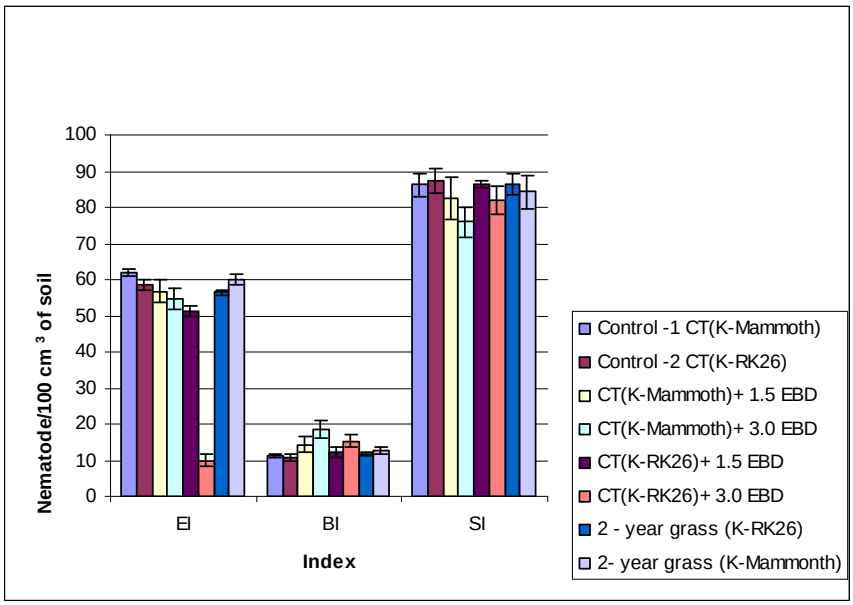
The effect of treatments on the mean values for maturity index (MI), plant parasitic index (PPI), Shannon diversity (H') and evenness (J') indices, enrichment index (EI) and structural index (SI) are shown in (Fig. 5.12). The MI was significantly ($p<0.05$) lower in K-RK26 variety treated with EDB at 3.0 kg a.i. /ha, as irt was same in the rest of treatments. In other treatments the PPI was significantly ($p<0.05$) higher in the K-RK26 variety after a 2-year of Katambora Rhodes grass. A significantly ($p<0.05$) higher Shannon-Weiner (H') (H') diversity index was observed in the K-Mammonth production after a 2-year rotation with Katambora Rhodes grass. The lowest H' value was recorded in the K-RK26 variety treated with EDB at 3.0 kg a.i./ha. Treatments had no effect on the (J') index.



CT = Continuous Tobacco
MI = Maturity index, PPI = Plant parasitic index, H' = Shannon diversity index,
J' = Evenness index

Fig. 5.12 Influence of treatments on nematode community structural indices: tobacco experiment (2007). Bars represent standard errors of the mean

EI values were significantly higher in the control plots of K-Mammonth variety. The K-RK26 variety treated with EDB at 3.0 kg a.i./ha recorded the significantly ($p<0.05$) lower values (Fig. 5.13). There were no significant treatment effects on the BI and SI value.



CT[a] = Continuous Tobacco
EI = Enrichment index, SI = Structural index and BI = Basal index

Fig 5.13 Influence of treatments on food web indices: tobacco experiment (2007). Bars represent standard errors of the mean

5.4 Discussion

5.4.1 Trend in nematode abundance

In the tomato experiment, the abundance of nematodes under different treatments gradually decreased with soil depth. The exception was *Pratylenchus* spp which was much higher at 0 – 15 cm depth. This is general observations that soil layers at 0 – 15 cm is the region of greatest biological activities that enfluences nematode populations build up. Findings from the tobacco study have revealed that treatments affected some nematode genera resulting into changes in nematode communities' composition. In the current study, ethylene dibromide reduced the abundance of nematode communities while its absence in the control plots led to higher abundance. The nematicide would not

be an ideal strategy for nematode pest management while managing soil health because it also affected free-living nematodes that are assential for organic matter decomposition and nutrient recycling. This observation is in agreement with a previous study by Yeates, Wardle and Watson, (1999) who reported that general biocides such as methyl bromide decreased microbial populations and nearly eliminated all the nematodes.

The higher abundances observed in the rotational sequence in the 2-year of K-Mammonth production after Katambora Rhodes grass and the K-Mammonth at lower dose of nematicide suggests that crop rotation may increase or decrease population of nematode densities in soil depending on the crop and nematode species. The higher abundance of bacterivores and fungivorse nematodes in the K-Mammonth at the lower dose of nematicide may prompt one to hypothesize that numbers of bacterivores were able to recover relatively earlier in the lower dose of nematicide applied. This may have been due to the survival of nematode eggs after nematicide application or the dose used was not effective. However, similar findings have been reported by Ettema and Bongers (2000) who observed that within 60 days after fumigation, progression of colonization by early successional species followed by more-specialized of later successional taxa can occur.

5.4.2 Trophic structure and genera distribution

The abundance of Rhabditidae was higher after application of organic amendment and decreased at the end of experiment. The abundance of Cephalobidae reached peak at the end of experiment. This suggests that there was a high population of bacteria after the rains at the beginning of the field trial that reflected higher abundance of Rhabditidae while Cephalobidae were more tolerant to drought conditions that prevailed at harvesting. Also, Cephalobidae have slower development and are less fecund than Rhabditidae. A succession from one to another is commonly seen after enrichment (Odum (1995). Cephalobidae being a general opportunist with c-p 2, reproduce more slowly which made them to be more abundant at the end of the field trial and bacterivorous nematodes tended to increase with the incorporation of organic amendments into the soil since bacteria that

provide a food base are greater after application of organic amendments. These results validated the second hypothesis of this study that different tomato management strategies affect the population dynamics of nematode communities and their distribution in the soil.

The decrease in abundance of fungivores observed in the tomato experiment after incorporation of treatments may be related to agricultural operations as these tend to favour a higher proportion of plant parasitic nematodes Kimpinski and Sturz (2003) and the reduction in diversity and abundance of free-living nematodes. The abundance of most families and genera of the free-living nematodes that were observed in the K-Mammonth production after a 2-year of Katambora Rhodes grass and K-Mammonth at lower dose of nematicide, may reflect that Katambora Rhodes grass is a good host of free-living nematodes.

The genera *Helicotylenchus, Scutellonema, Pratylenchus* and *Meloidogyne* were abundant and significantly associated with both tobacco varieties in plots with no nematicide and those with low nematicide levels. This suggests that the populations of nematodes may build-up significantly in these tobacco varieties if their resistance is not supplemented with nematicide. The lower abundance of *Meloidogyne* spp. was observed in the K-Mammonth production after a 2-year of Katambora Rhodes grass and they were abundant in the control plots planted with K-Mammonth variety. It implies that Katambora Rhodes grass is a poor hosts of *Meloidogyne* spp. It should be noted that the situation with the most common RKN is complex. Populations of *M. incognita* races 1 and 3, for which there is effective resistance, have been declining in recent years. In contrast, populations of race 2 and especially race 4, which attack the current resistant cultivars, have increased significantly. Thus, the changing nature of *M. incognita* and *M. javanica* species is complex and imposes challenges in the use of the 'resistance' cultivars (Fortnum, Lewis and Johnson, 2001).

Findings from the tomato field trial also showed that incorporation of either chicken manure or Fenamiphos was equally effective in suppressing *Pratylenchus* spp. and

Meloidogyne incognita and *M. javanica* species but less detrimental to populations of *Helicotylenchus* spp. and *Scutellonema* spp. as observed during the end of the experiments. Consistently high abundance of *Helicotylenchus* spp. and *Scutellonema* spp. observed at all four sampling dates after treatment incorporation, suggests that their populations may be more influenced by factors such as soil properties and environmental variables. In most treatments *Meloidogyne incognita* and *M. javanica* were more abundant in 0 – 15 cm depth while populations of *Helicotylenchus* spp. and *Scutellonema* species showed significant abundance in 15 – 30 cm in the tomato experiment. A study by Villanave, Bongers, Ekschmitt, Djigal and Cotte (2001) on reproductive strategies of *Helicotylenchus dihystera* and *Tylenchorhynchus* spp. found that these genera are more related to natural conditions and preferred sites of mature successional status. Davis, Bell, Watson and Rohan (2004) reported that *Helicotylenchus* spp. have a wide host range and have ability to persist in the absence of a host plant and that makes it difficult to remove from the soil. *Scutellonema* spp. are linked with persisters i.e. the ability to survive in dry conditions (Zoon *et al*., 2000).

Low abundance of *Pratylenchus* spp. observed in the field at 0 – 15 cm soil depth suggests that nematodes being migratory endo-parasites in the root cortex, their low population in soil could be associated with relative high nematode numbers feeding in roots after the tomato crop establishment. Abundance of *Pratylenchus* spp. was observed in the *Tagetes* spp. and Fenamiphos treated plots during the 2008/2009 season. Fenamiphos (a non-fumigant nematicide) does not kill eggs of nematodes in soil, but juveniles become either immobilized or disoriented and can not find their food source delaying nematode penetration at the early and sensitive seedling stage. It is only when the effect of nematicide lasts longer that the nematodes can die (Schomaker and Been, 2006). In this study, *Tagetes* spp. lacks consistent effect in the management of nematode genera as reported to perform elsewhere. This observation raised a need to propose that any nematode management strategy recommended in one part of the world should be tested against the local nematode populations present in another place before being recommended as a management strategy. It is the first time that this *Tagetes* species has been tested in Zimbabwe on tomato agro- ecosystems. However, it has been documented

that the effect of *Tagetes* spp. to RKNs is highly variable, depends on the combination of species and cultivar of the *Tagetes* spp. and the species and race of RKNs (Viaene, Coyne and Kerry, 2006). Higher abundance of Cephalobidae, Rhabditidae and fungivorous nematodes were observed in manure and *Tagetes* spp. treatments. These functional guilds play a vital role in the management of soil health as they influence decomposition of organic matter for minerals and nutrients recycling, influencing detoxification of pollutants in the environment, and biological regulators of pest spp. (Heterorhabditids and Steinernematids)

5.4.3 Nematode community and food web indices

Increased interest in biodiversity and the environment, and the concerns about maintaining the productivity of agricultural soils by integration of a growing knowledge of nematodes to soil and ecosystem have resulted in a wider use of indices. (Shannon-Weiner H', evenness J' and Nematode Channel Ratio and maturity index (MI). Changes due to an environmental perturbation, such as tillage, can usually be seen in changes of nematodes trophic structure. Results from this study showed that before the incorporation of treatments, MI values were relative higher in both plots and decreased after treatment incorporation. At the end of the field trial, significantly higher and lower values were recorded in the control and Fenamiphos plots respectively. This reflects that Fenamiphos plots were more disturbed from chemical application and incorporation in the soil. A low value of MI implies degradation of soil properties. Resulting low MI may be due to the fact that soil disturbance during land preparation and during incorporation of treatment altered the structure of the soil ecosystem, discriminating against large and more sensitive nematodes that are slower to reproduce in favour of those that are resistant to environmental stress and with short life span (Kimpinski and Sturz, 2003) Agricultural practices that have a reduced soil disturbance effect may be expected to show a more stable nematode community structure with long implications for crop health and sustainability.

Maturity index (MI), structural index (SI) and enrichment index (EI) values did not differ significantly among most treatments with an exception of the K-RK26 variety with EDB at 3.0 kg a.i./ha which recorded lowest MI and EI values. These results suggest that since most of the treatments showed well structured and enriched food webs, the indices were more prone to the higher level of the nematicide than the disturbance from the Katambora Rhodes grass rotation and in the control plots. This observation of the current study has shown SI and MI are dependent on the resource flow profile of the food web (Ferris, 2010), because the abundance of bacterivores, fungivores and herbivores were also lower in K-RK26 variety with EDB at 3.0 kg a.i./ha treated plots. Higher community structure observed in the tobacco in rotation with Katambora Rhodes grass and in the low nematicide dose plots reflect the higher abundance of the nematodes with high c-p values that always are prone to agricultural disturbance. It suggests a negative relationship between predator abundance and the high physical disturbance and biological activities present between production systems (Sánchez-Moreno *el al*., 2006).

PPI values were significantly higher in manure plots and in the K-RK26 production after a 2-year of Katambora Rhodes grass and the lowest values were recorded in the K-RK26 variety with EDB at 3.0 kg a.i./ha plots. The majority of the plant-parasitic nematodes in this study were ectoparasites, which are generally polyphagous (Cadet *et al*., 2005). For example, genera *Helicotylenchus*, *Scutellonema*, *Tylenchus* and *Filenchus* are epidermal root hair feeders (Yeates *et al*., 1993). Therefore, results of this study underscore the importance of using ectoparastic plant nematodes in determining the short term impact of human activities in various habitats (Freckman and Ettema, 1993).

Soil nematode assemblages have been used as indicators of soil conditions with the underlying assumption that larger, more diverse assemblages reflect “more healthy” soils and thus “desirable” (Yeates, 2003). In the tomato field trial, higher Shannon-Weiner index (H’) values were observed in the control and manure while the lowest values were obtained in Fenamiphos plots. These observations indicate that organic amendments are able to stimulate growth of more nematode genera than conventionally managed plots. Pattison, Badcock, Armour, Moody, Velupillai, Cobon, Lindsay, Gulino and Smith

(2004) reported H' values of nematode diversity for a banana field (1.35) pasture (1.97) and forest (2.07). This means that in soils where more food resources are available for the different genera, a high number of commonly perceived parasitic nematodes may not result in high crop damage. Thus, a certain risk of nematode attack can be reduced by the number of genera present in the soil. Higher genera evenness (J') values were observed in the manure and the plot with residual effect of *Tagetes* spp. in the top layers of the soil. Higher values indicate that they did not support a community that was dominated by few parasitic nematodes suggesting that the risk of having nematode problems is lower.

Higher species diversity and evenness observed in the control and in tobacco in rotation with Katambora Rhodes grass suggests that the two cropping systems created favourable conditions for species to proliferate than in other plots treated with nematicides. Plots of K-RK26 variety treated with EDB at 3.0 kg a.i./ha showed higher values of nematode channel ration NCR. The rest of the treatments recorded lower NCR values indicating the dominance of fungivore nematodes in organic matter decomposition and nutrient cycling. Ferris *et al.* (2001) observed that the changing in soil condition towards the harvesting of the crop could result in a switch to a fungal pathway probably accompanied by slow rate of decomposition of organic matter.

Significantly higher EI values recorded from manure and Fenamiphos plots in the tomato field trial, according to Ferris *et al*. (2001) suggests that a carbon source had been provided and favourable conditions created for bacterial decomposition. The trend of decreasing SI values observed in most treatments across the field trial plots indicated less abundance of predators and omnivores, trophic group highly prone to stress and environmental disturbances (Ferris *et al*., 2001; 2004). Lower values of NCR were observed in most treatments. With abundance of amendments with high C:N ratios in the rhizosphere, the soil food web will be selected for fungal dominated decomposition pathways, thus a slower mineralization rate but a longer lasting supply of organic materials will be available (Wang and McSorley, 2005).

5.4.4 Influence of treatment on Meloidogyne spp. sex ratio

The determination of the effect of treatment on male-juvenile ratio of *Meloidogyne* spp. revealed that numbers of juveniles were greater in manure while higher abundance of males was found in Fenamiphos treated plots. In general, individuals are capable of development into males or female based on conditions at certain development stages, such as temperature (Bull, Vogt and McCoy (1982), nutritional status and space (Colgrove and Niblack, 2005). This finding implies that Fenamiphos treatment put the nematode under stress resulting in more males. This, in turn may result into poor infection to the crop since males are generally non-infective.

5.5 Conclusion

Soil fertilizer amendments and yearly application can cause changes in the physical, chemical and biological properties of soil (Tu, Ristaino and Hu, 2005). Applying organic amendments has been shown to increase soil microbial activity (Liu and Ristaino, 2003), microbial diversity and bacterial densities (Van Bruggen and Semenov, 2000). Nematode community structure and trophic structure were affected by treatments. In this study, the manure treatments had higher abundance of fungivores nematodes. This succession of nematode species plays a significant role in decomposition of soil organic matter, mineralization of plant nutrients and nutrient cycling (Ferris, Venette and Scow, 2004).

