INFLUENCE OF AGRICULTURAL PRACTICES ON SOIL PROPERTIES, ABUNDANCE AND DIVERSITY OF PLANT PARASITIC NEMATODES IN SMALL SCALE TEA FARMS IN KENYA

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DECLARATION

I, Mogeni Isaac Harrison, hereby declare that this thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

Dedicated to my wife Peris Wanjiku Mogeni and our daughter Joy Shelby Nyaboke Mogeni

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Table of Contents

List of Tables

List of acronyms and abbreviations

AAS	Atomic Absorption Spectroscopy
BF	Bacterial feeders
DAP	Di - Ammonium Phosphate fertilizer
EMCA	Environmental Management and Coordination Act
FAO	Food and Agricultural Organization
FF	Fungal feeders
GAP(s)	Good Agricultural Practice(s)
J_2(s)	Nematode Second Stage Juvenile
Kg	Kilograms
KTDA	Kenya Tea Development Agency
LH0	Lower Highland 0
LH1	Lower Highland 1
M.a.s.l.	Meters above sea level
me	Milli equivalents
MoA	Ministry of Agriculture
NEMA	National Environment Management Authority
NPK	Nitrogen, Phosphorus, Potassium
OM	Omnivores
ppm	Parts per million
PPN	Plant Parasitic Nematodes

PR	Predatory
r.p.m	Revolutions per Minute
RA	Rainforest Alliance
RKN	Root knot nematodes
s.g	Specific gravity
SAN	Sustainable Agriculture Network
TBK	Tea Board of Kenya
TESA(s)	Tea Extension Services Assistant(s)
TRFK	Tea Research Foundation of Kenya
TRI	Tea Research Institute
UM1	Upper medium 1

ABSTRACT

Tea (*Camelia sinensis* L (O) Kuntze) is a major cash crop in Kenya contributing to the economy majorly through exports. Plant parasitic nematodes are widely distributed in tea fields and cause significant yield losses. In an effort to maximize production of green leaves from tea fields, farmers practice various cultural practices. Studies were carried out to determine the influence of farming practices and soil chemical properties on the abundance and diversity of nematodes as well as to evaluate the reaction of different tea clones to root knot nematodes. The experiments were carried out in Kangaita, Kirinyaga County, Weru, Tharaka Nithi County and Kionyo, Meru County. Three farming practices namely neglected, manure applied farms and inorganic fertilizer applied farms were used to assess the abundance and diversity of nematodes as well as the chemical properties of soil. Soil samples were randomly collected from the farms, nematodes were extracted, identified and quantified and chemical analysis was conducted on the soil samples. Tea clones TRFK 31/8, TRFK 430/90, TRFK301/4, TRFK 371/3, and TRFK 306/1 were assessed for reaction to root knot nematode infestation. Growth parameters assessed included stem girth, length of internode (internode space) and number of new (harvestable) leaves. Randomized complete block design was used. In both Kangaita and Weru sites, nematodes from all the five feeding groups (plant feeders, bacterial feeders, fungal feeders, predatory and omnivorous) were recovered. Nematode numbers decreased from neglected farms to manure applied farms to standard farms. There was a general reduction of the number of leaves produced, stem girth and internode space on clones TRFK 430/90, TRFK301/4, TRFK 371/3, and TRFK 306/1. Clone TRFK 430/90 was the most severely affected as most of the plants died while clone TRFK 31/8 did not show any significant effect on growth parameters. The farming practices had a significant effect on the soil pH, N, P, K and other trace elements in

the soil. Soil acidity increased from neglected farms to manure applied farms and to NPK fertilizer applied (Standard) farms. There was a positive correlation between the soil pH and nematode abundance, species diversity and all the five nematode trophic levels. There was a negative correlation between exchangeable acidity and total organic carbon with nematode abundance and species diversity. The soils had generally low levels of potassium, magnesium and zinc due to rapid removal through harvesting of the young shoots and leaves. PPNs led to reduction in crop productivity and general physical health of tea plants. Clone 430/90 is highly susceptible to nematode attack while Clone TFRK 31/8 is tolerant to nematode infestation. The high use of NPK fertilizer led to acidifying of the soil. High soil acidity negatively affects both nematode abundance and species diversity. Farmers should follow good agricultural practices to realize maximum benefit from their farms. These includes application of inorganic fertilizers using recommended rates and use of farmyard manure to avert increase in soil acidity. Use of resistant/tolerant plant cultivars/ tea clones will also help the farmers maximize yield and returns from their farms. Clone 31/8 can be recommended for planting in areas with incidence of plant parasitic nematodes. Clone 430/90 is highly susceptible to plant parasitic nematode attack and can only be grown when methods of nematode control are employed. More research is recommended on clone 430/90 to incorporate resistance to nematode attack. Manure application can be recommended as the most appropriate farming practice to maximize yield and reduce nematode numbers in farms.

CHAPTER 1: INTRODUCTION

1.1 Background information

The agricultural sector contributes 25% of the Gross Domestic Product to the Kenyan Economy. Tea (*Camelia sinensis* L [O] Kutze) contributes 4% to the GDP nationally (Tea Board of Kenya, 2013) and 26% of the total export earnings (Tabu *et. al.,* 2015). According to TBK (2013), in the year 2013, tea earned the country Ksh. 114 billion in export earnings and Ksh. 22 billion in local sales.

Tea is a shrub believed to have originated from China (Tapan, 2004). It was originally used by the people of China as a medicinal drink (Tapan, 2004). Later, the tea was used as a relaxing and stimulating drink. The use of tea as a beverage spread from China to other parts of the world. The British became tea drinkers in the 17th century after the devastation of coffee by the coffee berry disease. They introduced tea to other parts of the world, especially in India, to counter China's monopoly in tea production (Tapan, 2004).

Tea is currently grown in many countries of the world and on various geographical locations, with suitable climate able to support its growth. Tea is cultivated in Asia, Africa, and South America with the major tea producing countries including China, India, Japan, Sri Lanka (Ceylon), Taiwan, Kenya, among others. Kenya is ranked third in terms of annual tea production after China and India (TBK, 2013).

Tea is mainly cultivated for its use as a beverage, which is popular all over the world (Tapan, 2014). It has a wide range of habitats depending on the elevation and the climate of the area. These variations in climate and geographical features affect the plant growth habits, yields and quality (Owuor *et al.* 2010; Sarkar *et al.* 2010). As such, tea is very adaptable to the climatic

conditions of a number of countries in the world. Various research institutions have come up with tea clones and varieties, which are suitable for specific climatic and edaphic conditions intended to enhance the productivity of the plant.

Nematodes are worm like organisms inhabiting a wide range of ecosystems. Some are free living while others are parasitic. According to Coleman *et al*. (1984), nematodes interact in various ways with their environment, both directly and indirectly where they regulate decomposition of organic matter and the release of nutrients to plants. Due to their important role in the complex food webs in the soil ecosystems, nematodes, both pathogenic and beneficial, need to be given special attention (Yeates *et al.* 1999; Neher, 2010). Plant parasitic nematodes feed on tea plants affecting their growth and productivity.

Most tea farmers practice monoculture but in some instances, small scale tea farmers practice intercropping during various seasons. Some of the activities carried out by small-scale tea farmers on their farms include weeding, fertilizer application, manure application, irrigation, and intercropping (mostly practiced during the pruning season). These cultural practices affect the soils as well as the health and performance of the crops (TBK, 2003).