The addition of organic materials to soil infested with phytoparasitic nematodes (PPNs) has been clearly demonstrated as a satisfactory control method against these nematodes. Manure increased both nematode evenness and enrichment indeces. This implies that it promoted the soil which was not dominated with single species that may emerge as potential pests. MI being the measure of soil disturbance, it was found to be low in Fenamiphos treatment. It implies that there was low abundance of nematodes such as Mononchidae and Dorylaimidae that are characterized with large-bodies, the lowest fecundity and longest life spans. They are susceptible to soil disturbance such as plowing

and inputs application and reside in less disturbed soils. Their absence is reflection that the treatment is deleterious to ecosystem management. Production of tobacco after rotation with Katamboara Rhodes grass showed to supported low abumdance of *Meloidogyne* spp. and supported higher abundance for free-living species that have significant contribution in soil food web process. The impact of *Meloidogyne* spp to the tomato crop was much reduced by Fenamiphos because it stimulated differentiation of more juveniles into males which are non-feeding to the tomato.

CHAPTER SIX

EFFECT OF NEMATICIDES AND ORGANIC MANURES ON NEMATODE POPULATIONS IN A GLASSHOUSE EXPERIMENT

6.1 Introduction

Root-knot nematodes (*Meloidogyne* spp.) are serious and most important pests of many crops around the world (Trifonova, Karadjova and Georgieva (2009). They particularly damage vegetables in tropical and subtropical countries (Sikora, Bridge and Starr, 2005) and cause losses up to 80 % in heavily infested fields (Kaskavalci, 2007). In addition to directly affecting a crop's ability to develop normally, nematodes can interact with other phytopathogenic organisms to create a disease complex that may have more devastating effects than either pathogen individually (Webster, 1985). A short life cycle of six to eight weeks enables them to multiply several-folds in the presence of a suitable host. According to Shurtleff and Averre (2000), in susceptible crops, nematode populations build up to a maximum usually as the crop reaches maturity and in some cases the plants die even before reaching maturity (Singh and Khurma, 2007). Application of organic amendments may affect nematode populations and their virulence towards a host crop by improving plant vigor. This will thereby increase resistance to attack by promoting soil microorganism populations which may compete or be antagonistic towards parasitic nematodes (Coosemans, 1982). Effects of organic amendments on nematode populations vary with nematode species and type of amendment, and have been found to play a major role in an integrated nematode management program (Duncan and Noling, 1998).

Synthetic fertilizers, pesticides, and herbicides are important inputs in conventional agricultural systems. Insecticide and mineral fertilizer applications have been shown to impact on the diversity and abundance of nematode trophic groups (Yeates *et al*., (1999). Inorganic fertilization has also been shown to increase the numbers of free-living nematodes (Vestergard, 2004). Several reports have documented nematode suppression

by chicken manure applications. For example, *M. incognita* levels and root galls on tomato were reduced by the application of chicken manure at the rate of 2 t/ha and continued to decline with increased application rates. This effect was attributed to nematicidal properties in the manure (Chindo and Khan, 1990). It was speculated the decline in galling was associated with a corresponding increase in soil microbial levels as determined by urease activity (Mian and Rodríguez-Kábana 1982).

Although various organic amendments can have differential effects on soil properties and nematode communities (Neher *et al*., 2005), all tend to increase availability of nutrients such as nitrogen, microbial biomass and abundance of bacterivore and fungivore nematodes (Bulluck III, Barker and Ristaino, 2002b). Increase in organic matter in the soil increases microbial biomass by providing an enlarged food base for free-living nematodes (Ferris *et al*. 1999).

In agricultural production, both physical and chemical aspects of soil management practices have both direct and indirect effects on nematode communities. Great insensitivity to indirect than direct effects reflects that nematode communities are more responsive to secondary impacts of management mediated by the soil environment than the impacts of tillage or chemical/nutrients applied to the soil (Fiscus and Neher, 2002). Nematodes play a critical role in decomposition and nutrient cycling (Ferris *et al*., 2004). Free-living nematodes that feed on bacteria and fungi contribute as much as 30 % of the readily available nitrogen in the soil (Verhoef and Brussaard, 1990) and also promote rhizosphere colonization of beneficial rhizobacteria (Kimpinski and Sturz, 2003). Neher and Darby (2006) observed a negative correlation between free-living and plant parasitic nematodes in organically grown tomatoes. Therefore, one of the major goals of sustainable agriculture should be to enhance populations of free-living nematodes, reduce that of plant-parasitic nematodes (Fiscus and Neher, 2005) and reduce soil bulk density and increase soil nitrogen and carbon supply. This study was therefore undertaken to establish the effect of changes in nematode communities under the influence of nematode pest management strategies in tomato production systems in Zimbabwe as follows;

6.2 Specific Materials and Methods

6.2.1 Site description

Glasshouse experiments were carried out during the period between February 2007/2008 and August 2008/2009 at the Plant Protection Research Institute (PPRI) in Harare; situated at an altitude of 1 483 masl.

6.2.2 Treatments and experimental design

Experiment 1: Influence of Organic Amendment, Nematicide and Depth on Nematode Communities in Tomato Production

This study was carried out with the following objective:

- To monitor population dynamics of nematode communities in tomato production before and after application of a conventional nematicide, chicken manure and a botanical nematicide and to identify the effect of such management strategies on their distribution and interactions.

The hypothesis tested was:

- Application of chicken manure, conventional and botanical nematicides in tomato for nematode pest management strategies affect the population dynamics of nematode communities and their distribution in the soil.

Each plot in the experiment comprised of four, 12-cm diameter plastic pots, each containing 1200 cm^3 of soil categorized as medium grained clay with the following chemical characteristic: pH (H_2O) = 4.8, available P_20_5 = 205 ppm, exchangeable Ca = 6.25 Mg/100g, K = 0.8 Mg/100g, Mg = 1.65 Mg/100g. The soil has was naturally infested with nematodes. The trial was arranged in a randomized complete block design with four replications having the following factors: During the first cropping season 2007/2008, four treatments were tested that included; (i) Marigold (*Tagetes* spp.) var.

Orangeade, (ii) chicken manure (4 g/l soil), (iii) control and (iv) Fenamiphos (Nemacur® 400 EC) applied to the soil surface at the rate of 800 ml in 100 litres of water and plowed into the pots before tomato transplanting, together with a soil amended by marigold (*Tagetes* spp.) var. Orangeade which was grown in the pots was plowed at flowering stage two weeks before tomato transplanting. During the following cropping season 2008/2009, each pot was tested for residual effect of the previous season. One portion received the (i) Marigold (*Tagetes* spp.) var. Orangeade, (ii) chicken manure (4 g/l soil), (iii) control and (iv) Fenamiphos (Nemacur® as the previous season and the other portion was left untreated to test for possible residual effect of the previous treatment application. A total of six treatments were tested that included: (1) with and without Marigold, (2) with and without chicken manure and (3) with and without Fenamiphos. Plots were watered to field capacity prior to transplanting singly uniform 4-week-old 'Roma cultivar' tomato seedling into each pot. Carbaryl (Carbaryl® 85 WP) at the rate of 27 g/13.5 litres of water was sprayed for the control of cutworms and locusts. A basal dressing of fertilizer, Compound D (7 % N, 14 % P_20_5, 7 % K_20) was applied at transplanting at the rate of 300 kg/ha (i.e. 360 g/plot). Compound D is the recommended basal fertilizer dressing for tomato production at the experimental site. Nematode assay per 300 cm^3 of sub-soil sample from a plot was determined prior to treatment application. Plots were sampled for initial (Pi) nematode population before treatment application. Nematode populations were monitored at monthly intervals up to 120 days after planting, when the final (Pf) nematode population was assessed. The rate of reproduction of nematodes as final population/initial population (Pf/Pi) and the juvenile/male (J/M) ratio were calculated.

Experiment 2: Effect of Chicken Manure on the Population of Infective Juveniles of *Meloidogyne javanica* associated with Tomato Plant

This study was carried out to test the following hypothesis:

- That chicken manure has an immediate effect on *Meloidogyne spp.*

6.2.3 Glasshouse culture of Root-knot nematodes

Populations of *Meloidogyne javanica* were maintained on tomato var. Roma VF plants in large concrete bins measuring 0.5 m x 0.5 m in a glasshouse. The source of inoculum was culture requested from the Kutsaga Tobacco Research Station in Harare and galled root samples from field experiments and samples received for advisory purpose from different parts of the country.

6.2.4 Collection of Root-knot nematode juveniles

Galled root systems were dug out of the concrete bins in the glasshouse and washed free of soil under running tap water. The roots were then cut into small pieces, about 4 to 5 cm long, and placed in a petri dish with tap water (about 5 ml). Egg masses on the surface of roots were picked up under a light microscope at a magnification of x 250 and placed on 38 micron sieves in a petri dishes with tap water just enough to cover the egg masses. After about 24 hours, the water containing hatched infective juveniles (IJs) of *M. javanica* were collected from petri dishes into beakers and placed in a cooler box at 4 ^{0}C. Water in the petri dishes was replaced and collection of hatched IJs continued for several days until sufficient inoculum was collected. The numbers of IJs collected was estimated by counting a 1 ml aliquot in a De Grisse counting dish (Protocal by Sharma and Sharma, (1980).

6.2.5 Inoculation of IJs to chicken manure

Composted chicken manure was collected from Lenara Farm in Matebeleland South Province. The results of the chemical analysis of the chicken manure were as follows: pH 5.9, organic matter 2.4 %, Ammonia + nitrate = 52.1 ppm and P_20_5 = 6.3 ppm. Chicken manure at the rate of 1 kg/m^2 (10t/ha) were mixed into 1 200 cm^3 of soil in 12-cm diameter plastic pots. The pots were kept in a glasshouse at a temperatures ranging between 20 ^{0}C to 25 ^{0}C and 6 ^{0}C to 7 ^{0}C for maximum and minimum temperatures respectively. Each treatment was replicated five times. A control treatment with sterilized

soil and no chicken manure added was included. A day after incorporation of chicken manure to the soil, about 2 500-one to five day old IJs of *M. javanica* collected in section 6.2.3 above were inoculated into each pot. The IJs were inoculated by pipetting the inoculum into small holes dug all over the soil surface in the pots. The holes were covered with soil immediately after inoculation to prevent drying out of the nematodes. The experiment was sampled on a three-day interval basis and terminated after 30 days, a duration presumed adequate for the first generation of nematodes to complete a full cycle.

Experiment 3: Evaluation of Inorganic and Organic Amendment Practices on Nematode Communities while Managing Root-Knot Nematodes in Tomato Production.

This study was carried out to meet the needs of the following objective:

- To compare the effect of conventional and botanical ammendements on nematode communities.

The hypothesis tested was:

- Application of chicken manure, conventional and botanical nematicides in tomato for nematode pest management strategies affect the population dynamics of nematode communities and their distribution in the soil.

Each plot in the experiment was comprised of four, 12-cm diameter plastic pots, each containing 1200 cm^3 of soil which was naturally infested with nematodes. Three treatments were included in the test: soil amended with soybean cake (4 g/l soil), soil amended with ammonia nitrate and plot amended with compound D fertilizer (NPK). Treatments were arranged in a randomized complete design with four replications. The soybean cakes were incorporated into the soil 4 weeks before transplanting to allow proper decomposition before transplanting. A day after irrigating the plots to field capacity, uniform 4-week-old 'Roma cultivar' tomato seedlings were singly transplanted to each plot. A basal dressing of fertilizer, Compound D (7 % N, 14 % P_20_5, 7% K_20) was

applied at transplanting at rate of 120 Nkg/ha (i.e. 5.85 g/plot). Ammonia (3.5 g/plot**)** was supplied to atomato crop a week after planting. Compound D was the recommended basal application. Temperatures in glasshouse during the experiment ranged between 16 and 26 ^{0}C. Pots were sampled for initial (Pi) nematode population before treatment application. Nematode population was determined at month interval up to 90 days after planting when the final (Pf) nematode population was assessed. At the end of the experiment, the nematodes reproduction rate was calculated as final population/initial population (Pf/Pi) ratio.

6.3 Results

Experiment: 1 Influence of Organic Amendment, Nematicide and Depth on Nematode Communities on Tomato Production

6.3.1 Trend in nematode abundance during the course of the experiment

In both 2007/2008 and 2008/2009 seasons, the nematode abundance showed rapid decline within 30 days after treatment incorporation in the control and Fenamiphos treated plots but later started rising (Fig. 6.1 and 6.2). Maximum abundance across the treatments was achieved in the 60-day sampling, and thereafter the abundance declined steadily in both treatments towards the end of the experiment.

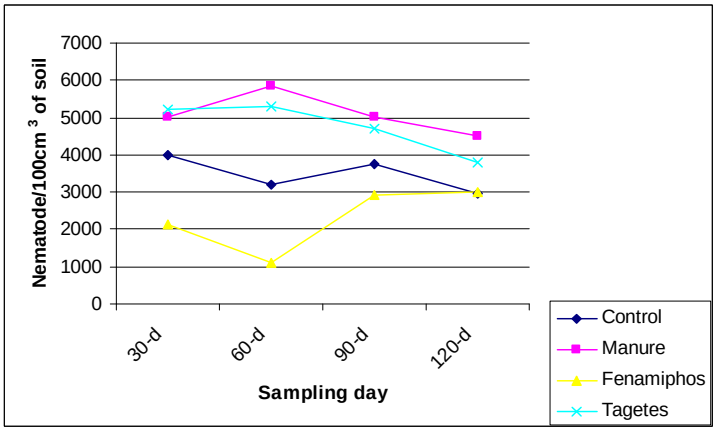
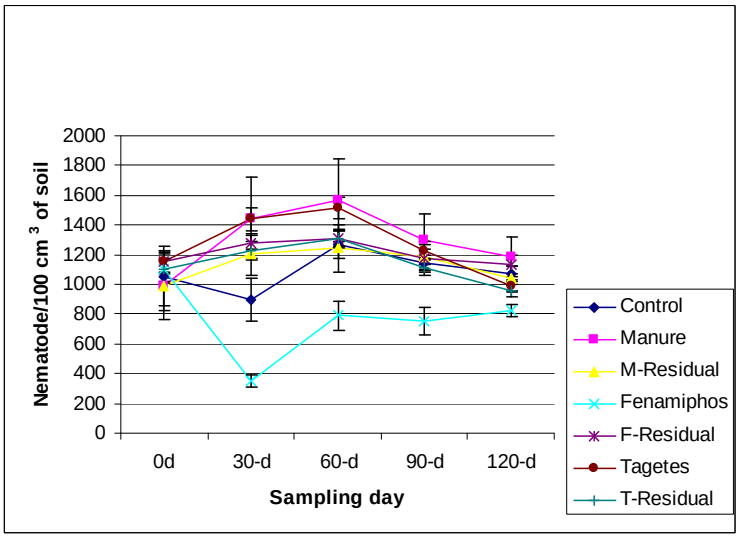


Fig. 6.1 Trend of nematode abundance: glasshouse experiment at PPRI (2008). Bars represent standard errors of the mean



M-Residual = Manure Residual; F-Residual = Fenamiphos Residual;
T-Residual = Tagetes Residual

Fig 6.2 Trend in nematode abundance: glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

6.3.2 Trophic structure and genera distribution

At the final sampling during 2007/2008 season, abundance of herbivores was significantly ($p<0.05$) higher than other guilds in all treatments. Altogether, significantly

($p<0.05$) higher abundance of predators was observed in the manure plots. Significantly ($p<0.05$) lower abundance of omnivores was recorded in the Fenamiphos plots (Fig. 6.3).

Abundance of herbivores was significantly ($p<0.05$) higher than other guilds in most treatments at the end of the experiment during 2008/2009 season (Fig. 6.4). Significantly ($p<0.05$) lower abundance of herbivores were observed in plots with residual effect of *Tagetes* spp. Significant ($p<0.05$) higher abundance of omnivores was observed in the manure plots. There were no significant effects of treatments among other guilds.