1.2 Problem statement

Good agricultural practices (GAPs) should produce the best returns in terms of production per unit. Agricultural practices employed affect soil nutrient balance and soil physical properties which in turn affect soil biodiversity. Pests and diseases in tea hamper development of the plant leading to reduced production and eventual death of the plant. Plant parasitic nematodes affect tea plants causing diseases thus affecting the productivity of affected plants. Studies in India have shown an association of declining populations of tea with nematode infestation (Mukherjee

et al. 1982). In Kenya, Otieno *et al.* (2002) reported an outbreak of root knot nematodes in tea in Kerugoya and Imenti areas. Kamunya *et al.* (2008) recorded nematodes associated with tea in Kenya and reported that root knot nematodes were responsible for death of some tea clones. It is not known how the applied agricultural practices influence population and diversity of nematodes. It is important to establish how various farming practices applied by small-scale holder tea farmers in Kenya in various environmental conditions affect the soil chemical and physical characteristics, diversity and abundance of plant parasitic nematodes and the effects of those nematodes on the growth and productivity of tea.

1.3 Justification

In an effort to maximize yields per bush from tea farms, farmers practice various methods of farming. These practices affect the composition and population of soil microorganisms that in turn affect the plants in various ways. Research has shown that cultivated lands have lower numbers of nematodes compared to non-cultivated lands and that nematode diversity declines with increase in the intensity of cultivation (Kimenju *et al.* 2009). Farms practicing monoculture tend to have a low diversity of nematodes. Research conducted on tea farms in Ngere, Murang'a County, showed that 16 genera of nematodes existed on the tea farms studied (Kibet *et al.* 2003). These included both beneficial and pathogenic nematodes.

The research work conducted on tea farms in the past have not taken into consideration the type of farming practices applied on those farms. As a result, it is not known which type of commonly applied farming practices contribute to high or low levels of both harmful and beneficial nematodes. Consequently, it is important to establish how various agricultural practices affect the abundance and diversity of soil nematodes. It is also important to establish how the farming practices impact on the soil chemical properties and the effect of those soil properties on the

abundance and diversity of nematodes. It is also important to establish the effect of nematodes on the health, growth and productivity of the tea plant. This will help farmers choose efficient farming practices beneficial to them in terms of increased production from healthy tea plants.

1.4 Objectives of the study

The main objective of the study was to contribute to better management of nematodes in tea farms by studying the influence of commonly applied farming practices in small-scale tea farms on the establishment of soil nematodes

The specific objectives of the study were;

1. To determine the abundance and diversity of nematodes under different farming practices and tea production zones
2. To determine the soil chemical properties that influence nematode abundance and diversity in tea production zones
3. To evaluate the reaction of different tea clones to root knot nematodes

1.5 Hypotheses

- Farming practices under different tea production zones do not affect the population and diversity of soil nematodes.
- Soil properties do not influence nematode abundance and diversity.
- Tea clones do not react differently to root knot nematodes.

CHAPTER 2: LITERATURE REVIEW

2.1 Tea industry in Kenya

Tea plays a major role in the Kenyan agriculture accounting for 26% of total export earnings and contributing to about 4% of the GDP (TRFK, 2009; TBK, 2013). This cash crop supports over 650,000 small scale farmers directly and others indirectly along the value chain. Kenya is the leading tea exporter in the world accounting for 23% of total world tea export (Owuor, 2011) hence tea is an important source of foreign exchange. Kenya's tea accounts for 14% of world production. The tea industry in Kenya is divided into two sectors: Plantation and small scale. The small scale sector contributes a significant portion of the total production of over 80% of the total annual tea production. Private companies run large scale tea production in Kenya. Small-scale tea production in Kenya is organized, coordinated, and managed by the Kenya Tea Development Agency (KTDA). KTDA manages 66 tea factory companies on behalf of the farmers who are shareholders and owners of those companies. Under the management of KTDA, the small holder sector has been a success owing to the fact that farmers are paid on time (Owuor, 2011).

Despite this, the sector is still faced with a number of challenges. One major challenge is the fluctuation of prices owing to the fact that the country's local consumption is very low hence external factors highly influence the market. There is minimal value addition in Kenya as noted by Kagira *et al*. (2012) as Kenya exports 88% of her tea in bulk while the rest is sold as value added. Another challenge is the increasing cost of production affected by the cost of labor, low labor productivity, high costs of electricity, poor agronomic practices and poor extension services (Sanne van der Wal, 2008).

2.2 Ecological requirements for tea production

Successful tea cultivation requires a minimum annual rainfall of between 1200 mm and 1400 mm, well distributed throughout the year (TRFK, 2002). However, Waheed *et al*. (2013) considers optimal rainfall requirement to be 2500mm-3000mm. Tea can be cultivated from sea level to mountainous regions of up to 2700 meters above sea level (M.a.s.l) (TBK, 2013). Cultivation has also been reported in areas below sea level in Iran (TRFK, 2002). Tea requires tropical, red volcanic, acidic soils of pH between 5.0 and 5.6 (Njogu *et al*. 2013). Soil pH is an important consideration in site selection for the growth of tea (De Silva, 2007). Tea growth is affected by soil and air temperatures. Ideal air temperatures should range from 18 to 25^{o}C (Waheed *et al*. 2013). According to Waheed *et al*. (2013), temperatures below 13^{o}C lead to foliage damage while those above 30^{o}C lead to reduced shoot extension and growth due to reduced humidity. There is a direct relationship between mean air temperature and tea yields as noted by Cheserek *et al*. (2015). In Kenya, tea is mainly grown in areas experiencing moderate to cool temperatures and in highlands to mountainous regions of altitude between 1500 m to 2200 meters above sea level.

The tea growing regions in Kenya include Mt. Kenya region, the Aberdare ranges, along the Nyambene hills, the Mau escarpment, Kericho highlands, Nandi hills and Kisii highlands (TBK, 2013; TRFK, 2002).

2.3 Good agricultural practices (GAPs) in tea

In all tea farming systems, GAPs are an essential part of the farming culture to ensure production of quality tea and sustainability of the tea production. GAPs should be applied right from site selection, cultivar/planting material selection, nursery preparation, field preparation, planting, weeding, plucking, pruning, disease and pest control and chemical application. Technologies to

promote these GAPs are developed in collaboration with tea stakeholders including the Ministry of Agriculture (MoA), Tea Board of Kenya (TBK), Tea Research Foundation of Kenya (TRFK), KTDA, and multinational tea producing companies (Waarts *et al*. 2012). Other international organizations and certification bodies like Sustainable Agriculture Network (SAN), Rainforest Alliance (RA), and Fairtrade also assist in formulation, promotion and monitoring of the implementation of GAPs for sustainable production of safe teas in a safe environment while conserving the environment (Waats *et al.* 2012).

2.4 Site selection for tea growing

In Kenya, site selection for tea growing is governed by a number of national and international regulations. These include the Agricultural Act, Cap. 318 of the Laws of Kenya, the TRFK Growers' Handbook, Environmental Management and Coordination Act (EMCA) No. 8 of 1999, The Forest Act, 2005 and the stipulations of Food and Agricultural Organization (FAO). National Environment Management Agency (NEMA) requires that an environmental impact assessment is conducted in an area before the site can be licensed for tea production. This is in line with the laws governing environmental protection. Such information is disseminated to the farmers through the agricultural extension services. In KTDA, the Tea Extension Assistants (TESAs) are tasked to offer these services to farmers. Tea should also be grown in areas with favorable environmental, climatic and geographical conditions favorable for its sustainable crop production (TBK, 2003).

2.5 Farming practices in tea farms

A field prepared for tea growing should be planted with a cover crop to minimize soil erosion and environmental degradation (TBK, 2003). The young tea should also be planted together with other crops until the plantation establishes well to safeguard the soil. This will majorly depend on

the slope of the land under cultivation. Control of weeds is mostly done manually especially in smallholder tea production even though in some instances controlled chemical application is practiced (TBK, 2003).

Tea farms are pruned at an interval of 3 – 4 years depending on the productivity of the tea farm (TBK, 2003). Pruning is aimed at rejuvenating the production potential of the tea bushes by breaking the tea's reproduction cycle. It also helps to lower the plucking table for ease of tea plucking. The pruned branches of the tea plant are supposed to be left *in situ* to decompose in the farm to improve soil fertility by increasing soil organic matter. This is also important in the balance of soil micro and macro fauna. Organic matter also suppresses parasitic microorganisms like nematodes thus improving the health of the tea plants (TBK, 2003; Sultan *et al.* 2014).

In Kenya's small scale holder tea farms, chemical use in control of pests and diseases is not common. This makes tea production in this system safe from pesticide residues. Chemical use is however employed in treatment of extreme cases and for study purposes (TBK, 2003). The Pest Control Products Act, Cap 346 of the Laws of Kenya, does this under close monitoring by experts and according to the laid down procedures.

Chemical fertilizers commonly used include Di Ammonium Phosphate (DAP) and Nitrogen Phosphorus Potassium (NPK) (TBK, 2003). Double Ammonium Phosphate is used during nursery establishment and transplanting. For top dressing, NPK is used. Excessive application of fertilizer can cause imbalance in nutrient uptake and fix some nutrients leading to poor performance of the tea plant (Hamid, 2006; Thenmonzi, 2012; Sultan *et al.* 2014). In KTDA, the recommended NPK application rate is 50ks per 700 bushes (TBK, 2003).

2.6 Ecology and biology of nematodes

Nematodes are worm like multi-cellular organisms inhabiting a wide area of ecosystems. They are bilaterally symmetrical and non-segmented. Nematodes lack the respiratory and circulation systems while their excretory and nervous systems are primitive (Coleman *et al.* 1996). Nematodes interact with plants directly and indirectly and play an important role in the complex soil ecosystem, especially in regulating decomposition, release of nutrients and parasitizing on plants (Yeates *et al.* 1999; Neher, 2010).

Generally, nematodes are free-living in a wide range of environments including marine, fresh water, and soil environments. However, a number of species are parasitic and infest different species of plants and animals (O'Halloran *et al.* 2003). Free-living nematodes can survive in various environmental conditions. Some can withstand very low temperatures, below freezing point, while others have been found in hot springs (Ferris *et al.* 2008). Plant parasitic nematodes (PPN), however, can only survive in restricted temperature ranges with 27^{o}C being optimal (Agrios, 2005). PPN cannot survive temperatures beyond 50^{o}C.

Plant parasitic nematodes (PPN) normally undergo four molting stages in their life cycle from egg to adult. The larval stage, first stage juvenile (J_1), develops inside the egg. This undergoes first molting to form second stage juvenile (J2). The J_2 emerge from the egg and move in the soil until it finds a suitable and susceptible root to be its host or to feed on. In most nematodes, especially the root knot nematodes (RKN), the J_2s are the only active stage in their life cycle (Agrios, 2005). The J_2 undergoes a second molt to form a J_3. In J_3 stage nematodes lack a stylet. The third molt gives a J_4, which can be distinguished as either male or female. The fourth and final molt gives an adult nematode, which may become a free-living male nematode or a parasitic adult female.

Nematodes lay eggs in egg masses covered with a sac-like gelatinous matrix that prevents the eggs from adverse external conditions (Evans *et al.* 2009). Under favorable conditions, especially temperature, moisture and availability of food, an individual nematode can lay up to 2800 eggs and raise a nematode generation within 25 days (Agrios, 2005). Under unfavorable conditions, reproduction rate may be slowed or cease (Moens *et al.* 2009).

2.7 Nematode pathology

Plant parasitic nematodes (PPNs) cause injury to plants as they feed on them. The nematodes have a hollow feeding structure, with a stylet and a pharynx that have undergone morphological and physiological adaptations to suit the nematode's mode of feeding (Lee, 2002). They feed by forming diverse and sometimes complex feeding relationships with their host plants (Davis et *al*. 2004; Luc *et al*. 2005).

In general, PPNs use their stylet to mechanically injure plants through piercing as they withdraw and ingest nutrients from plants (Bilgrami *et al.* 2004; Guagler *et al.* 2004). In the process of feeding or in the attempt to obtain food from plants, the nematodes may also inject secretions into the plant cells weakening or modifying those plants (Gheysen *et al.* 2006).

2.8 Nematodes associated with tea

Around ten genera of bacteriophores, fungiphores and omniphores have been found to be associated with tea (Kibet *et al.* 2003; Kimenju *et al.* 2009). Plant parasitic nematodes have also been found in tea plantations. These include *Pratylenchus* spp., *Helicotylenchus* spp., *Rotylenchus* spp., *Aphelenchus* spp., *Rotylechulus* spp., *Xiphinema* spp., and *Meloidogyne* spp. Just like in other crops, RKN are found to be widely spread in tea farms (Kibet *et al.* 2003).

2.9 Management of plant parasitic nematodes in tea

Application of nematicides has been used to control PPN but the chemicals have been banned due to human health and environmental effects (Wachira *et al.* 2014). A number of studies have been conducted on the incidence and pathogenicity of nematodes in tea (Kibet *et al*, 2003; Gnapragasam *et al.* 2005; Kimenju *et al*, 2009). Such studies have however been done mainly on tea plants in nurseries or on young tea farms (Gnapragasam *et al.* 2005). As a result, management and control measures of plant parasitic nematodes have largely been developed in tea under nursery conditions. In countries like Sri Lanka and Japan where PPN are a major threat to tea farming in mature fields, a number of methods have been developed to minimize the effects on the growth, health and productivity of the tea plant. Such methods include cultural methods, physical methods, using resistant and tolerant tea varieties and clones, chemical application and biological control (TRFK, 2002; Gnapragasam *et al.* 2005).

Cultural control methods are premised on the fact that a plant is able to withstand the effects of the nematode damage if it can grow vigorously and replace the damaged parts at a high rate (Gnapragasam *et al.* 2005). Therefore, those cultural methods that enhance growth are used such as incorporation of organic matter, soil cultivation (forking) to prevent soil compaction and remove hard pans that impede the normal replenishment of damaged and dying feeder roots, fertilizer application, use of cover crops, planting antagonistic crops and irrigation (Gnapragasam *et al.* 2005).

2.10 Influence of land use practices on abundance and diversity of nematodes

Biodiversity is the variety of life below the ground and it's an indicator of sustainable land use (Wachira *et al.* 2014. Soil hosts a wide range of microbes (fungi and bacteria), macrobes

(termites and earthworms) and mesofauna (acari, collembolan and nematodes) (Bardgett, 2005; Wachira *et al.* 2014). The occurrence of this biodiversity is greatly affected by human activities. Wachira *et al.* (2014) noted that land use affects soil characteristics like carbon percentage which was highest in least disturbed land. Wachira *et al.* (2014) further noted that soil nematodes were affected by land use types whereby they were least reported in tea land. This was attributed to low biological activity in tea husbandry and the monocrop husbandry characteristic in tea growing. Soil chemical properties, agro-ecological zones and land management levels also affect the distribution and abundance of nematode species as noted by Nzesya *et al.* (2014). Nzesya *et al.* (2014) noted that farms that are well managed had less plant parasitic nematodes.