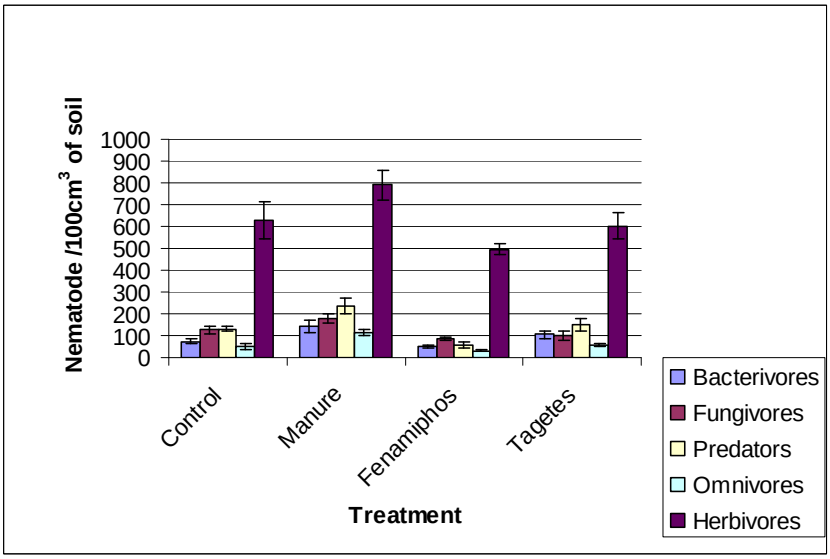
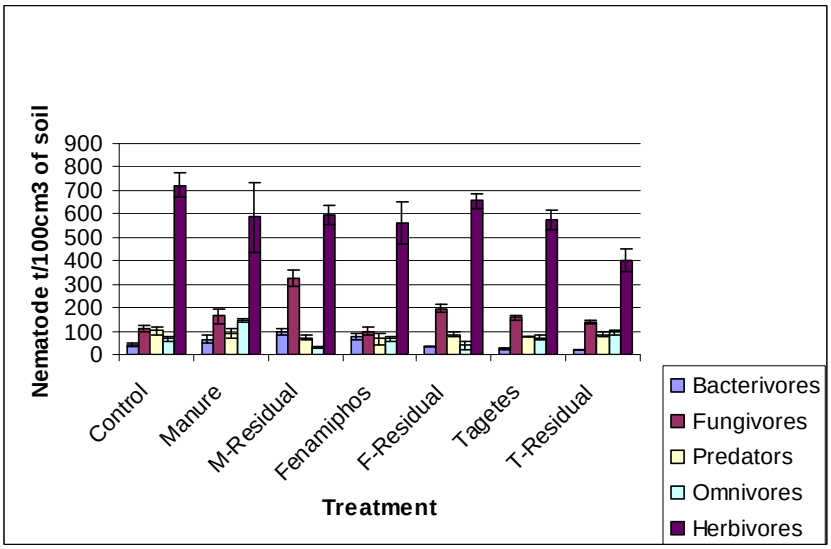


Fig. 6.3 Trophic distribution at the end of experiment (120-day): glasshouse experiment at PPRI (2008). Bars represent standard errors of the mean



M-Residual = Manure Residual; F-Residual = Fenamiphos Residual;
T-Residual = Tagetes Residual

Fig.6.4 Trophic distribution at the end of experiment (120-day): glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

During 2007/2008 season, the abundances of the free-living nematodes (Mononchidae, Predatory Dorylaimidae and Omnivory Dorylaimidae were significantly ($p<0.05$) higher in manure in manure pots. Their lowest significant abundance was observed in Fenamiphos pots (Table 6.1). Dominant plant parasitic nematodes genera were mainly *Pratylenchus*, *Xiphinema*, and two species of *Meloidogyne*, *M. javanica*, and *M. incognita*. Occasionally present were *Criconemoides*, *Tylenchorhynchus*, *Hemicycliophora*, *Rotylenchulus*, *Trichodorus* and *Hemicriconemoides*. Neither of the treatments had a consistent effect on the abundance of most dominant plant-parasitic.

The reproduction factors i.e. final population-to-initiation population ratio (R=Pf/Pi) is an indication of nematode multiplication. During the 2007/2008 season, treatments did not show significant effects on reproduction factors among nematode communities. However, lower abundance for Cephalobidae and Rhabditidae were observed in Fenamiphos plots whereas higher abundance of *Aphelenchus* spp. was recorded in the manure plots (Table 6.2).

Table 6.1 Effect of treatment on abundance of nematode genera at (120-day): glasshouse experiment at PPRI (2008)

Genus	Control	Manure	Fenamiphos	Tagetes
Bacterivores				
Cephalobidae	3.95**ab**	4.56**a**	3.45**b**	3.92**ab**
Rhabditidae	2.87	3.58	2.92	3.05
Fungivores				
Aphelenchoides	0.53	0	0	0
Tylenchus	1.28	1.56	0	0.72
Aphelenchus	3.91	4.43	3.20	2.89
Filenchus	0.53	0.67	0	1.01
Fungi Dorylaimidae	4.10	4.31	4.11	3.66
Predators				
Mononchidae	3.66**a**	3.87**a**	0.56**b**	3.64**a**
Predatory Dorylaimidae	4.52**bc**	5.20**a**	3.97**c**	4.67**bc**
Omnivores				
Omnivore Dorylaimidae	3.88**b**	4.73**a**	3.45**b**	4.06**b**
Herbivores				
Helicotylenchus	5.45	5.86	5.34	5.46
Scutellonema	4.76	5.08	4.90	4.88
Criconemoides	1.38	0	0	0.89
Pratylenchus	4.35	4.22	4.27	4.39
Xiphinema	2.35	0.84	0.52	0
Tylenchorhynchus	0	0	0	0
Rotylenchulus	0	0	0	0
Hemicycliophora	1.66	1.78	0.67	0.82
M. javanica	4.33	4.61	3.94	4.31
M. incognita	4.18**a**	4.14**a**	1.67**b**	3.65**ab**

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Table 6.2 Reproduction factors for nematode genera as influenced by treatments: glasshouse experiment at PPRI (2008)

Genus/ Trophic group	Control	Manure	Fenamiphos	Tagetes
Bacterivores				
Cephalobidae	1.55	1.74	0.66	1.29
Rhabditidae	1.70	1.54	0.96	1.37
Fungivores				
Aphelenchoides	0	0	0	0
Tylenchus	0.33	0.14	0	0.35
Aphelenchus	1.64**ab**	2.33**a**	0.89**b**	0.32**b**
Filenchus	0	0	0	0
Fungi	0.59	0.39	0.53	0.28
Dorylaimidae				
Predators				
Mononchidae	0.82	0.72	0	1.61
Predatory				
Dorylaimidae	2.89	3.21	1.33	1.46
Omnivores				
Omnivore				
Dorylaimidae	0.89	3.76	1.31	1.45
Herbivores				
Helicotylenchus	1.65	1.52	1.82	1.04
Scutellonema	0.97	1.06	1.22	0.82
Criconemoides	0	0	0	0.40
Pratylenchus	0.57	0.35	0.65	0.33
Xiphinema	0.27	0	0	0
Tylenchorhynchus	0	0	0	0
Rotylenchulus	0	0	0	0
Hemicycliophora	0.65	0.93	0	0
M. javanica	3.12	3.41	1.57	1.24
M. incognita	2.74	3.11	0.87	1.92
Trichodorus	0	0	0	0

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

During the 2008/2009 season, plots treated with Fenamiphos and that with residual effects of manure had higher reproduction factor for Cephalobidae, fungi and predatory dorylaimids (Table 6.3)

Table 6.3 Reproduction factors for nematode genera as influenced by treatments: glasshouse experiment at PPRI (2009)

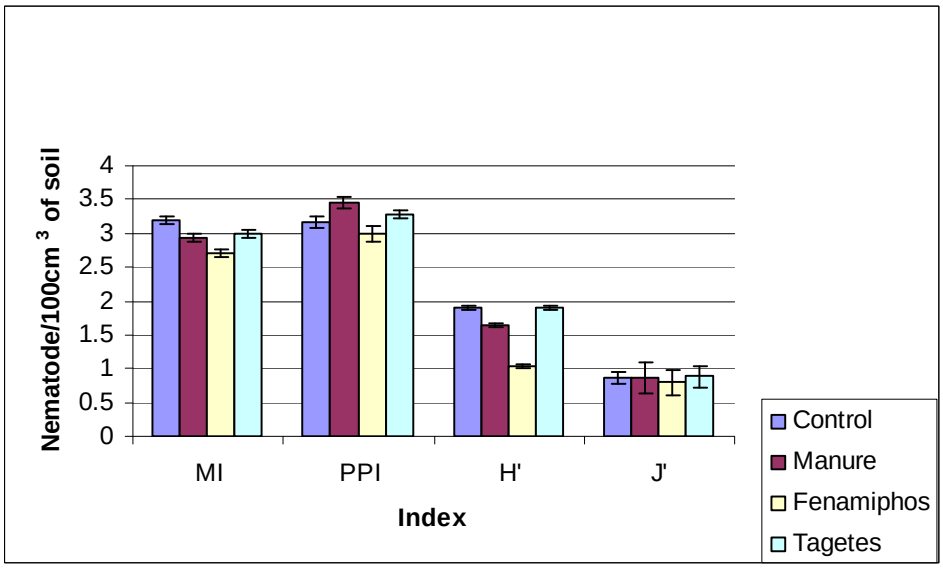
Genus	Control	Manure	M-Residual	Fenamiphos	F-Residual	Tagetes	T-Residual
Bacterivores							
Cephalobidae	0.57**bc**	0.93**bc**	2.29**ab**	3.21**a**	0.84b**c**	0.59**bc**	0.32**c**
Rhabditidae	0.95	1.00	1.07	1.48	1.05	0.82	0.84
Fungivores							
Aphelenchoides	0	0	0	0	0	0	0
Tylenchus	0.64	0	0.94	0	1.25	0.16	0.62
Aphelenchus	0.49	0.43	1.94	2.39	1.12	1.02	0.54
Filenchus	0.43**bc**	0**c**	0.32**bc**	0.17**c**	1.69**a**	1.30**ab**	0.62**abc**
Fungi Dorylaimidae	0.22**b**	1.03**ab**	2.71**a**	0.70**ab**	2.35**ab**	1.41**ab**	0.79**ab**
Predators							
Mononchidae	0.29	0.43	0.99	2.27	1.51	0.13	2.08
Predatory Dorylaimidae	1.50**ab**	0.32**b**	0.37**b**	2.30**a**	1.18**ab**	0.43**b**	0.52**b**
Omnivores							
Omnivore Dorylaimidae	2.14	0.74	0.56	2.27	1.59	0.58	1.37
Herbivores							
Helicotylenchus	1.33	0.77	1.22	1.55	1.37	0.74	0.42
Scutellonema	0.63	0.88	0.94	3.18	1.16	1.22	0.61
Criconemoides	0	1.47	0.84	0.45	0.81	0	0.73
Pratylenchus	0.93	0.69	0.86	1.10	0.89	1.69	0.65
Xiphinema	0.55	0.41	0	1.16	0.35	0	0.29
Tylenchorhynchus	0	0	0	0	1.16	0	2.04
Rotylenchulus	0	0	0	1.26	0	0	0
Hemicycliophora	0	0	0	0	0	0	0
M. javanica	1.10	1.54	2.04	0.62	2.84	0.16	1.40
M. incognita	0	2.31	0.54	0.22	1.61	0	0.89
Trichodorus	0	0	0	0	0	0	0

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

6.3.3 Nematode community and food web indices

During the 2007/2008 season, treatment had significant effect on maturity index (MI) values. At the final sampling (Fig. 6.5), the control plots recorded significantly ($p<0.05$) higher values of MI. The significantly ($p<0.05$) lowest MI was observed in plots treated with Fenamiphos. Significantly high ($p<0.05$) PPI values were observed in manure treatment at final sampling. Fenamiphos pots recorded dignificany ($p<0.005$) low H'. There was no significant difference in J' was observed among treatments.

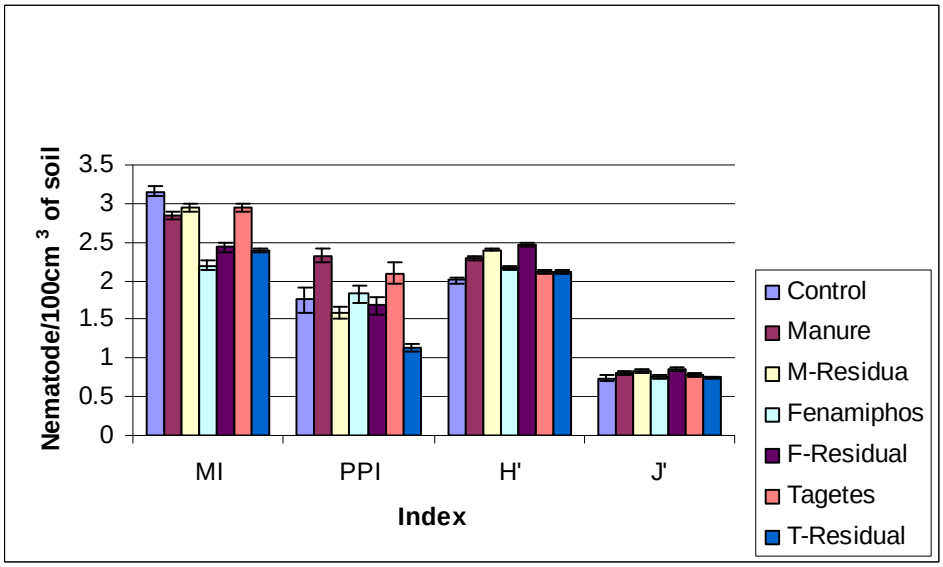


MI = Maturity index, PPI = Plant parasitic index, Shannon diversity index, J' = Evenness index

Fig. 6.5 Community structural indices at the end of experiment (120-day): glasshouse experiment at PPRI (2008). Bars represent standard errors of the mean

During the 2008/2009 season, during the final sampling MI was significantly ($p<0.05$) higher in the control. Significantly ($p<0.05$) lower values were observed in the Fenamiphos plots (Fig 6.6). PPI values were significant ($p<0.05$) higher in the manure treatment, followed by *Tagetes* spp. and Fenamiphos. Significantly ($p<0.05$) lower PPI values were recorded in the pots with residual effects of *Tagetes* spp. In *Tagetes* spp. treatment, PPI values were high followed by Fenamihos. Significantly ($p<0.05$) higher H' was observed in the pots with residual effect of Fenamiphos followed by pots under

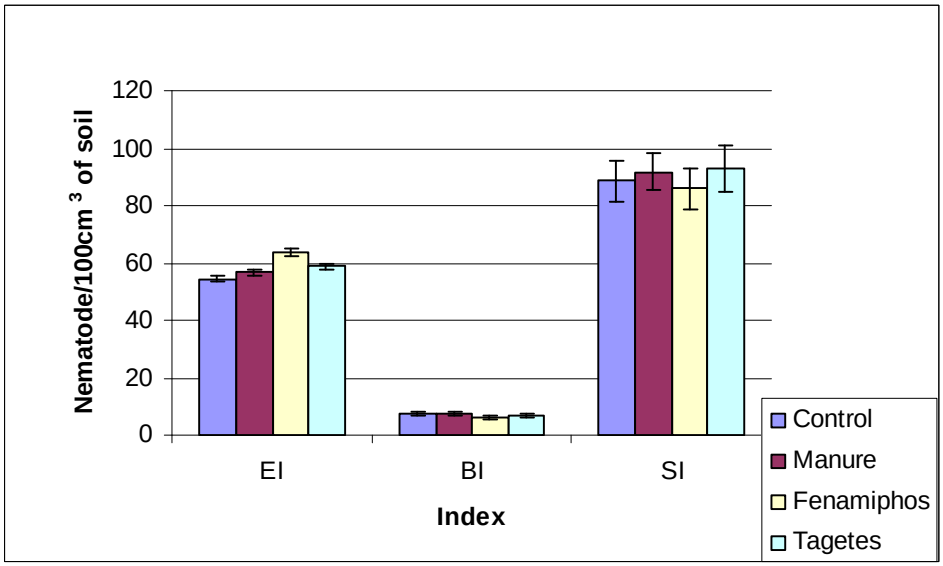
residual effect of manure. The lower values of H' were recorded in the control. Treatments showed no effect on the J'.



MI = Maturity index, PPI = Plant parasitic index, H' = Shannon diversity index, J' = Evenness index

Fig. 6.6 Community structural indices at the end of experiment (120-day): glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

The EI values were significantly ($p<0.05$) higher in the Fenamiphos treated plots. Treatments did not cause significant differences of BI and SI values on nematode genera (Fig. 6.7). The nematode channel ratio NCR values were lower in all treatments in both experiments and both cropping seasons (Table 6.4).



EI = Enrichment index, SI = Structural index and BI = Basal index

Fig. 6.7 Food web indices at the end of experiment (120-day): glasshouse experiment at PPRI (2008). Bars represent standard errors of the mean

Table 6.4 Influence of treatments on nematode channel ratio (NCR): glasshouse experiment at PPRI (2008 and 2009)

Year	Control	Manure	M-Residual	Fenamiphos	F-Residual	Tagetes	T-Residual
2008	0.36	0.44	-	0.37	-	0.51	-
2009	0.27	0.28	0.23	0.43	0.15	0.13	0.12

6.3.4 Influence of treatment on Meloidogyne spp. sex ratio

The mean male-juvenile ratio of *Meloidogyne* spp. was significantly affected by treatment at the end of the experiment (120-day). During the 2008 season, significantly ($p<0.05$) higher abundance of males was observed in the Fenamiphos plots (Table 6.5).

Table 6.5 Mean male-juvenile ratio during 120-day as influenced by treatments: glasshouse experiment at PPRI (2008)

Species	Control	Manure	Fenamiphos	Tagetes
M. javanica	0.16**b**	0.17**b**	0.86**a**	0.09**b**
M. incognita	0.08**b**	0.03**b**	0.65**a**	0.10**b**

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

During the 2008/2009 season, significantly ($p<0.05$) higher abundance of juveniles were recovered from control and residual Fenamiphos. More males were observed from Fenamiphos plots (Table 6.6).

Experiment 2: Effect of Chicken Manure on the Population of Infective Juveniles of *Meloidogyne javanica* associated with Tomato Plant

There were changes in the population of infective juveniles IJs with time after incorporation of chicken manure. There was relative decrease in the abundance of IJs in the third day after beginning of the experiment in both the chicken manure and the control treatments (Fig. 6.8). a significant ($p<0.05$) decline in the abundance of IJs was observed in chicken manure plots on the ninth day of sampling, and the same decreasing trend continued towards the end of the experiment (30-day) (Table 6.7).

Table 6.6 Mean male-juvenile ratio during at 120 days as influenced by treatments: glasshouse experiment at PPRI (2009)

Species	Control	Manure	M-Residual	Fenamiphos	F-Residual	Tagetes	T-Residual
M. javanica	0.93	0.69	0.71	1.30	0.91	0.55	0.45
M. incognita	0.22	0.26	0.13	0.22	0.08	0.45	0.86

M-Residual = Manure Residual; F-Residual = Fenamiphos Residual; T-Residual = Tagetes Residual

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

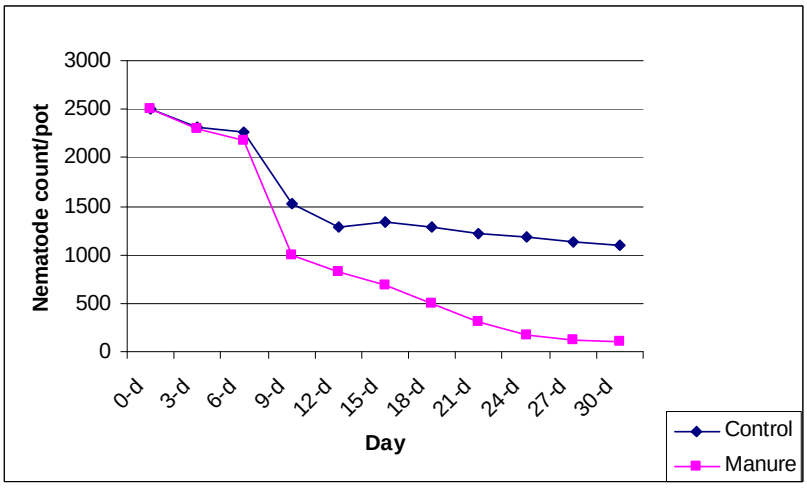


Fig. 6.8 Population change of *Meloidogyne javanica* (IJ) juveniles treated with chicken manure: glasshouse experiment at PPRI (2009)

Table 6.7 Effect of chicken manure on population density infective juveniles (IJ) of *Meloidogyne Javanica*: glasshouse experiment at PPRI (2009)

Day	Treatment		Treatment effect
	Control	Manure	
0-day	2500	2500	
3-day	2318	2290	Ns
6-day	2255	2172	Ns
9-day	1519	1002	**
12-day	1278	828	*
15-day	1335	680	**
18-day	1282	501	**
21-day	1221	316	**
24-day	1186	180	**
27-day	1139	114	**
30-day	1095	99	**

p-values are between treatment effect. *: p< 0.05, **:p< 0.01, n.s.: p > 0. 05

Experiment: 3 Evaluation of Inorganic and Organic Amendment Practices on Nematode Communities while Managing Root-Knot Nematodes in Tomato Production

6.3.5 Nematode abundance and population dynamics

The trend for nematode population dynamics is presented in Fig. 6.9. In all treatments with the exception of control plots, nematodes abundances were significantly higher in the 30-day sampling compared to the initial sampling prior to treatment application. Soybean cake application had the highest nematodes abundance followed by the control treatments. The pick abundances were observed in the 60-day sampling. The nematode abundance in the ammonia treatment showed quick decline within 30 days after treatment incorporation and showed slow growth with the lowest abundance towards the end of the experiment.

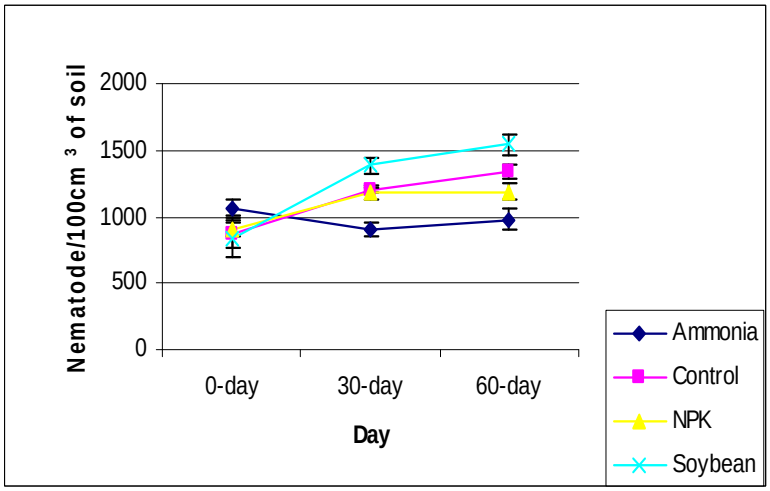


Fig. 6.9 Effect of treatments on nematode population dynamics: glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

6.3.6 *Trophic structure and genera distribution*

Abundance of herbivores was significantly ($p<0.05$) higher than other guilds in most treatments at the end of the experiment (Fig. 6.10). Inorganic fertilizers negatively affected the abundance of fungivore nematodes. Significantly ($p<0.05$) higher abundances of fungivores were observed in soybean cake treatment followed by the control plots. The soybean cake had higher abundance of bacterivores in the last sampling. Significantly ($p<0.05$) higher abundance of omnivores was recorded in the control and soybean treatments. Soybean cake treatment recorded significantly ($p<0.05$) higher abundance of predators.

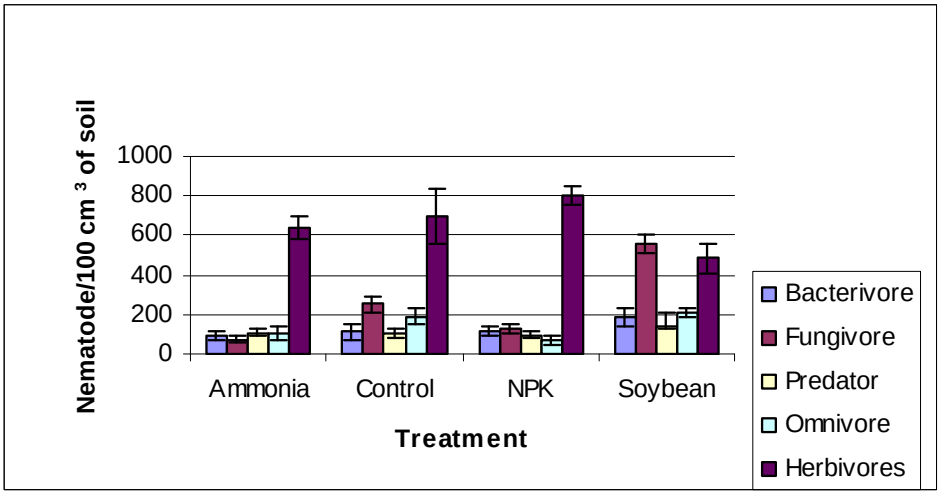


Fig. 6.10 Influence of treatments on trophic groups distribution: glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

Bacterivores were identified ias belonging to two families as Rhabditidae and Cephalobidae; while one fungivore family group i.e. fungi Dorylaimidae and genera *Aphelenchus, Filenchus* and *Tylenchus* were identified in the study (Table 6.8).

Table 6.8 Influence of treatments on reproduction factor for nematode genera: glasshouse experiment at PPRI (2009)

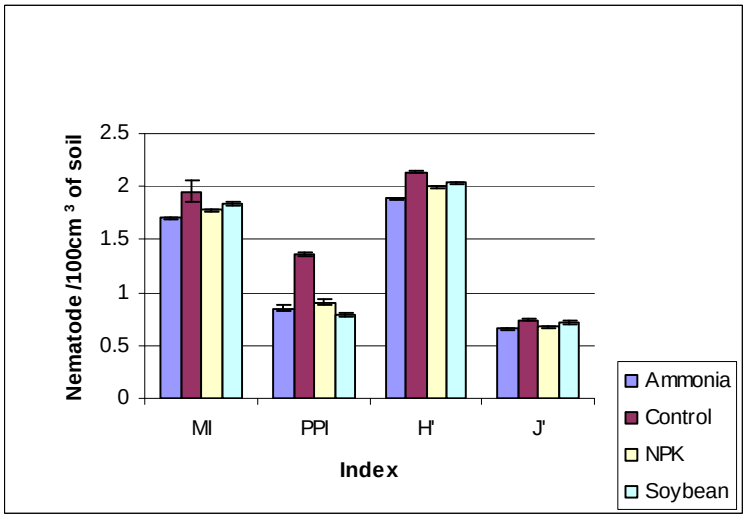
Genus/trophic group	Ammonia	Control	NPK	Soybean Cake
Bacterivores				
Cephalobidae	1.15	1.21	1.27	1.44
Rhabditidae	0.93	1.13	1.17	1.14
Fungivores				
Tylenchus	0.81**ab**	1.10**ab**	0.18**b**	1.51**a**
Aphelenchus	0.81	1.01	0.73	0.91
Filenchus	0.48	0.00	0.69	1.79
Fungi Dorylaimidae	0.67**c**	1.14**ab**	0.89**bc**	1.43**a**
Predators				
Mononchidae	0.86	1.82	0.93	0.60
Predatory				
Dorylaimidae	0.18	1.96	0.62	1.91
Omnivores				
Omnivore				
Dorylaimidae	1.01	1.31	1.18	1.47
Herbivores				
Helicotylenchus	1.02	1.02	1.07	0.96
Scutellonema	1.03	0.98	0.95	0.89
Criconemoides	0.0	0.54	0.20	0.0
Pratylenchus	0.81	0.72	0.54	0.71
Xiphinema	0.83	1.06	0.52	1.13
Tylenchorhynchus	0.19**b**	0.72**b**	1.94**a**	0.82**b**
Rotylenchulus	0.0	0.0	0.0	0.0
Hemicycliophora	0.31**ab**	0.54**ab**	1.05**a**	0.0**b**
M. javanica	1.16	1.55	1.61	1.44
M. incognita	0.32	1.06	1.52	0.0

NB: Row means followed by the same letter were not significantly different (p=0.05) according to the Tukey-Kramer HSD test

Predators and omnivores identified belonged to Mononchidae, predatory Dorylaimidae and omnivore Dorylaimidae family. Plant parasitic genera observed were *Helicotylenchus, Scutellonema, Pratylenchus, Criconemoides Tylenchorhynchus, Xiphinema, Rotylenchulus, Hemicycliophora* and *Meloidogyne javanica* and *M. incognita*. Results showed soybean cake had higher reproduction factor for most free-living nematodes. Most plant parasitic nematodes showed higher reproduction factor in the NPK fertilizer plots. Higher reproduction factors were observed in *Hemicycliophora* spp and significantly ($p<0.05$) higher values was observed in *Tylenchorhynchus* spp. respectively. These genera are not considered as potential pests in tomato production in the study area.

6.3.7 Nematode community and food web indices

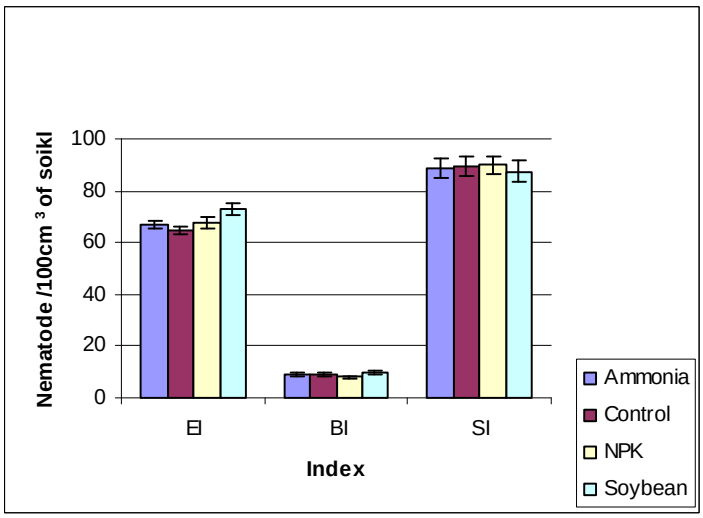
At the last sampling, the control pots recorded significantly higher MI, PPI, H' and J' values. Soybean plots had significantly lower PPI values (Fig. 6.11).



MI = Maturity index, PPI = Plant parasitic index, H' = Shannon diversity index, J' = Evenness index

Fig. 6.11 Influence of treatments on the community structural indices: glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

At the end of the experiment, soybean plots had significantly ($p<0.05$) higher EI values. There was no significant effect of treatments among other indices (Fig. 6.12). Nematode channel ratio (NCR) was higher (i.e. 0.56) in ammonia plots. Other treatments had lower values of less than 50 % (Fig. 6.13).