CHAPTER 3: INFLUENCE OF FARMING PRACTICES ON THE ABUNDANCE AND DIVERSITY OF PLANT PARASITIC NEMATODES IN SMALL SCALE TEA FARMS IN KIRINYAGA AND THARAKA-NITHI COUNTIES OF KENYA

3.1 Abstract

Nematodes are known to be well distributed in tea farms. Farming practices are known to influence positively or negatively the nematode populations. Studies were carried out to determine the influence of farming practices on the abundance and diversity of nematodes in small scale tea farms. The experiments were carried out in Kangaita, Kirinyaga County and Weru, Tharaka-Nithi County using randomized complete block design. Three commonly used farming practices were used as treatments. These farming practices were neglected farms, inorganic fertilizer applied farms with regular weeding and prescribed pruning (standard) and manure applied farms. Soil samples were randomly obtained from each farm representing farming practices in three agro-ecological zones in each of the two study sites namely lower highland sub zone 0 (LH0), lower highland subzone 1 (LH1) and upper medium subzone 1 (UM1). Nematodes were extracted from the soil samples in the laboratory using centrifugal floatation technique. The extracted nematodes were identified, classified and quantified. Nematodes from 23 genera were recovered in the two study sites representing all the five feeding groups; plant feeders, fungal feeders, bacterial feeders, omnivores and predatory nematodes. Of the 23 genera, 11 were plant feeders, 6 bacterial feeders, 3 fungal feeders 2 omnivores and 1 predatory nematode. Nematode numbers decreased from neglected farms to manure applied farms to NPK fertilizer applied farms. The nematode species diversity was highest in neglected farms followed by manure applied farms and lowest in inorganic fertilizer applied (Standard)

farms. Application of inorganic fertilizer (NPK) leads to reduction of both nematode abundance and species diversity.

3.2 Introduction

Kirinyaga and Tharaka-Nithi counties are some of the major tea growing areas in Kenya representing the Mt. Kenya region, others being Nyambene hills, the Mau escarpment, the Aberdare ranges, Kericho highlands, Nandi hills and Kisii highlands (TBK, 2013). Tea is grown in these areas mainly for export while a small percentage is consumed locally (TRFK, 2009; TBK, 2013). Farmers engage in various cultural practices with the aim of maximizing profit from their farms. The practices include inorganic fertilizer application manure application and neglect of the farms. The practices affect the soil microorganisms which in turn affect not only the nutrient availability and uptake of the plant, but also the health and productivity of the tea plant (Hamid, 2006; Thenmonzi, 2012; Sultan *et al.* 2014). The study was carried out with the aim of evaluating the impact of farming practices on the abundance and diversity of plant parasitic nematodes.

3.3 Materials and Methods

3.3.1 Study area

The study was carried out in already established small-scale tea farms in Kirinyaga and Tharaka-Nithi counties of Kenya. The two counties were chosen to allow for comparison between various ecological zones. One tea factory catchment managed by KTDA was chosen per county. Each factory catchment was zoned into three based on elevation, that is, high, medium and low elevation as represented in agro-ecological zones LH0, LH1 and UM1 as described by Jaetzold *et al.* (2010).

Three farms were randomly selected per farming practice of interest in each of the three zones in each factory catchment with the help of the Agricultural Services Department of the KTDA managed factories within the two counties. Kangaita area, Kirinyaga County was chosen because it is located in high elevation with most of the farms lying above 2,000 meters above sea level while Weru, Tharaka-Nithi County was chosen because most of its farms lie in low elevation of about 1,400 meters above sea level.

3.3.2 Selection criteria for farming practices

Information used to classify the farms into the three farming practices were given by the tea extension department in each of the factory where the study took place. A standard farm was chosen if the farm was kept weed free throughout the year, inorganic fertilizer applied annually and the tea farm pruned at the interval of three years as recommended. A manure applied farm was selected if the farm followed same practice as a standard farm with additional application of farmyard manure at recommended rates of one bucket per bush at the interval of three years. A farm was considered neglected if it was left weedy and with neither inorganic fertilizer application nor manure application for at least three years.

3.3.3 Experimental design

The experiments were set up in a randomized complete block design. Soil samples were collected from different farms applying the three different farming practices. Three types of agricultural/farming practices were considered across the ecological zones within the area of study. These were non-cultivated (neglected) farms, cultivated farms with regular application of NPK fertilizer and farms practicing organic farming with organic mulching and/or manure application.

The factory catchments were zoned into three zones depending on elevation using agro ecological zones as described by Jaetzold *et al.* (2010). Three farms per farming practice per zone were selected and sampled. Five sub-samples were randomly obtained from each farm. Twenty-seven samples were collected from the three farming practices replicated three times. The samples were transported in a cool box to the laboratory for analysis.

3.3.4 Soil sampling

Random sampling was done in each farm under study. Five sub samples of 200g each were collected in each farm using a soil auger from the surface to a depth of 45 cm. The soil sub samples were thoroughly mixed to come up with a composite sample of 500g. Twenty-seven farms were sampled per county making total sampled farms 54. The 54 samples were transported to the laboratory in a cool box at 15^{o}C for analysis. The samples were divided into three parts; 200g for nematode extraction, 200g for soil chemical properties and 100g library sample.

3.3.5 Extraction of nematodes from the soil, their identification and quantification

The nematodes were extracted using centrifugal floatation technique as described by Jenkins (1964). This involved first dissolving the 200g soil sample in 5 liters of water in a bucket and stirring to make homogenate slurry. The stirring was done to release the nematodes from the soil. The slurry was then passed through sieves of fine apertures; 250µm, 150 µm and 38 µm sieves. The slurry collected from the 38 µm aperture sieve was backwashed and loaded into 50 ml falcon tubes. The mixture in the tubes was centrifuged at 1700 rpm for 7 minutes. The supernatant obtained from the first spin was discarded and the pellet was topped up with sugar solution to balance at the 30ml mark. The sugar solution was prepared by dissolving 454g of sugar in 1 liter of water. This formed a sugar solution at 1.18 s.g. The contents of the falcon tubes topped up with the sugar solution underwent a second spin at 1700 rpm for 3 minutes. The

supernatant formed was then passed over a 38µm sieve and the contents backwashed to make a 3 ml nematode suspension. The suspension was placed in tubes and the nematodes were fixed using formalin at 75^{o}C. The nematodes were identified using morphological features to genus level by observation through a compound microscope. The nematode numbers per genera were determined by counting.

3.3.6 Statistical analysis

All statistical analysis was done using GENSTAT edition 14 statistical software. The data was subjected to ANOVA. Comparison of treatment means was done and the data obtained interpreted.

3.4 Results

Nematodes from 19 different families and 23 genera were recovered from the soil obtained from the three farming practices in the two study sites; Kangaita and Weru (Table 3.1). These nematodes could be grouped into the five main trophic levels namely herbivores/plant feeders (PF), bacterial feeders (BF), Fungal feeders FF), omnivores (OM), and predatoty (PR) nematodes as described by Yeates *et al.* (1993). The nematodes were assigned to the Colonizer-Persister value (C-P Value) based on a scale of 1-5 as described by Bongers, (1990) (Table 3.1). C-P 1s are colonizers characterized by short generation time while C-P 5s are persisters characterized by long generation time.

Out of the 23 recovered nematode genera, eleven of them were plant parasitic nematodes (Plant Feeders). The plant parasitic nematodes identified were *Criconemella* Spp., *Filenchus* Spp., *Helicotylenchus* Spp., *Hemicyclophora* Spp., *Heterodera* Spp., *Longidorus* Spp., *Meloidogyne* Spp., *Pratylenchus* Spp., *Rotylenchus* Spp., *Tricodorus* Spp., and *Tylenchus* Spp (Tables 3.1).

Six genera of Bacterial feeders were identified and these included *Alaimus, Cephalobus, Cervidellus, Eucephalobus, Prismatolaimus,* and *Wilsonema*. Three Fungal feeding nematode genera were identified including *Aphelenchus, Ditylenchus* and *Leptochus.* Two genera of Omnivorous nematodes identified were *Dorylaimus* and *Prodorylaimus.* Only one genus of predatory nematodes was identified and this was *Mononchus* (Tables 3.1).