EI = Enrichment index, SI = Structural index and BI = Basal index

Fig. 6.12 Influence of treatments on the food web indices: glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

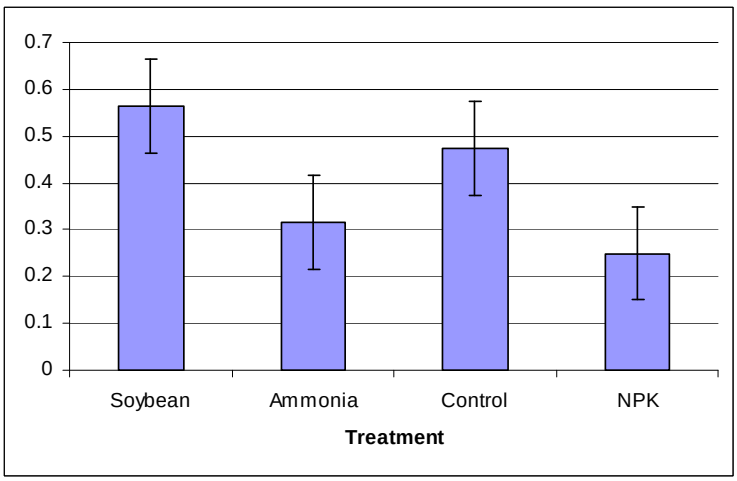


Fig. 6.13 Influence of treatments on the nematode channel ratio: glasshouse experiment at PPRI (2009). Bars represent standard errors of the mean

6.4 Discussion

Trend in nematode abundance

The temporal analysis of nematode abundance showed a strong fluctuation during the study period. In the experiments, the abundance of nematodes in the Fenamiphos and Ammonia treatments was observed to decrease drastically during 30 days after treatment application. The decrease in the abundances may be associated with toxic compounds released to the rhizosphere during mineralization of the fertilizer. Fertilization may affect free-living nematodes which are prone to environmental pollution resulting to the reduced abundance and diversity. The repellent nature of the ammonium radical can affect soil invertebrates adversely (Porter, 1993). However, the accumulation of heavy metals due to repeated fertilizations may kill omnivorous and predaceous nematodes (Weiss and Larink, 1991), resulting in reduced nematode abundances**.**

The nematode abundance in the control, manure, residual manure, residual Fenamiphos, *Tagetes* spp and residual *Tagetes* spp. treatments picked up during 30 days after treatment application, and later declined steadily towards the end of sampling. This observation suggests that time had an effect on nematodes abundance. This may result from ageing of host roots which makes it difficult for juvenile penetration for food and development, and water might have been a crucial factor that influenced such population dynamism as the soils were dry at the last two samplings following cessation of rains.

The decreasing abundance of IJs of *M. javanica* with time observed in both treatments, it can be hypothesized that the decrease in abundance of IJs observed in both treatments in the 3-day and 6-day sampling was due to chemicals realized from slow decomposition of the chicken manure and some IJs failing to adapt to the environmental conditions after inoculations. For the significant decline in the abundances of IJs observed in chicken manure plots implies that by 9-day after manure incorporation, it was able to suppress about 39 % of the initial population. Alternatively, soil quality was negatively affected by chicken manure through the increase of soil acidity and thereby adversely affecting the IJ

populations. However, this finding did not support the working hypothesis of the current study that manure application will immediately decrease the IJs population of *M. javanica*. Wang and Chao (1995) reported that the poultry manure can alter soil physical or chemical properties that kill or repel the nematode juveniles.

Trophic structure and genera distribution

The higher abundance of Rhabditidae and Cephalodidae was observed in Fenamiphos treated plots. This is probably due to the multiplication of populations which survived in the soil after the application of the nematicide. These nematodes were able to exploit the niche after elimination of other groups following disturbance by the nematicide. The large number of bacterivores found in fumigated plots agrees with findings by Yeates, Bamforth, Ross, Tate and Sparling (1991), who observed that bacteria can survive in spaces of 2.5 – 6.0 µm in diameter, which are generally unaffected by moisture fluctuations and not penetrated by fumigants. Higher abundance of fungal feeders and bacterial feeders observed in the soybean cake plots suggests that the increase might be attributed to the availability of their food substartes. Bacterial feeders are more favored by low C:N ratio substrates while material with high C:N ratio stimulates populations of fungal feeders. The higher abundance of these guilds may indicate some level of succession in the soil food web.

After treatment application, the abundance of predators and omnivores declined before increasing towards the end of the experiment. These nematode guilds are large-bodied with the lowest fecundity and the longest life cycle among soil nematodes. They are generally considered to be susceptible to soil perturbation in intensively managed soils and by pollution of soils with pesticides such as nematicides. This can give an insight to the lower abundances of these guilds in the soils observed in this study. Omnivores and predators are well known for their role to the food web by feeding on more than one food source (Coleman, Reid and Cole, 1983) and are found to present only a small portion of the total nematodes in agricultural ecosystem (Neher and Campbell, 1996). The higher abundance before the commencement of the experiments, suggested the presence of fungi

decomposing crop debris of the previous seasons and rise in their abundance towards the end of experiments is probably indicative of the presence of complex substrates available in the rhizosphere at the end of growing season requiring fungal activity for their decomposition. These findings are in agreement with Ferris *et al*. (2001) who reported that fungal nematodes only become prominent as high carbon labile substrates accumulate in the habitat as biomass of mature roots become abundant in the rhizosphere. According to Yardim and Edwards (1998) the densities of omnivores and predators may be decreased by agricultural management during the growing season and may picked up later due to high population of herbivores and bacterivores along the growing season. Such observations, partially explain the constant low abundance of predators and omnivores in the glasshouse experiment. It might be was being influenced by fluctuating populations of bacterivores and some herbivores during the growing season.

In the experiment 1, the populations of herbivores were high acroo the treatments during the sampling period. This implies they were probably connected with increased root biomass of the growing crop. In this study, dominant genera were *Helicotylenchus*, *Scutellonema*, *Pratylenchus*, *Xiphinema*, *Meloidogyne javanica* and *M. incognita* and occasionally *Criconemoides*, *Tylenchorhynchus*, *Hemicycliophora*, *Rotylenchulus*, *Trichodorus*. These findings on the abundance of the genera are in agreement with dominance of these genera in Zimbabwe as earlier reported (Page *et al*., 1985). Another study by Kandji, Ogol and Albrecht (2002) reported that though genera *Helicotylenchus* and *Scutellonema* are monovoltine species (one generation per year) they were found to be dominant in agricultural lands. The higher abundance of *Meloidogyne* spp. that was observed in both experiments support findings by Perry and Moens (2006) who observed that for nematodes with more than one generation per year, populations can increase tremendously within a short period of time in the presence a of suitable host. Also findings by Wang *et al*. (2004) hypothesized that *Meloidogyne* spp. and *Paratrichodorus* spp. nematodes may have been more abundant in micro-habitats where plant roots might have taken up soil nutrients thus resulting in lower soil nutrient concentrations.

Although abundances of dominant genera of plant-parasitic nematodes were not affected significantly by treatments, abundances of *Tylenchorhynchus* and *Hemicycliophora* were significantly increased by the NPK fertilizer compared to the control plots. The genera *Helicotylenchus, Scutellonema, Meloidogyne javanica* and *M. incognita* in that order of population densities, were observed relatively higher in NPK fertilizer plots. The result suggests that NPK fertilizer supported higher reproduction factors for plant parasitic nematodes than the rest of the treatments. According to Yeates (1987), generally the density of nematodes increases with plant productivity and is related to nutritional quality of plants in terms of tissue-nutrient concentration (Yingchun and Cheng (2007). Plowright and Hunt (1994) observed that *M. incognita* density was influenced by fertilizer application in upland rice. The nitrogen-rich seedlings are attractive food sources for young nematodes (Mattson, 1980) and are particularly vulnerable to infestation by nematodes or other pathogens (Marschner, 1995). On the other hand, mineral fertilizers are known to be the reason for softer plant tissues as carbon and carbohydrates are diverted to protein synthesis instead of cell wall construction (Akhtar and Malik, 2000), which make plants more susceptible to phytoparasites (Tsiafouli *et al*., 2007). Phosphorus reinforces plant tissues, possibly contributing to extensive root biomass production that provides more food for phytoparasite nematodes (Coyne, D., Görres, M. C. and Amodor, 2004). In a nutrient deficient experiment, Quraishi (1985) observed that omission of potassium element in soil was associated with lower population of *Pratylenchus zeae* in grape vineyards. This suggests that some nematodes may be more abundant in the presence of potassium elements.

Nematode community and food web indices

The MI is a measure of sensitivity of high c-p value nematodes to physical disturbance. There was less soil disturbance in the control plots than the rest of the plots that treatments were incorporated. Reduced disturbance showed higher values for the nematodes structural indices than where the soil was frequently disturbed. In Experiment 1, PPI values increased with sampling time and were significantly higher in manure plots. These values are determined by the vigour of their host plants which in turn is determined

by system enrichment. Consequently, under poor nutrient conditions often associated with a high proportion of Tylenchidae (c-p), the values are lower than under enriched agricultural conditions. This is an inverse response of MI to enrichment (Bongers *et al*., 1997). The plant parasitic index (PPI) is generally considered to be higher in the nutrient enriched conditions because it is affected by the host conditions. In the Experiment 3, higher PPI was observed in the control treatments. This was not expected because PPI values are normally higher in soil that has been enriched. The highest EI value observed in soybean cake plots is an indication of the response of primary decomposers or enrichment opportunists like Rhabditidae towards the labile organic material (Ferris and Matute, 2003) that might be associated with applied soybean cake.

The SI value provides information about the levels of trophic links indicated by the abundance of high c-p value nematodes mainly omnivorous and predatory nematodes in the soils. This study revealed that SI was less sensitive than EI in detecting the differences among the treatments. Nematode channel ratio NCR indicates predominant decomposition channels in the soil food web (Baniyamuddin, Tomar and Ahmad, 2007). It was observed that all the habitats had moderately enriched food webs with low EIs ranging from 0.24 to 0.41 with the exception of the ammonia plots that recorded higher 0.56 values. When the field is organic enriched, the fungivorous and bacterivorous nematodes exploit the abundant resource (fungi and bacteria), and increase rapidly in abundance due to their short life cycles and higher fecundity (Bongers, 1990). Lower values of NCR indicates slower, fungal-mediated, decomposition pathway (Wang and Sorley, 2005). It is possible to suggest on the observations of this study that; soil nutrients can influence nematode infestation in tomato production and abundance of some nematode genera can be used as an indicator of soil nutrients status.

Influence of treatment on Meloidogyne spp. sex ratio

Fenamiphos treatment influenced the abundance of male *Meloidogyne* spp. This implies that the Fenamiphos treated plots created unfavorable condition for the growth and

development of the *Meloidogyne* spp. resulting in more males. This, in turn would result in the crop being less infected since males are generally non-infective.

This study found Fenamiphos to be effective more in reducing the abundance of nematodes in the glasshouse experiment than in the field experiment. This might have been attributed to the micro-climate conditions of reduced wind speed control from excessive watering from rains. Field observations sometimes are complicated as the nematodes have a wide host range and can maintain higher densities on weeds and even cut roots (Sikora and Fernández, 2005)

6.5 Conclusion

Nematode management strategies altered nematode communities in different ways. Management regimes lead to the gradual decline of phytoparasites from organic amendments in favour of bacterivores and fungivores. Plant parasitic nematodes were more in NPK fertizer plots and communities were more diverse in control treatments. Alterations in the generic structure of the community were also revealed, driven mostly by the trends of increased in abundance of *Helicotylenchus* spp., *Scutellonema* spp. Seasonal agricultural practices appeared to induce short-term responses of functional guilds of lower c-p values, and were reflected in all nematodes indices studied except SI.

Organic fertilizers are expected to favour bacterivores and fungivores, since they act via the microbial soil component. Feeding activity of these groups stimulates decomposition and nitrogen mineralization in the ecosystem. On the other hand, mineral fertilizers are known to be the reason for softer plant tissues as carbohydrates are diverted to protein synthesis instead of cell wall construction (Tisdale and Nelson, 1975), which makes plants more susceptible to phytoparasites.

The juvenile: male ratio of the *Meloidogyne* spp. was altered by treatments. More males were observed in Fenamiphos treated plots. Reasons for the marked increase in the number of males are unclear, it is more likely that the relatively greater abundance of

males in the Fenamiphos plots is indicative of stressed or resource limited environment to the juveniles or a change in nutritional quality of dietary substrate (Boag and Thomas, 1977). However, assigning community effect to a single edaphic factor is uncertain as Moens and Vincx (2000) commented that studying single factors did not take into account the complex interactions between many of the abiotic and biotic components of the cultivars.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 General Discusion

This study evaluated the effects of land management systems under varying soil depth and practices for management of root-knot nematodes on the dynamics and composition of the nematode communities. The relations observed between nematode communities and plant inputs increased understanding on the influence of agricultural intensification on below-ground agroecosystem properties in general and nematodes in particular. Abundance of bacterivores was much higher in the 0 - 15 cm depth which leads one to suggest that they were influenced by food availability. The observations from the current study concur with other reports of (Liang *et al*., 2005) that most nematode families and genera were abundant in 0 - 15 cm depth, and vertical distribution of most nematodes are influenced by land use and suitability of factors such as temperature, moisture regime and pore size distribution. Sohlenius and Sandor (1987) suggested that bacterivoous nematodes are adapted to stable food supply and difference in their vertical distribution is probably caused partially by differences in vertical distribution of their food sources. Population densities of many nematode trophic groups, particularly bacterivores, fungivores and predators correlate positively with soil nutrients (Wang *et al*., 2004), while herbivorous nematodes (mainly *Meloidogyne* spp.) correlate negatively with most nutrients and are found more in low nutrient soils or where previous plant roots might have taken up soil nutrients (Bouwman *et al*., 1993). Some nematodes are susceptible to environmental disturbances and reside in less disturbed soils at the shallow depths. Nematodes in guilds Mononchidae, Dorylaimidae are large-bodied, and have the lowest fecundity and longest life spans of soil nematodes. They are susceptible to soil disturbance and are often absent from disturbed, polluted or intensively managed environments (Bongers, 1990).

A relationship between nematode communities' distribution and management practices in agro ecosystems were observed in this study. The higher nematode abundance observed in the agricultural soils is consistent with observations by Neher and Campbell (1996) who concluded that bacterial-feeding nematodes such as Cephalobidae and Rhabditidae, and plant-feeding nematodes are mostly abundant in agricultural soils. Omnivorous nematodes such as some Dorylaimidae (Neher and Campbell, 1996) and predatory nematodes (Moore and de Ruiter, 1991) make up a small portion of the total nematodes in agricultural ecosystems but add significantly to the soil food web through feeding on more than one food source (Coleman *at el*., 1983). In this study, higher bulk density was observed in ago-ecosystem soils than soils from Botanic Gardenss. This result may reflect the difference in agricultural intensification between the soils. Intensive cultivation in the agricultural ecosystem has resulted into compacted soil with reduced pore spaces that are vital for taking water and air for needed by plants for their food manufacturing. Armendariz and Arpin (1996) noted higher bulk density of soils in agro-ecosystems characterized by small pore size distribution and low water holding capacity. Lower populations of nematodes were found to cause more damage in a soil with poor water-holding capacity than in one with good water-holding capacity (Chen, Chen, and Dickson, 2004).

Nematodes play a significant role in decomposition of organic matter and mineralization of plant nutrients (Neher *et al*. 2005). Although abundances of nematode communities were not significantly different before application of treatments in the tomato experiments, the abundances changed after the application of the treatments. The greater abundance of bacterial feeding nematodes in the *Tagetes* spp. and manure plots was related to the organic matter incorporated into the soil. Freckman and Ettema (1983) also observed significant greater numbers of bacterial feeding nematodes in organic than in conventional farming systems a month after tomato was planted. In this study, in the Fenamiphos treated plots, bacterial feeding nematodes were dominant at the first sampling after treatment incorporation; at the last sampling Fenamiphos plots had the lowest abundances of nematode communities than in the organic and untreated plots. The

observation leads to suggested that the multiplication of surviving nematodes between the completion of nematicide application and the following sampling could have contributed to the increased abundance of bacterivorous nematodes that was observed. A previous study by Chavelier and Webster (2006) has shown temporal population increases for some opportunist bacterivores only three days after the treatment of soils by Fenamiphos. Yeates *et al*. (1991) observed values of mineral N higher in fumigated soils (after 14 days of fumigation) than untreated soils due to mineralization of substrates liberated from organisms killed by methyl bromide, and suggested that their diversity could provide a useful medium term assessment of soil ecological activities following major soil pollution or disturbance.