1. Table 3.1: Family, genera, C-P value and trophic groups of nematodes recovered at Kangaita and Weru

Family	Genera	C-P Value	Trophic Group
Alaimidae	Alaimus	4	BF
Aphelenchidae	Aphelenchus	2	FF
Cephalobidae	Cephalobus	2	BF
Cephalobidae	Cervidellus	2	BF
Criconematidae	Criconemella	3	PF
Anguinidae	Ditylenchus	2	FF
Dorylaimidae	Dorylaimus	4	OM
Cephalobidae	Eucephalobus	2	BF
Tylenchidae	Filenchus	2	PF
Hoplolaimidae	Helicotylenchus	3	PF
Hemicyclophoridae	Hemicyclophora	3	PF
Heteroderidae	Heterodera	2	PF
Leptonchidae	Leptochus	4	FF
Longidoridae	Longidorus	5	PF
Meloidogynidae	Meloidogyne	3	PF
Monochidae	Mononchus	4	PR
Pratylenchidae	Pratylenchus	3	PF
Prismatolaimidae	Prismatolaimus	3	BF
Bunonematidae	Prodorylaimus	5	OM
Hoplolaimidae	Rotylenchus	3	PF
Trichodoridae	Trichodorus	4	PF

Tylenchidae	Tylenchus	2	PF
Plectidae	Wilsonema	2	BF

C-P – colonizer persister, PF – plant feeders, BF – bacterial feeders, FF – fungal feeders, PR – predatory, OM - omnivores

Nematode numbers varied significantly ($P<0.05$) across the zones and among the farming practices in both study sites (Tables 3.2 and 3.3). Generally, it was observed that the nematode numbers were highest in neglected farms, followed by manure applied farms and least in NPK fertilizer applied (standard) farms (Tables 3.2 and 3.3).

2. Table 3.2: Nematode species recovered at Kangaita and their distribution in the three farming practices across the three zones

Zone	Upper			Medium			Lower					
Genus	Normal	Manure	Neglected	Normal	Manure	Neglected	Normal	Manure	Neglected	LSD	C.V%	P Value
Alaimus	5.00bcd	6.67de	8.67ef	2.67ab	6.00cde	9.67f	3.67bc	0.00a	9.67f	2.79	28.00	<.001
Aphelenchus	15.00b	32.67d	9.67a	19.33c	31.00d	16.00b	13.00b	37.67e	30.67d	3.05	7.70	<.001
Cephalobus	14.67ab	22.00c	21.67c	13.33a	22.33c	18.67bc	17.67abc	17.67abc	20.67c	5.04	15.60	0.012
Cervidellus	0.00a	0.00a	0.67b	0.00a	0.00a	0.67b	0.00a	0.00a	0.67b	0.61	159.10	0.045
Criconemella	13.33e	1.67a	6.33c	11.33d	2.67ab	3.67b	10.00d	3.67b	6.00c	1.76	15.60	<.001
Dorylaimus	2.33c	0.00a	0.00a	1.67b	0.00a	0.00a	2.00bc	0.00a	0.00a	0.45	39.50	<.001
Ditylenchus	0.00a	0.00a	2.33b	0.00a	0.00a	2.33b	0.00a	0.00a	2.00b	1.60	124.90	0.006
Eucephalobus	2.33a	17.67bc	26.00d	3.00a	15.00b	17.33bc	2.33a	19.33bc	19.33bc	4.91	20.60	<.001
Filenchus	2.67a	1.33a	18.67d	11.33c	3.33a	24.33e	6.67b	1.67a	18.67d	2.60	15.30	<.001
Helicotylenchus	3.67ab	1.67a	5.67bc	5.33bc	2.67a	6.33c	9.67d	2.67a	9.67d	2.01	22.10	<.001
Hemicyclophora	0.00a	0.00a	2.67b	0.00a	0.00a	3.00b	0.00a	0.00a	3.33b	1.71	99.30	<.001
Heterodera	0.00a	0.00a	1.00ab	0.00a	0.00a	1.33b	0.00a	0.00a	1.33b	1.09	159.90	0.034
Leptonchus	9.33cd	6.33abc	9.00cd	4.33a	9.00cd	10.67d	8.33bcd	5.00ab	11.33d	3.54	25.20	0.007
Longidorus	1.33ab	3.33c	1.00ab	0.00a	3.67c	1.00ab	0.00a	2.33bc	1.00ab	1.48	56.30	<.001
Meloidogyne	0.00a	10.33b	37.67e	25.00d	63.67g	41.67f	14.33c	7.67b	34.00e	3.78	8.40	0.005
Mononchus	0.67ab	2.00b	5.33c	0.00a	1.33ab	5.33c	0.00a	2.00b	6.00c	1.8	41.50	<.001
Pratylenchus	0.00a	0.00a	1.67b	0.00a	0.00a	1.67b	0.00a	0.00a	1.67b	1.22	127.30	0.007
Primastolaimus	0.00a	8.67bc	8.33bc	0.00a	11.00cd	7.33b	0.00a	12.00d	8.33bc	3.13	29.30	<.001
Prodorylaimus	0.00a	0.67ab	3.67e	0.00a	0.67ab	1.67cd	0.00a	1.00bc	2.00d	0.92	49.90	<.001
Rotylenchus	0.00a	0.00a	5.67bc	0.00a	0.00a	6.00c	0.00a	0.00a	4.67b	1.33	42.40	<.001
Trichodorus	0.00a	0.00a	3.33c	0.00a	0.00a	2.67bc	0.00a	0.00a	2.33b	0.85	53.50	<.001
Tylenchus	8.33bc	4.67a	16.67d	9.67c	4.33a	21.00e	10.67c	6.00ab	36.00f	3.13	13.90	<.001
Wilsonema	4.33c	0.00a	22.00c	6.67b	0.00a	25.00c	4.67b	0.00a	25.00c	3.13	18.80	<.001

Means followed by a different letter(s) within the same row are significantly different. Upper - LH0, Medium - LH1, Lower - UM1

3. Table 3.3: Nematode species recovered at Weru and their distribution in the three farming practices across the three zones

Zone	Upper			Medium			Lower					
Genus	Normal	Manure	Neglected	Normal	Manure	Neglected	Normal	Manure	Neglected	LSD	C.V%	P Value
Alaimus	1.00a	0.00a	7.00b	1.00a	0.00a	7.33b	1.00a	0.00a	7.00b	2.14	45.90	<.001
Aphelenchus	8.00c	11.00d	2.33a	5.33b	13.00d	4.67ab	4.67ab	16.33e	4.00ab	2.41	18.10	<.001
Cephalobus	3.33b	25.33f	6.67c	1.33a	22.67e	13.33d	3.67b	25.33f	8.00c	1.70	8.00	<.001
Cervidellus	0.00a	0.00a	0.67b	0.00a	0.00a	0.67b	0.00a	0.00a	0.67b	0.57	150.00	0.029
Criconemella	8.33e	5.67bc	4.67b	7.33cde	7.67de	1.33a	8.33e	6.33bcd	4.67b	1.67	16.10	<.001
Dorylaimus	0.00a	1.33b	4.33c	0.00a	1.33b	4.00c	0.00a	1.33b	3.33c	1.30	43.20	<.001
Ditylenchus	0.00a	0.00a	1.33b	0.00a	0.00a	1.67b	0.00a	0.00a	1.33b	0.60	72.10	<.001
Eucephalobus	7.67b	14.67cd	25.33f	5.33ab	12.00c	14.67cd	4.33a	15.67d	20.67e	2.94	12.70	<.001
Filenchus	2.00a	8.33b	17.00c	3.33a	5.33ab	17.67cd	4.33ab	8.67b	22.33d	4.78	28.00	<.001
Helicotylenchus	2.33a	4.33abc	8.33e	2.67ab	2.67ab	7.67de	6.33cde	5.33bcd	7.00cde	2.92	32.60	0.002
Hemicyclophora	0.00a	0.00a	6.00b	0.00a	0.00a	7.33b	0.00a	0.00a	6.67b	1.64	42.80	<.001
Heterodera	0.00a	0.00a	6.33b	0.00a	0.00a	6.67b	0.00a	0.00a	7.00b	1.75	45.60	<.001
Leptonchus	0.00a	1.67b	4.67c	0.33ab	1.67b	3.33c	0.00a	1.33ab	3.33c	1.54	49.30	<.001
Longidorus	0.00a	0.00a	2.33c	0.00a	0.00a	1.67b	0.00a	0.00a	1.33b	0.60	58.50	<.001
Meloidogyne	8.33ab	5.00a	23.67c	10.33b	10.00b	22.00c	10.33b	10.00b	24.33c	3.73	15.70	<.001
Mononchus	0.67a	2.00b	4.00c	0.67a	2.00b	5.33d	2.33b	2.33b	5.00cd	1.30	27.80	<.001
Pratylenchus	3.67b	0.00a	7.33c	3.33b	0.00a	7.00c	1.67ab	0.00a	6.67c	2.14	37.60	<.001
Primastolaimus	1.67b	0.00a	6.33c	1.67b	0.00a	6.67cd	1.33ab	0.00a	8.00d	1.54	31.40	<.001
Prodorylaimus	0.00a	0.00a	1.67b	0.00a	0.00a	1.33b	0.00a	0.00a	1.33b	0.75	90.50	<.001
Rotylenchus	4.33a	0.00a	123.33c	2.00a	0.00a	110.33b	4.67a	0.00a	127.33c	8.85	12.40	<.001
Trichodorus	0.00a	0.00a	2.33b	0.00a	0.00a	2.00b	0.00a	0.00a	2.00b	0.69	57.20	<.001
Tylenchus	5.00a	8.67ab	45.67f	7.33ab	11.00bc	38.33e	18.67d	14.33c	52.00g	4.29	11.10	<.001
Wilsonema	0.00a	2.00b	1.33ab	0.00a	1.33ab	1.67b	0.00a	1.67b	2.00b	1.49	77.90	<.001