Findings from the effects of organic amendments experiments were both promising and inconsistent. In this present study, the effect of *Tagetes* spp on most plant parasitic nematodes was not consistent. It caused higher reproduction factors for the genera *Helicotylenchus* and *Scutellonema* and lower for *Meloidogyne* spp. These observations tally with a previous report by Karsen and Moens (2006) that effect of *Tagetes* spp. on populations of *Meloidogyne* species was highly variable. In glasshouses, Sellami and Cheifa (1997) reported that *Tagetes erecta*, grown 2.5 months prior to planting tomato, reduced root-knot density, whereas El-Hamawi and Mohamed (1990) observed that planting *T. erecta* together with tomato had only a slight effect on galling and had no effect on *M. incognita* infections. French marigold, *Tagetes patula,* reduced populations of *Rotylenchulus reniformis* (Ko and Schmitt, 1993), whereas *T. erecta* increased populations of these nematodes (Wang, Sipes and Schmitt, 2001). This discrepancy may suggest that the efficiency of marigolds on plant parasitic nematodes will depend on the combination of species and cultivar of *Tagetes* as well as species and the race of nematode. Although marigolds help to reduce nematode populations in agricultural systems, using them as intercrops is discouraged since they compete for soil moisture and nutrients in young crops (Gnanapragasam and Mohotti, 2005).

General observations based on this study, showed that organic amendments stimulated populations of free living nematodes and were less consistent on plant parasitic

nematodes. These results are supported by previous observations by (Viaene *et al*., 2006) who agreed in general that organic amendment application to soil improves crop production, primarily through improving soil fertility, and has a significant effect on the chemical, physical and biological properties of the soil, and can lead to reduced plant parasitic nematode densities. However, their effect on nematodes can vary with the nematode species, type of amendment, its content and length of time after application (McSorley and Gallaher, 1997).

Despite the fact that there are few pests with a narrow host range, crop rotation with plants that have narrow host ranges, has proved an important component in managing plant parasitic nematodes (Turner and Rowe, 2006). Acosta, Roman, Vicente and Sachez (1991) demonstrated that the yields of tomato from fields previously planted with maize were significantly higher than those from continuous tomato or tomato treated with granular nematicides. In this study it was observed that a continuous tomato cropping system had the highest number of nematodes than when a tomato crop followed a fallow, whereas the lowest number of plant parasitic nematodes were recorded in a fallow. These results add to the findings of McSorley and Gallaher (1994) who observed reduced nematode population densities and increased corn yields after land fallowing. Increased nematode populations in the cropping system tomato after tomato may be the influence of plant status and phenology than soil properties (Sanchez-Moreno *et al*., 2006). Total nematode abundance and proportions of plant parasitic nematodes increased with disturbance (Neher *et al*., 2005) and when a narrow range of crops was planted (Desaeger and Rao, 2000).

Use of plant host resistance provides an improved method of managing root knot nematode in tobacco production. The populations of *Meloidogyne incognita* and *M. javanica* able to reproduce on tobacco plants carrying the M*i* resistance gene have been reported (Ornat, Verdejo-Lucas and Sorribas, 2001). The durability of resistance has been shown to be enhanced when multiple genes for resistance are used together to reduce selection for virulence (Wilson, Gates and Panwar, 2001). However, repeated use of resistant cultivars against *Meloidogyne incognita* and *M. javanica* may result in the

selection of virulent races in these species thereby rendering the resistant cultivars susceptible (Sikora *et al.,* 2005).

In this study, tobacco in rotation with Katambora Rhodes grass had higher abundances of most families and genera of free-living nematodes than other treatments. Supporting the the same observations, Viaene *et al*. (2006) reported that grasses and cereals were generally poor hosts of *Meloidogyne* spp. and were often successful in reducing *M. javanica* and *M.incognita*. When some of these crops and grasses are incorporated into soils, they produce or release nematoxic compounds upon decomposition, resulting in biofumigation. Shepherd and Barker (1990) working in tobacco fields in Zimbabwe also observed the reduction in population of *M. javanica* in tobacco intercropped with groundnuts. The study observed considerable differences in nematode community abundances when different levels of ethylene dibromide were used in the experiment. Low nematode abundances were recovered in the higher nematicide dose i.e. 3.0 kg a.i./ha than in the 1.5 kg a.i./ha plots. It is generally accepted that the currently recommended doses usually inhibit nematode activities in the soil or roots for a limited time period, and at the end of season the final populations are often equal to the levels attained without chemical treatment (Sikora *et al*., 2005).

Fertilization is reported to influence the population abundance and composition of microbials in soils. This outcome may be a result of factors such as fertilizer quality and quantity (Neher and Barbercheck, 1999). High reproduction factors of *Meloidogyn*e, *Tylenchorhynchus* and *Hemicycliophora* spp. were observed in the NPK fertilizer plots. The same observations were reported by Verhoef and Brussaard (1990) who found addition of potassium in soil to be associated with increased reproduction rate of several nematode species, such as *Tylenchorhynchus, Pratylenchus, Meloidogyne* and *Rotylenchulus,* and excessive potassium facilitated the penetration of juveniles into host plants (Yingchun and Cheng, 2007). In this study, the population of the *M. javanica* predominated over *M. incognita* in most experiments. *Meloidogyne javanica* was reported to be dominant and more abundant than races of *M. incognita* because of its greater reproductive efficiency (Khan and Haider, 1991). More adult males of

Meloidogyne spp. were observed in the Fenamiphos treated plots which suggest that the nematicide stressed the nematode communities in the plots. These observations add to previous findings by Karssen and Moens (2006) that the proportion of males in a population varies according to plant host and the environmental conditions. Food supply may be an important factor as males are more abundant under adverse conditions. Under such conditions, male juveniles can become adults and these are generally non infectious.

Nematode community structure indices reflect changes in soil conditions, and have promise for monitoring the ecological condition of soils (Neher and Campbell, 1994). The current study recorded higher maturity index (MI) in less disturbed soils, concuring with Bongers (1990) and Bongers *et al*. (1997) who reported that MI decreasd with increasing disturbance i.e. cultivation, nutrition and chemical application. Plant parasitic index (PPI) is comparable to MI but only computed for plant parasitic nematodes. The values were low under poor nutrient conditions which is an inverse of the response of the MI to enrichment. A high structural index (SI) indicated nematode communities rich in predators and omnivores, trophic groups associated with low stress and low disturbance environments, according to Ferris *et al*. (2001; 2004). The study observed the enrichment index (EI) to vary inconsistently with different treatments suggesting that it was related to the varying levels of disturbances and enrichment regimes in the different nematode management strategies.

During decomposition of organic matter with a low C:N ratio, populations of enrichment-opportunist bacterivorous nematodes (Ba_1 guild) increased rapidly in response to additions of low C:N substrates. Nematode channel ratio (NCR) selected bacterial dominated decomposition pathways which is characterized by rapid nutrient availability for the crop. In pots where higher C:N ratio substrates dominated, NCR selected fungal dominated decomposition pathways, thus a slower mineralization rate but a longer lasting supply of nutrients to the soil, that is more desirable (Wang and McSorley, 2005).

7.2 Conclusions

The broad interest of this study was to identify management practices for nematode pests affecting tomato production in Zimbabwe with special interest on evaluating and promoting strategies and tactics that are central to their management thereby resulting in sustainable agro-ecosystems. This study has increased understanding of specific ways in which environmental factors within human management regimes altered nematode communities while suppressing root-knot nematodes in different tomato production systems. Use of soil nematodes and the indices derived from the analysis of their community structure have demonstrated that changes in soil management are either beneficial or deleterious to the soil ecology.

Findings from this study revealed that the majority of nematode communities are recovered between 0 – 30 cm depth. This study concluded that sampling deeper than the 30 cm used by the current study was a wasted effort, which may be unjustifiable unless objectives require assessment of deep-dwelling nematodes. It was observed that increase in soil disturbance i.e. cultivation, organic matter amendment supported high abundance of nematode communities. This could be attributed to the increased feeding sites for the nematodes because many roots are produced by crops due to fertilizer application. Intensive agriculture that was characterized by monocropping was observed to support higher abundance of plant parasitic nematodes and reduced species diversity compared to the less disturbed soils. This study noted suppression of numbers of plant parasitic nematodes by composted manure and supported higher abundances of free-living genera. The population of most plant parasitic genera rose during the growing seasons indicating that none of the treatments affected the population build-up for a long time. This reflects that the profitable cultivation of the susceptible host after organic amendments and Fenamiphos soil treatments which are some of the strategies recommended for management of root-knot nematode populations is possible only for one season with no advantage of residual effects for the subsequent cropping.

Well-managed crop rotations result in better use of nutrients, improved soil texture and control of some of the soil pathogens, nematodes and weeds. For successful nematode control using crop rotation, the nematode host range, including weeds, must be known for significant reduction in their populations and for an economic production of the crop. Crop rotation that involves use of non-host plants must adapt to the practices of the grower and easily marketable. The principle of controlling nematodes by leaving fields fallow is related to the fact that plant parasitic nematodes populations will decline in the absence of food. In order for fallowing to be effective as a nematode control strategy, farmers need to have sufficient land to enable them to fallow part of it for extended periods. This is usually not a viable option for Zimbabwe's smallholder farmers whose average land holding is about 3 acres.

Tagetes spp. and soybean cake were observed to stimulate the abundance of free-living nematodes in the current study. However, use of *Tagetes* spp. and soybean cake is likely to be adopted as management strategies for root-knot nematodes in vegetable Gardenss by smallholder farmers in Zimbabwe. Large quantities of soybean cake are locally available annually of which portions can be utilized to amend soil to reduce root-knot nematode infection in vegetables and increase plant growth. *Tagetes* spp. are readily available growing in diverse habitats. Smallholder subsistence farmers often have limited land on which to grow their crops, inclusion of *Tagetes* spp. in intercropping to control nematodes will be a viable option rather than in crop rotation or relay cropping. Use of host plant resistance is an important part of nematode management programs, and when available, is not a universal solution for nematode management as most examples are highly specific which can lead to selection pressure from those not targeted. For subsistence agriculture, host plant resistance plants are of little significance to farmers due to their unavailability and costs associated with them because new seeds need to be purchased in each season.

Nematicides are applied primarily to limit damage to plants by reducing the number of nematodes invading plant roots. In the current study, treatment with Fenamiphos reduced the abundance of all nematode communities and populations of fungivores and

omnivores remained the lowest at the last sampling. A notable population recovery was observed for bacterivores and plant parasitic nematodes. The population rise of the nematodes suggests that there was resilience of some nematode communities driven by their higher fecundity and probably due to suppression of their natural enemies. Fenamiphos, a non fumigant which was used in this study proved to have less residual effect on the soil as populations of nematodes were found to increase towards the end of the season. Uses of nematicides needs proper handling of the chemical and are toxic to human and environment. Although either practice alone improves yield of many crops, there are undesirable features associated with each practice have been outlined. This observation is necessitating the development of a pest programme for the management of any pest with the judicious selection of those available management techniques which are appealing to the environment and with overall economic soundness the farming community (Barkerand Koenning, 1998).

The results of this study supported the objective of using nematode communities to monitor soil health. It is proposed that in monitoring soil health status in agricultural soils, an entire nematode community has to be considered as part of the program. Contrary to the past where strategies for nematode pest management in crops focused on key plant-parasitic species, in recent years, maintenance of plant health and sustainable agro-ecosystems has broadened to encompass all trophic groups of nematode communities (plant parasites, bacterivores, fungivores, omnivores, and predators). Thus, the approach of this study looked at nematode communities as both pest and beneficial arthropods. They are pests due to direct damage to crops, by promoting *Fusarium* wilt in tomato and as vectors of tobacco rattle virus in tobacco. Free-living nematodes are regarded as beneficial because of their roles in the decomposition of organic matter, cycling minerals and nutrients, redistribution of mineral and nutrients in space and time. They also influence in detoxification of pollutants, modification of soil physical and chemical properties and biological regulators of pest species by entomopathogenic nematodes.

Finally, the future of sustainable management of nematode-pests and agricultural ecology systems must therefore address general soil health as well as specific threats from plant-parasitic nematodes, since they impair the efficiency of plants to utilize water and nutrients. The 'all or nothing approach' to nematode control, or 'fumigate them', is a thing of the past. We need to improve 'nematode management tactics' and maintain these pests at or below threshold levels. Living with them and managing them to remain at sub economic crop damage levels is the concept of the future.

7.3 Recommendations

(i) The results of this study supported my objective of the value of using nematode communities to quantify soil health. I focused mainly on understanding the effect of different human interventions from natural to intensive managed ecosystems. Further, investigation on impact of different crops on nematode communities deserves further studies.

(ii) Emphasize for training in nematology programme and regular courses to undergraduate, extension agents and farmers on how management of nematode pest while maintain soil health. Use of soybean cakes, chicken manure and *Tagetes* spp. should be encouraged because they showed to support high abundance of free-living nematodes that are substantial for organic matter decomposition and plant nutrients cyicling. Nematodes have to be considered as pest and beneficials. I explored their roles in agricultural production in this study.

(iii) Higher abundances of *Helicotylenchus* spp. and *Scutellonema* spp. were observed in both land management systems and in all strategies for management of root-knot nematode evaluated in this study. Windham (1998) found higher numbers of *Helicotylenchus* spp. and *Scutellonema* spp. associated with decline in maize yield, but Fortuner (1991) considered them as weak and moderate pathogens of most crops. This emphasizes the need for establishing the parthogenicity of these nematodes as a priority of future research undertaking.

(iv) Calculation of enrichment (EI), structure (SI) and nematode channel ratio (NCR) indices is based strictly on free-living nematodes. Therefore, plant-parasitic nematodes have been excluded and their inclusion and may provide useful information in determing the magnitude ecosystem functioning.

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APPENDICES

Appendix 3.1

5. Simplified key to common Orders of soil nematodes

When a specimen has been keyed out, please confirm the Order by cross-checking the with the description and illustration in Sections 2 and 4.

1. Spear or stylet present in mouth cavity (Fig. 5.1) ..... 2.
   Spear or stylet absent in mouth cavity (Fig. 5.2) ..... 5.

2. Spear with a conical front section attached to a straight shaft which usually has basal knobs or swellings visible (Fig. 5.1.a-e) ..... 3.
   Spear not so formed; may be needle-like, chisel-shaped or curved and bristle-like (Fig. 5.1.f-h) ..... 4.

3. Spear usually with small basal swellings or smooth (Fig. 5.1.d) ..... **Aphelenchida**
   Spear with small to well developed knobs (Fig. 5.1a-c, e) ..... **Tylenchida**

4. Spear usually chisel-shaped; rarely needle-like (Fig. 5.1.f, h) ..... **Dorylaimida**
   Spear slender, curved and bristle-like (Fig. 5.1.g) ..... **Triplonchida**

5. Oesophagus in form of a single tube or in two major parts (a basal bulb may be present) (Fig. 5.3.e, f; 5.4.b, c, f-h) ..... 8.
   Oesophagus in three major parts (i.e. anterior and posterior sections separated by a narrow section or isthmus) (Fig. 5.4.a, d, e) ..... 6.

6. Valve plates present in posterior section of procorpus (Fig. 5.4.e) ..... **Diplogasterida**
   Valve plates present in basal bulb (Fig. 5.4.a) ..... 7.