Means followed by a different letter(s) within the same row are significantly different. Upper - LH0, Medium - LH1, Lower - UM1

The nematode numbers varied significantly ($P<0.05$) among the three farming practices in the two study sites (Tables 3.4 and 3.5). At Kangaita, seven nematode species recorded in the neglected tea farms were not recorded in the other two farming practices. These nematodes include *Cervidellus spp.*, *Ditylenchus spp.*, *Hemicyclophora spp.*, *Heterodera spp.*, *Pratylenchus spp.*, *Rotylenchus spp.*, and *Trichodorus spp*. (Table 3.4). Similarly, at Weru, seven nematode species recorded in the neglected teas farms were not recorded in the other two farming practices. These include *Cervidellus spp.*, *Ditylenchus spp.*, *Hemicyclophora spp.*, *Heterodera spp.*, *Longidorus spp.*, *Prodorylaimus spp.*, and *Trichodorus spp*. (Table 3.5).

4. Table 3.4: Nematode numbers and their distribution in the different farming practices at Kangaita

Genus	Manure	Standard	Neglected	LSD	C.V%	P Value
Alaimus	4.22a	3.78a	9.33b	2.31	39.90	<.001
Aphelenchus	33.78b	15.78a	18.78a	6.01	26.40	<.001
Cephalobus	20.67b	15.22a	20.33b	3.51	18.70	0.007
Cervidellus	0.00a	0.00a	0.67b	0.29	129.90	<.001
Criconemella	2.67a	11.56c	5.33b	1.60	24.50	<.001
Dorylaimus	0.00a	2.00b	0.00a	0.29	43.30	<.001
Ditylenchus	0.00a	0.00a	2.22b	0.86	115.50	<.001
Eucephalobus	17.33b	2.56a	21.44c	3.26	23.70	<.001
Filenchus	2.11a	6.89b	20.56c	2.03	20.60	<.001
Helicotylenchus	2.33a	6.22b	7.22b	1.64	31.30	<.001
Hemicyclophora	0.00a	0.00a	3.00b	0.87	86.60	<.001
Heterodera	0.00a	0.00a	1.22b	0.56	137.70	<.001
Leptonchus	6.78a	7.33a	10.33b	2.91	35.70	0.042
Longidorus	3.11b	0.44a	1.00a	0.88	57.90	<.001
Meloidogyne	27.22b	13.11a	37.78b	13.61	52.30	0.005
Mononchus	1.78b	0.22a	5.56c	0.89	35.20	<.001
Pratylenchus	0.00a	0.00a	1.667b	0.58	103.90	<.001
Primastolaimus	10.56c	0.00a	8.00b	1.86	30.10	<.001
Prodorylaimus	0.78b	0.00a	2.44c	0.71	65.50	<.001
Rotylenchus	0.00a	0.00a	5.44b	0.82	45.30	<.001
Trichodorus	0.00a	0.00a	2.78b	0.48	52.00	<.001
Tylenchus	5.00a	9.56a	24.56b	4.93	37.80	<.001
Wilsonema	0.00a	5.22b	24.00c	1.84	18.90	<.001

Numbers followed by a different letter within the same row are significantly different

5. Table 3.5: Nematode numbers and their distribution in the different farming practices at Weru

Genus	Manure	Standard	Neglected	LSD	C.V%	P Value
Alaimus	0.00a	1.00a	7.11b	1.14	42.00	<.001
Aphelenchus	13.44c	6.00b	3.67a	2.32	30.10	<.001
Cephalobus	25.00c	2.78a	9.33b	2.74	22.20	<.001
Cervidellus	0.00a	0.00a	0.67b	0.29	129.90	<.001
Criconemella	6.56b	8.00b	3.56a	1.54	25.60	<.001
Dorylaimus	1.33b	0.00a	3.89c	0.69	39.90	<.001
Ditylenchus	0.00a	0.00a	1.44b	0.30	63.20	<.001
Eucephalobus	14.11b	5.78a	20.22c	2.69	20.20	<.001
Filenchus	7.44b	3.22a	19.00c	2.95	29.80	<.001
Helicotylenchus	4.11a	3.78a	7.67b	1.94	37.50	<.001
Hemicyclophora	0.00a	0.00a	6.67b	0.91	41.10	<.001
Heterodera	0.00a	0.00a	6.67b	0.99	45.00	<.001
Leptonchus	1.56b	0.11a	3.78c	0.84	46.20	<.001
Longidorus	0.00a	0.00a	1.78b	0.38	65.00	<.001
Meloidogyne	8.33a	9.67a	23.33b	2.55	18.60	<.001
Mononchus	2.11b	1.22a	4.78c	0.81	29.80	<.001
Pratylenchus	0.00a	2.89b	7.00c	1.15	35.00	<.001
Primastolaimus	0.00a	1.56b	7.00c	0.89	31.40	<.001
Prodorylaimus	0.00a	0.00a	1.44b	0.42	87.10	<.001
Rotylenchus	0.00a	3.67a	120.33b	6.23	15.10	<.001
Trichodorus	0.00a	0.00a	2.11b	0.35	49.30	<.001
Tylenchus	11.33a	10.33a	45.33b	3.74	16.80	<.001
Wilsonema	1.67b	0.00a	1.67b	0.87	77.90	<.001

Numbers followed by a different letter within the same row are significantly different

The distribution of the number of nematode species across the zones was not significantly different ($P > 0.05$) at both study sites (Tables 3.6 and 3.7). At Kangaita study site, only five out of the twenty-three nematode genera had significant difference in distribution of the nematode numbers ($P<0.05$) across the zones. These were *Aphelenchus, Filenchus, Helicotylenchus, Meloidogyne* and *Tylenchus* (Table 3.6). At Weru Study site only three genera out of the twenty-three recovered had their numbers having significantly difference in their distribution ($P<0.005$) across the three zones. These were *Eucephalobus*, *Filenchus* and *Tylenchus* (Table 3.7)