7. Stoma tube-like; not clearly formed from separate rings of cuticle (Fig. 5.2.a) ..... **Rhabditida**
   Stoma clearly formed from separate rings (Fig. 5.2.c) ..... **Cephalobida**

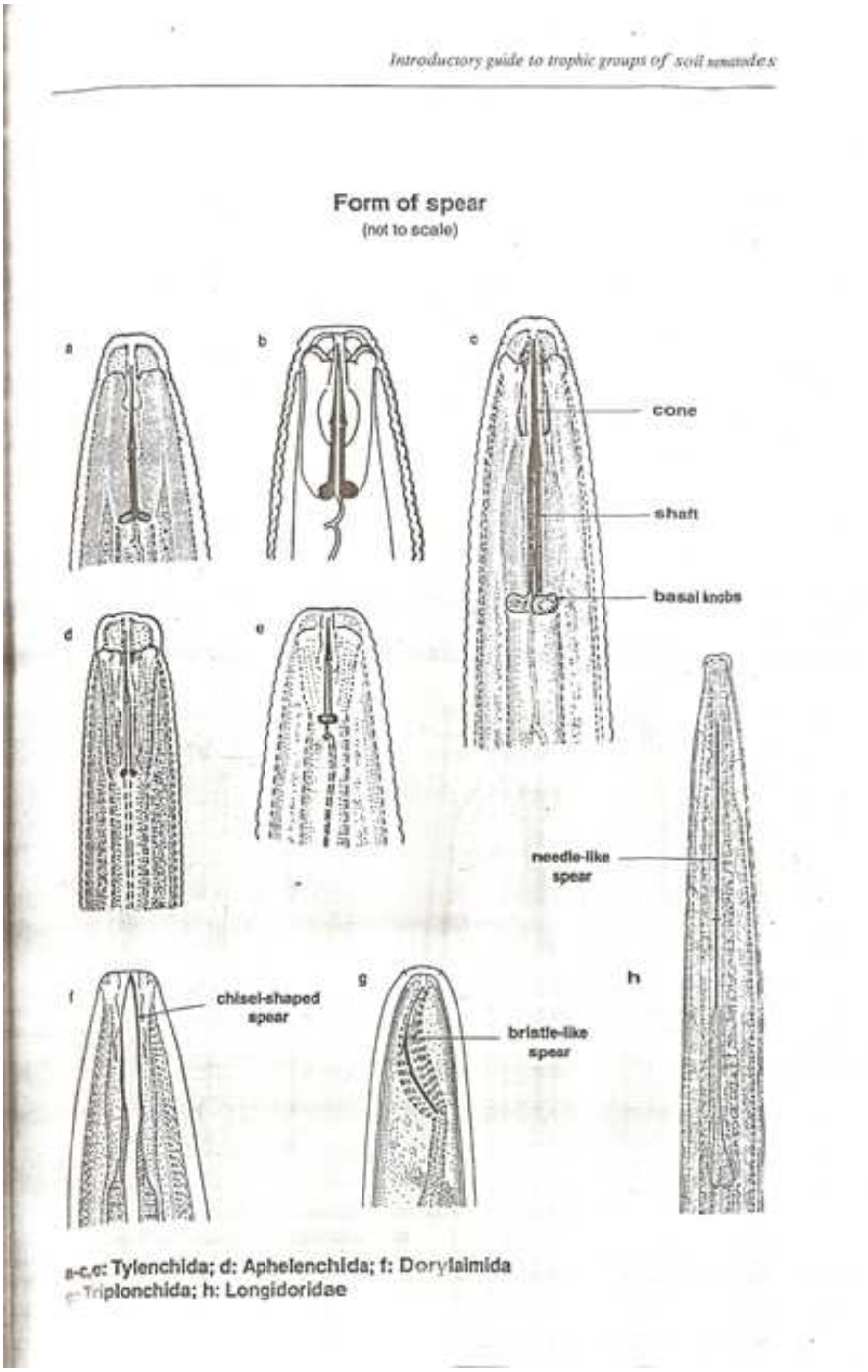
8. Oesophagus with a distinct basal bulb with valve plates (Fig. 5.4.c) ..... **Araeolaimida**
   Oesophagus lacking a distinct basal bulb with valve plates (Fig. 5.4.b, f, h) ..... 9.

9. Mouth cavity very large and barrel-shaped; armed with a conspicuous tooth or teeth (Fig. 5.2.f) ..... **Mononchida**
   Mouth cavity inconspicuous, shallow; maybe cup-shaped; but not armed with prominent teeth (Fig. 5.2.d, e) ..... 10.

10. Oesophagus well developed and cylindrical (Fig. 5.4.b); body not unusually slender and with truncate head ..... **Monhysterida**
    Oesophagus indistinct; narrow anteriorly and then slightly expanded posteriorly (Fig. 5.4.f); body unusually slender ..... **Alaimida**

Source: Hunt, D. J. (2005)

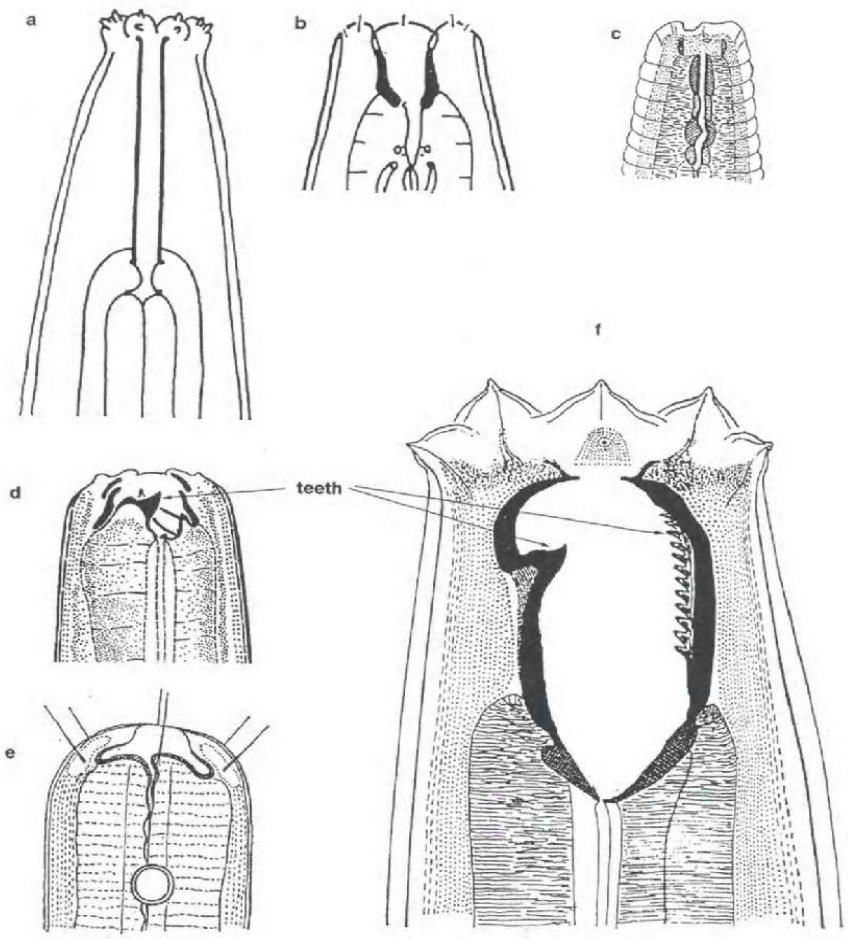
Appendix 3.2



Source: Hunt, D. J. (2005)

Appendix 3.3

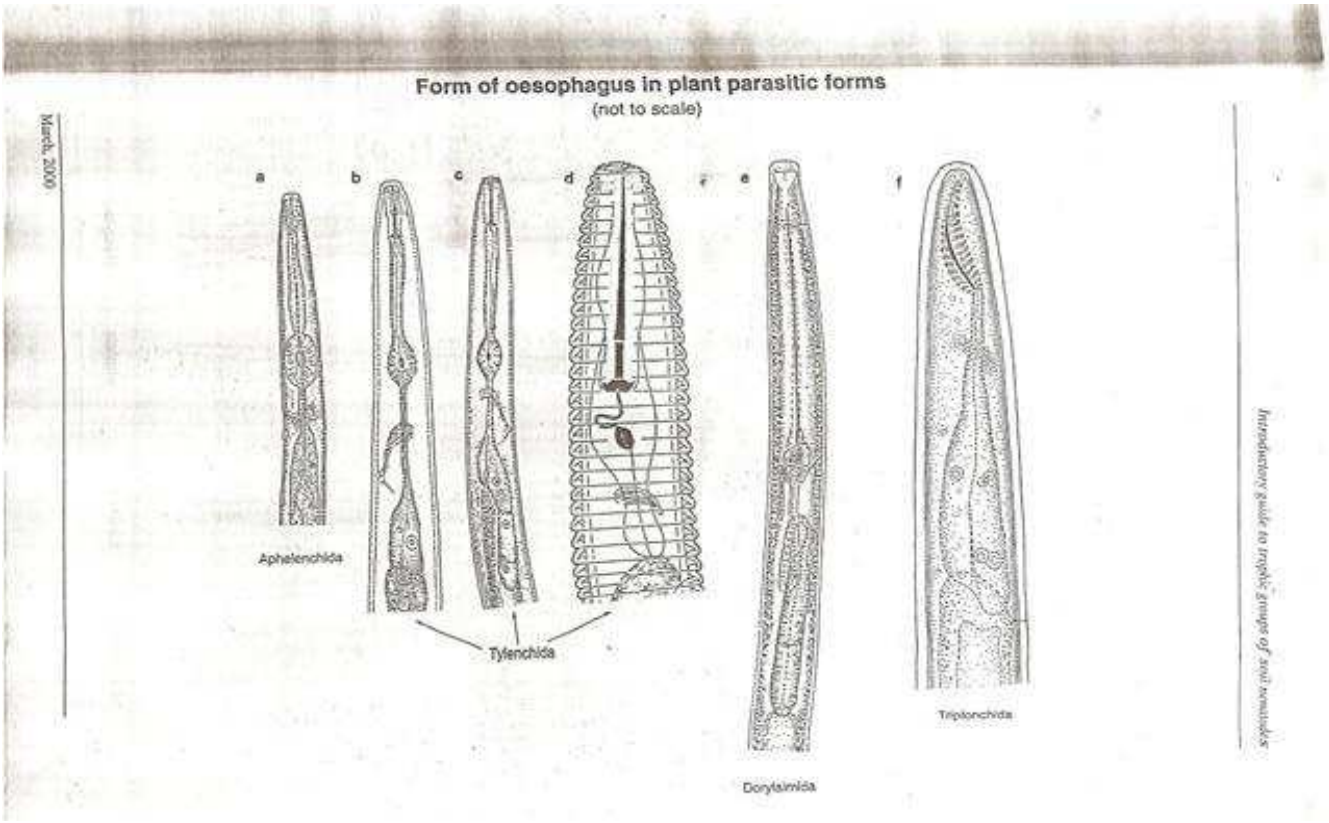
Form of stoma
(not to scale)



a, b: Rhabditida; c: Cephalobida; d: Diplogasterida
e: Monhysterida; f: Mononchida

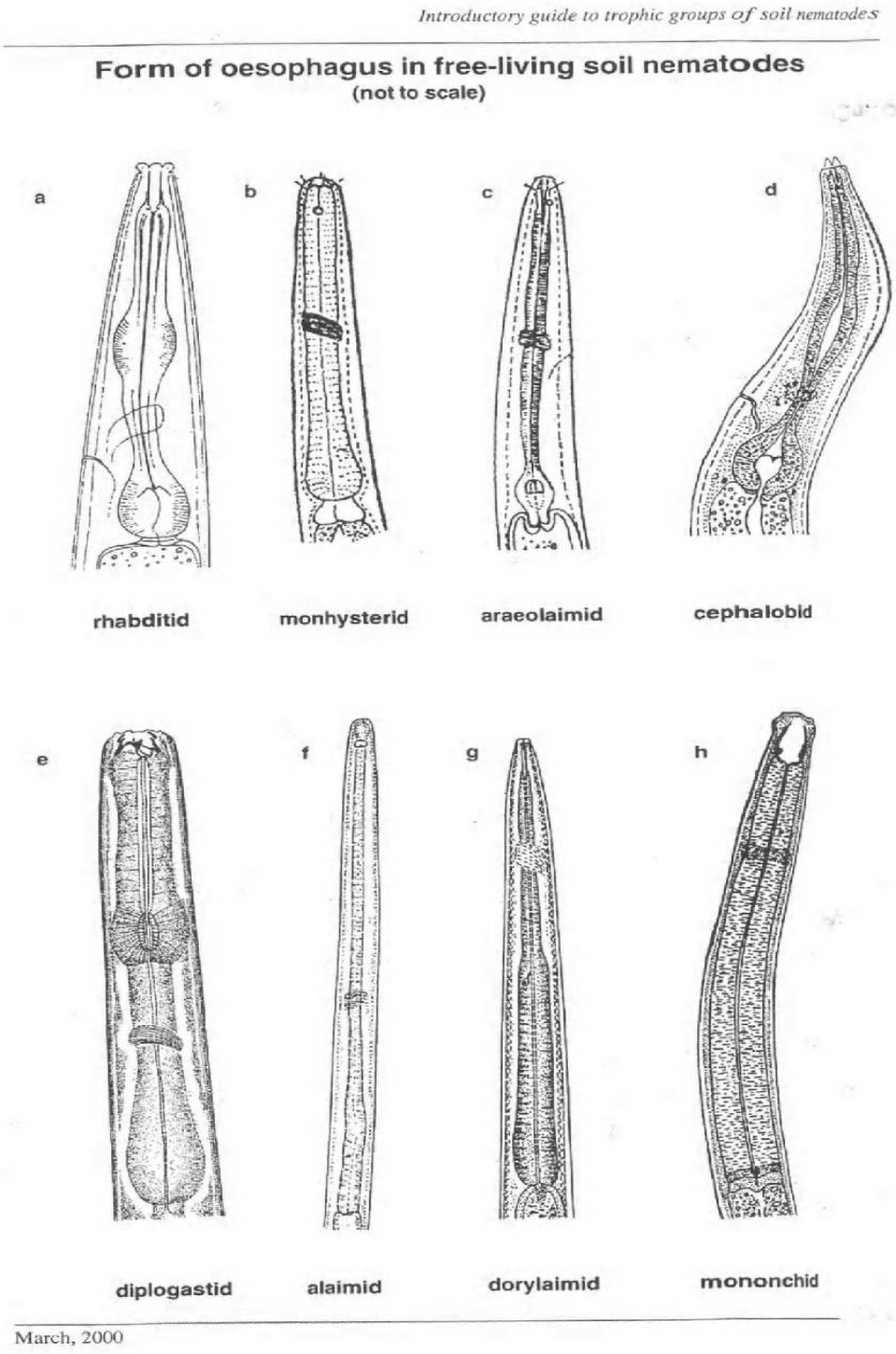
Source: Hunt, D. J. (2005)

Appendix 3.4



Source: Hunt, D. J. (2005)

Appendix 3.5



Source: Hunt, D. J. (2005)

Appendix: 4.1

Survey Questionnaire Form

Section A: Area Introduction

Location name…… Date……..
Farmer name…….
Village name……..
Type of agro-ecological zone…….

Section B: Land Use and Management History

Main crop(s) grown……
Land management system practices:

(i) Fallow……
(ii) Crop rotation……
(iii) Farm yard manure……
(iv) Continuous cropping ……..
(v) Conventional cropping……
(vi) Commercial farming……..
(vii) Subsistence farming……
(viii) Land preparation Methods
Hand hoe……..
Tractor…….
No-till practice……

Section C: Nematode Pests Management practices in Tomato

What are the different nematode management practices that you have practiced?

None……
Use of resistant or tolerant tomato varieties……
Crop rotation……
Destroy sources of infection seed treatment……
Trap crop or catch crop…….
Chemicals……
Others (Specify)……

(√ as appropriate)

Comments……
……
…….

Thank you for your valuable time spent in answering these questions

Appendix 6.1 Plant parasitic nematodes

Plate 6.1.1

Meloidogyne spp. (Female)

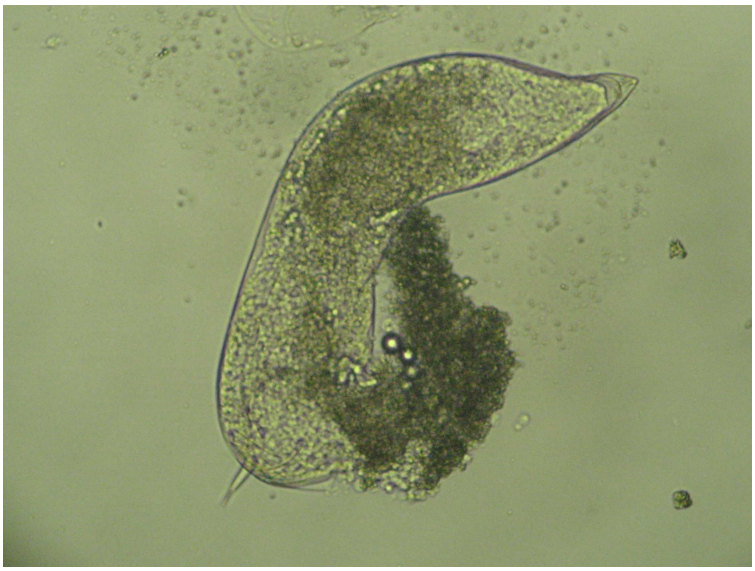


Plate 6.1.2

Pratylenchus spp.