6. Table 3.6: Nematode numbers and their distribution in the different zones at Kangaita

Genus	Upper	Medium	Lower	LSD	C.V%
Alaimus	6.78a	6.11a	4.44a	2.38	41.4
Aphelenchus	19.11a	22.11ab	27.11b	6.01	26.4
Cephalobus	19.44a	18.11a	18.67a	3.41	18.2
Cervidellus	0.22a	0.22a	0.22a	0.35	159.1
Criconemella	7.11a	5.89a	6.56a	1.6	24.6
Dorylaimus	0.77a	0.55a	0.66a	0.26	39.5
Ditylenchus	0.78a	0.78a	0.67a	0.64	86.7
Eucephalobus	15.33a	11.78a	14.22a	3.35	24.3
Filenchus	7.56a	13.00b	9.00a	2.08	21.2
Helicotylenchus	3.66a	4.77a	7.33b	1.63	31.2
Hemicyclophora	0.89a	1.00a	1.11a	0.9	90.5
Heterodera	0.33a	0.44a	0.44a	0.53	131.5
Leptonchus	8.22a	8.00a	8.22a	2.82	34.7
Longidorus	1.89a	1.56a	1.11a	0.93	61.4
Meloidogyne	16.00a	43.44b	18.67a	13.56	52.1
Mononchus	2.67a	2.22a	2.67a	0.96	38.2
Pratylenchus	0.56a	0.56a	0.56a	0.7	127.3
Primastolaimus	5.67a	6.11a	6.78a	1.62	26.3
Prodorylaimus	1.44a	0.78a	1.00a	0.73	68.2
Rotylenchus	1.88a	2.00a	1.55a	0.48	26.5
Trichodorus	1.11a	0.89a	0.78a	0.54	59.2
Tylenchus	9.89a	11.67a	17.56b	4.79	36.8
Wilsonema	8.78a	10.56a	9.89a	1.79	18.4

Numbers followed by a different letter within the same row are significantly different

7. Table 3.7: Nematode numbers and their distribution in the different zones at Weru

Genus	Upper	Medium	Lower	LSD	C.V%
Alaimus	2.67a	2.78a	2.67a	1.17	43.3
Aphelenchus	7.11a	7.67a	8.33a	2.21	15.3
Cephalobus	12.33a	12.44a	12.33a	2.81	22.8
Cervidellus	0.22a	0.22a	0.22a	0.28	129.9
Criconemella	6.22a	5.44a	6.44a	1.53	25.4
Dorylaimus	1.89a	1.78a	1.56a	1.71	41
Ditylenchus	0.44a	0.55a	0.44a	0.34	72.1
Eucephalobus	15.89a	10.67a	13.56b	2.81	21.1
Filenchus	9.11a	8.77a	11.77b	2.47	24
Helicotylenchus	5.00a	4.33a	6.22a	1.78	34.4
Hemicyclophora	2.00a	2.44a	2.22a	0.8	36.4
Heterodera	2.11a	2.22a	2.33a	0.44	19.8
Leptonchus	2.11a	1.78a	1.56a	0.81	44.8
Longidorus	0.77a	0.55a	0.44a	0.41	70.8
Meloidogyne	12.33a	14.11a	14.89b	2.14	15.6
Mononchus	2.22a	2.67a	3.22a	NS	31.3
Pratylenchus	3.67a	3.44a	2.78a	1.06	32.3
Primastolaimus	2.67a	2.78a	3.11a	0.96	34
Prodorylaimus	0.55a	0.44a	0.44a	0.28	58.3
Rotylenchus	42.60a	37.40a	44.00b	5.85	14.2
Trichodorus	0.77a	0.66a	0.66a	0.4	57.2
Tylenchus	28.33b	18.89a	19.78a	3.85	5.8
Wilsonema	1.11a	1.00a	1.22a	0.88	79.4

Numbers followed by a different letter within the same row are significantly different

The numbers of nematode trophic levels, nematode abundance and nematode species diversity were significantly distributed ($P<0.05$) across the zones and among the farming practices in both study sites (Tables 3.8). Generally, it was observed that the plant parasitic nematodes were highest in neglected farms, followed by manure applied farms and least in NPK fertilizer applied (Standard) farms. Similarly, nematode abundance and species diversity was highest in neglected farms, followed by manure applied farms and least in NPK fertilizer applied (standard) farms (Table 3.8)

8. Table 3.8: Nematode trophic levels, abundance and species diversity and their distribution in different farming practices across the three agro ecological zones at Kangaita and Weru

	Zone	Upper			Medium			Lower					
	Farming practice	Standard	Manure	Neglected	Standard	Manure	Neglected	Standard	Manure	Neglected	LSD	C.V%	P Value
Kangaita	PPN	29.33a	23.00a	100.33e	62.67c	80.33d	112.67f	51.33b	24.00a	118.67f	6.44	5.6	<.001
	BF	26.33a	55.00b	87.33d	25.67a	54.33b	78.67c	28.33a	49.00b	85.33cd	6.68	7.1	<.001
	FF	24.33ab	39.00c	21.00a	23.63a	40.00c	29.00b	21.33a	42.67c	44.00c	5.05	9.2	<.001
	PR	0.00a	2.33b	5.33c	0.00a	1.33ab	5.33c	0.00a	2.00b	6.00c	1.54	36.1	<.001
	OM	2.33c	0.67a	3.67d	1.67abc	0.67a	1.67abc	2.00bc	1.00ab	2.00bc	1.03	34.3	<.001
	Total	82.30a	120.00c	217.70e	113.70bc	176.70d	227.30e	104.00b	118.70c	256.00f	12.53	4.6	<.001
	Species	12.00a	13.67b	21.00c	12.00a	13.67b	20.67c	12.00a	13.00ab	21.00c	1.2	4.5	<.001
Weru	PPN	34.00a	32.00a	247.00d	36.30a	36.70a	222.00c	54.30b	44.70ab	261.3d	14.5	7.8	<.001
	BF	13.67b	43.67de	47.33e	9.33a	36.00c	44.33de	10.33ab	42.67d	46.33de	4.28	7.6	<.001
	FF	8.00bc	12.67d	8.33bc	5.67ab	14.67d	9.67c	4.67a	17.67e	8.67c	2.75	15.9	<.001
	PR	0.67a	2.00b	4.00c	0.67a	2.00b	5.33d	2.33b	2.33b	5.00cd	1.3	13.2	<.001
	OM	0.00a	1.33a	6.00b	0.00a	1.33a	5.33b	0.00a	1.33a	4.67b	1.39	36.4	<.001
	Total	56.30a	91.70b	312.70cd	52.00a	90.70b	286.70c	71.70ab	91.30b	326.00d	27.46	10.4	<.001
	Species	11.67a	13.00b	22.33c	11.00a	11.67a	22.33c	12.00ab	13.00b	22.33c	1.13	4.2	<.001

Means followed by a different letter(s) within the same row are significantly different. PPN – plant parasitic nematodes, BF – bacterial feeders, FF – fungal feeders, PR – predators, OM – Omnivores, Total – nematode abundance, Species – Species diversity, Upper - LH0, Medium - LH1, Lower - UM1

The total nematode numbers varied significantly ($P<0.05$) among the different farming practices in the two study sites (Tables 3.9). Nematode abundance and species diversity varied significantly ($P<0.05$) among the three farming practices in both study sites (Table3.9). Nematode abundance was highest in neglected farms in both study sites while it was lowest in standard farms. Nematode diversity was highest in the neglected farms while it was lowest in the standard farms in the two study sites (Table 3.9). All the five trophic groups had a significant difference ($P<0.005$) in distribution in the three farming practices in both study sites. The nematode trophic levels also varied significantly ($P<0.05$) with the different farming practices (Table 3.8). In both sites, plant parasitic nematodes were highest in neglected farms followed by standard farms and lowest in manure applied farms, BF were highest in neglected farms followed by manure farms and lowest in standard farms. Fungal feeders were highest in manure farms followed by neglected farms and lowest in standard farms, predatory nematodes were highest in neglected farms followed by manure farms and lowest in standard farms. Omnivorous nematodes were highest in neglected farms. The omnivorous nematodes were however lowest in manure farms for Kangaita site while they were lowest in standard farms for Weru site.