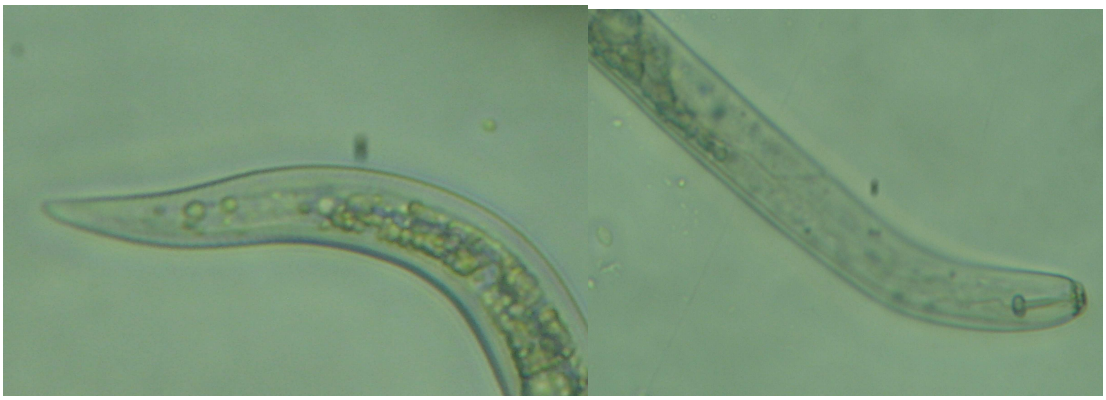


Plate 6.1.3

Hemicycliophora spp.

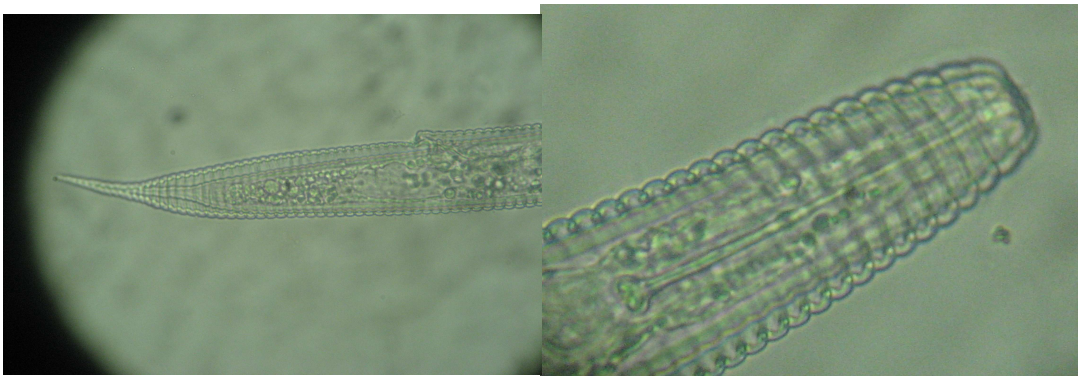


Plate 6.1.4

Xiphinema spp.

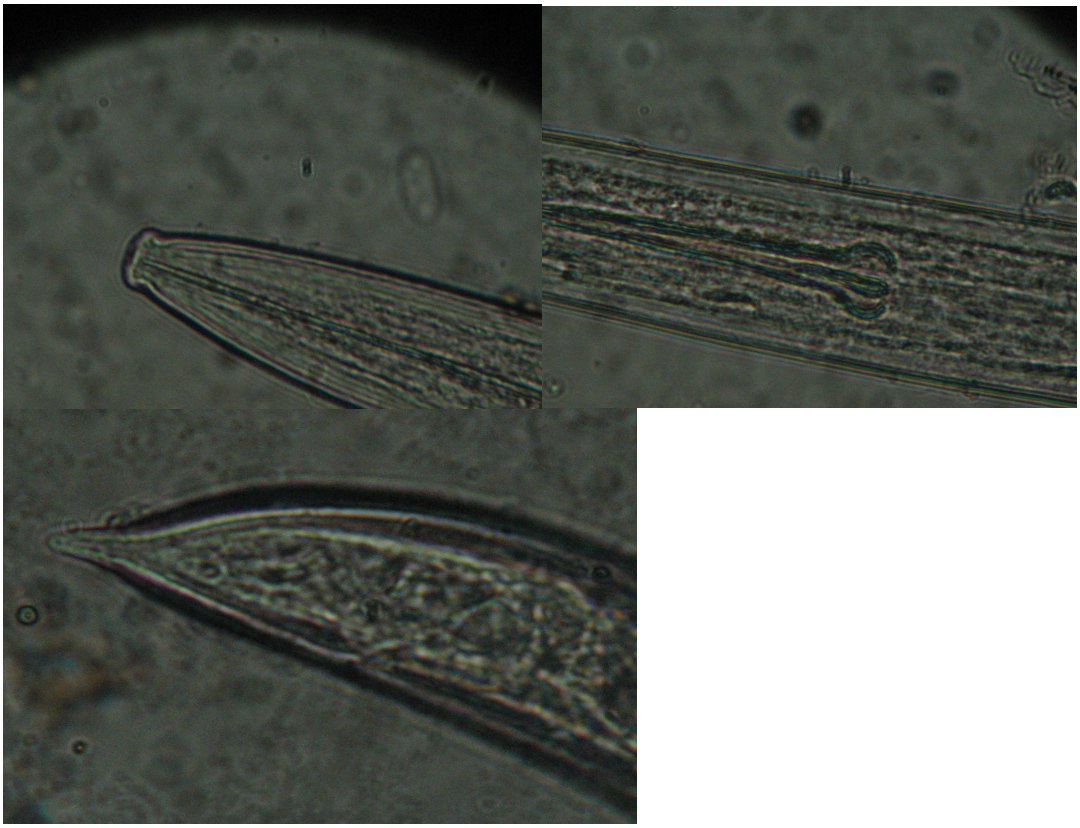


Plate 6.1.5

Tylenchorhynchus spp.

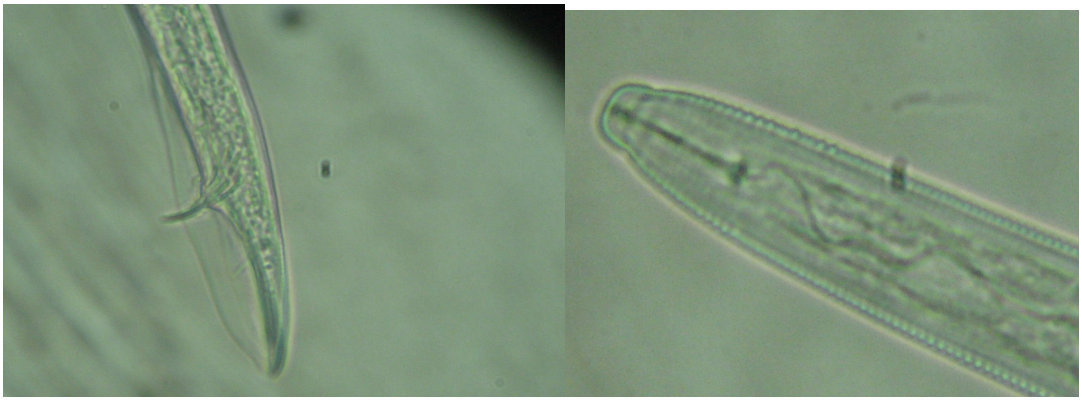
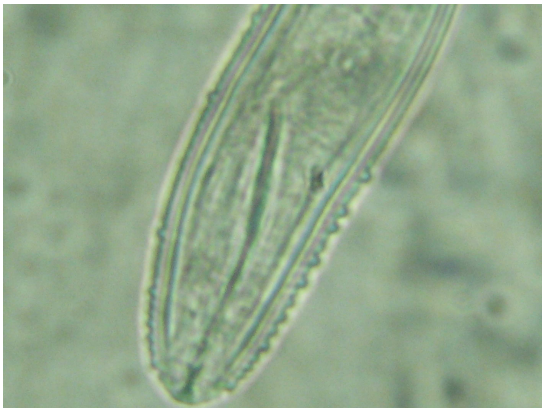
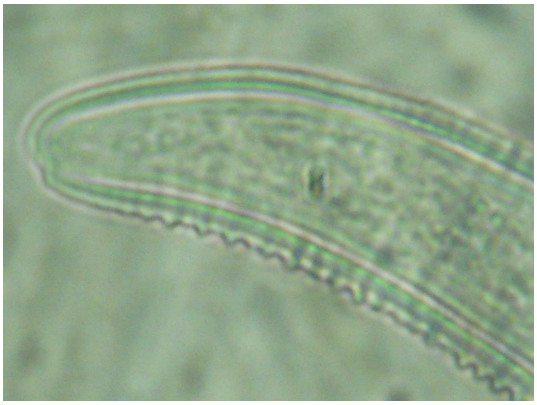


Plate 6.1.6

Trichodorus spp.





Appendix 6.2 Free-living nematodes

Plate 6.2

Bacterivore

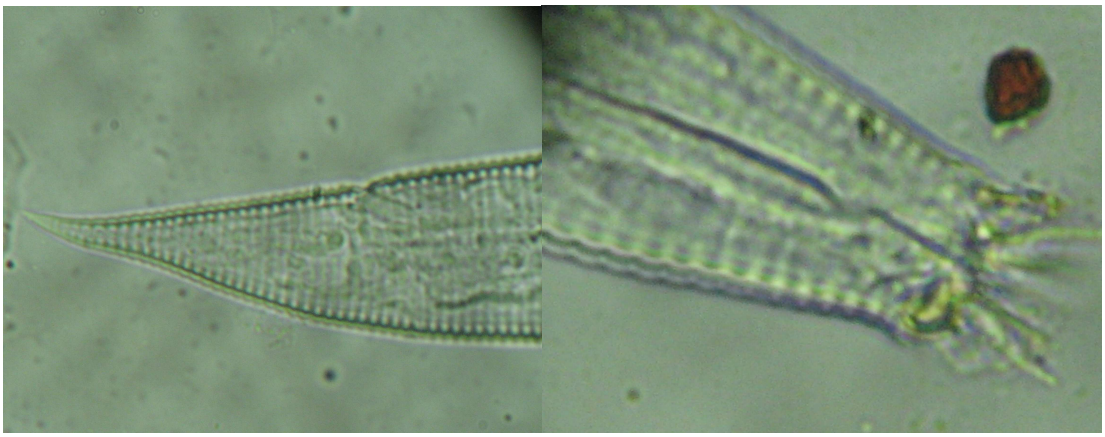


Plate 6.2.1 Fungivore

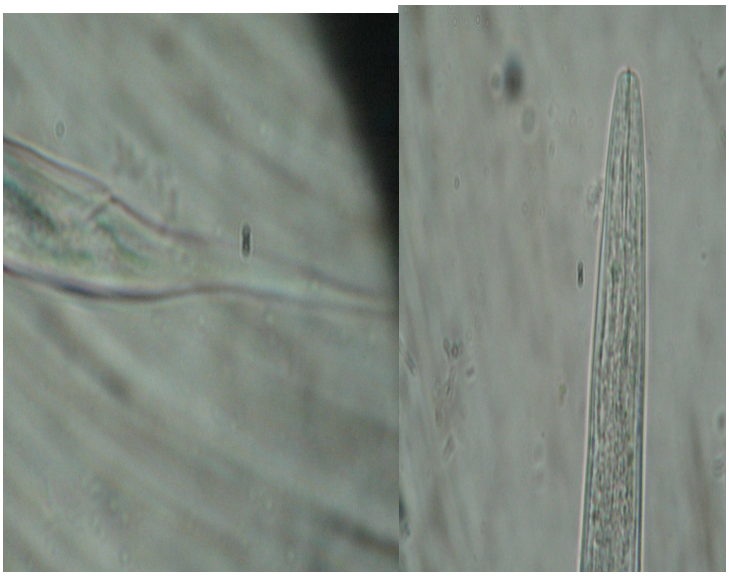


Plate 6.2.2

Omnivore

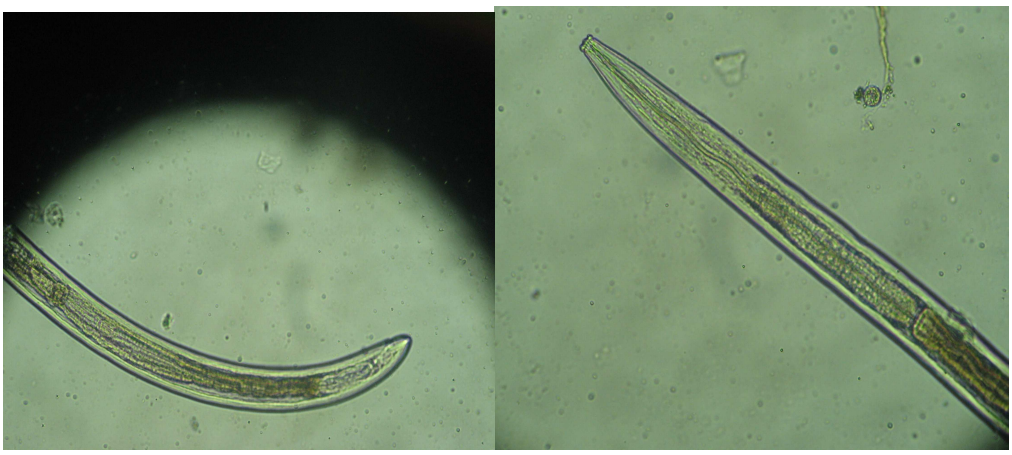


Plate 6.2.3

Predators

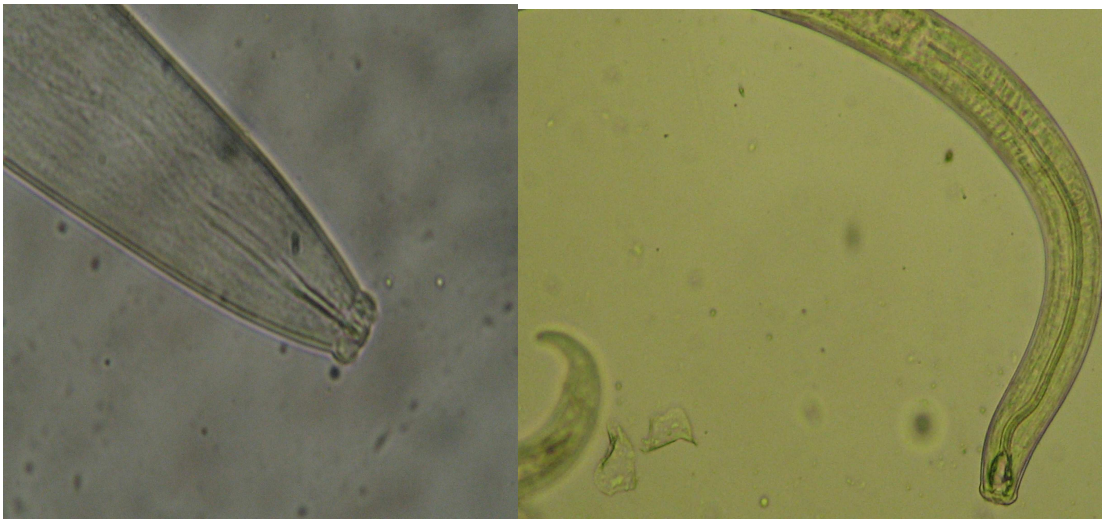


Plate 6.2.4

Meloidogyne spp. (Male)