Across the zones in the two study sites, the numbers of plant parasitic nematodes, nematode abundance and species diversity had a significant difference ($P<0.005$) in distribution. At Kangaita, the numbers of bacterial feeders, fungal feeders, predatory and omnivorous nematodes' distribution was not significantly different ($P>0.005$) while at Weru, the numbers of fungal feeders, predatory and omnivorous nematodes did not show significant difference ($P>0.005$) in distribution across the zones (Table 3.10).

9. Table 3.9: Distribution of nematodes trophic levels, nematode abundance and nematode species diversity different farming practices at Kangaita and Weru

	Nematodes	Manure	Standard	Neglected	LSD	C.V%
Kangaita	PPN	42.44a	47.78a	110.56b	14.84	22.2
	BF	52.78b	26.78a	83.78c	4.351	8
	FF	40.56c	23.11a	31.33b	6.55	20.7
	PR	1.89b	0.00a	5.56c	0.723	29.1
	OM	0.78a	2.00b	2.44b	0.673	38.7
	Abundance	138.4b	100.0a	233.7c	19.76	12.6
	Diversity	13.44b	12.00a	20.89c	0.697	4.5
Weru	PPN	37.8a	41.6a	243.4b	11.07	10.3
	BF	40.78b	11.11a	46.00c	2.693	8.3
	FF	15.00c	6.11a	8.89b	2.241	22.4
	PR	2.11b	1.22a	4.78c	0.805	29.8
	OM	1.33b	0.00a	5.33c	0.763	34.4
	Abundance	91.20b	60.00a	308.40c	16.4	10.7
	Diversity	12.56b	11.56a	22.33c	0.693	4.5

Means followed by different letters within the same row are significantly different, PPN – Plant parasitic nematodes (plant feeders), BF – bacterial feeders, FF – Fungal feeders, PR – predatory nematodes, OM – omnivorous nematodes

10. Table 3.10: Distribution of nematodes trophic levels, nematode abundance and nematode species diversity across zones at Kangaita and Weru

	Nematodes	Upper	Medium	Lower	LSD	C.V%
Kangaita	PPN	50.89a	85.22b	64.67a	14.77	22.1
	BF	56.22a	52.89a	54.22a	4.52	8.3
	FF	29.10a	30.90a	36.00a	7.59	20.8
	PR	2.56a	2.22a	2.67a	0.9	36.4
	OM	2.02a	1.33a	1.67a	0.72	41.6
	Abundance	140.00a	172.60b	159.60ab	19.61	3.4
	Diversity	15.56a	15.44a	15.33a	0.69	4.5
Weru	PPN	104.30a	98.30a	120.10b	9.92	9.2
	BF	34.89b	29.89a	33.11b	2.77	8.5
	FF	9.67a	10.00a	10.33a	2.34	23.5
	PR	2.22a	2.67a	3.22a	0.84	31.3
	OM	2.44a	2.22a	2.00a	0.78	35.2
	Abundance	153.60ab	143.10a	163.00b	15.04	9.8
	Diversity	15.67a	15.00a	15.78a	0.86	4.4

Means followed by different letters within the same row are significantly different, PPN – Plant parasitic nematodes (plant feeders), BF – bacterial feeders, FF – Fungal feeders, PR – predatory nematodes, OM – omnivorous nematodes

3.6 Discussion

This study showed that nematode abundance and diversity varied depending on the farming practice used by farmers. Neglected farms had the highest nematode numbers and species diversity compared to standard and manure applied farms. The neglected farms are characterized by long-term freedom from human interference in terms of cultivation/weeding, fertilizer application, plucking and other cultural practices associated with tea farming. As a result, these farms end up having high above ground plant diversity and high organic matter. The natural balance in such an ecosystem promotes prolific growth of nematode numbers and survival of diverse nematode species hence high nematode diversity (Maina *et al.* 2009; Wachira *et al.* 2014).

The standard farming practice involves regular weeding and application of inorganic fertilizer once or twice every year. In order to maximize production per bush from the tea plant, farmers have a tendency of applying inorganic fertilizer above the recommended rate (TBK 2013). This excess application of fertilizers boost productivity in the short period but in the long run has more detrimental effects. The farms become over dependent on chemical fertilizers to produce and becomes unproductive in the long run. The chemical fertilizer (NPK) lock nutrients in the soil and render them unavailable for uptake by the plants (Hamid, 2006; Thenmonzi, 2012; Sultan *et al.* 2014). The fertilizer also makes the soil acidic, which makes survival conditions for nematodes unfavorable leading to decline in their numbers (Thenmonzi, 2012).

The manure applied farms follow the same cultural practice as standard farming practice with an additional application of animal manure and other organic mulch. Due to application of manure in these farms, the use of inorganic fertilizer is minimized. The amount of organic matter in such farms is relatively high compared to farms without manure application. This promotes robust

growth of soil microorganisms including soil nematodes. It also promotes good growth and health of the tea plant.

This study results agree with other studies conducted earlier which revealed that increased disturbance in an ecosystem in terms of intensity of cultivation leads to decrease in nematode abundance, species richness and species composition (Bloemers *et al.* 1997; Bongers and Bongers. 1998; Yeates *et al.* 1999). This in the long run interferes with the functions of an ecosystem (Giller *et al.* 1997). Human interference in an agro ecosystem alters both the density and heterogeneity of plant communities (Kimenju *et al.* 2005). This in turn plays a role in restructuring nematode communities, which depend on the plants (Yeates, 1999). It has also been revealed that destruction of natural forests to pave way for establishment of a single species plantation results to a decline in nematode abundance and species richness (Kimenju *et al.* 2005).

From the survey, it was observed that the nematodes in the genus *Meloidogyne* are well distributed in the tea farms in the two study sites. This is because tea plants are host to the plant parasitic nematode and supports its proliferation. This is consistent with a research carried earlier in India which concluded that root knot nematodes, *Meloidogyne javanica, Meloidogyne incognita and Meloidogyne brevica,* are widely distributed in tea plants (Glover, PM., 1961).

Five trophic groups of nematodes were recovered in the study areas. These are herbivores, bacteriovores, fungivores, omnivores and predators. This is due to the natural balance of nematode communities in their trophic levels in the ecosystem. The availability of the tea plant leads to proliferation of plant parasitic nematodes and the fungus supported by decomposing organic matter around the plant supports growth of fungal feeders. There is a large amount of bacteria around the rizosphere of the tea plants (Kibet *et al.* 2013) which supports the growth of

fungal feeders. The mix of these three trophic levels supports the growth of predatory and omnivorous nematodes. This finding is in line with many research findings which have indicated that the five trophic levels are represented in almost every soil sample (Freckman and Baldwin, 1990; Kibet *et al.* 2013).

Nematodes of *Aphelenchus* spp. were widespread in the tea fields of both Kangaita and Weru. The nematode is a fungal feeder. The numbers of proliferate in tea farms due to high availability of fungus in the tea farms (Kibet *et al.* 2013). The high amount of fungus in the tea farms is supported by the availability of high amount of decomposing matter (Kibet *et al.* 2013) from old tea leaves, pruned shoots and branches, organic mulch and manure applied to tea farms. These findings agree with studies previously conducted in tea fields (Kibet *et al.* 2003; Kimenju *et al.* 2009).

The study also reveals that more nematode species are found in tea farms than those observed earlier in other studies. Kibet *et. al.* (2003) reported 16 genera of nematodes in their study while this study revealed that 23 genera of nematodes were found to thrive in tea farms. The zones did not have an effect in nematode species diversity in both Kangaita nand weru study sites.

In conclusion, the neglected farming practice had high nematode numbers as compared to standard and manure applied farms. The weeds in the neglected farms contributed to the high nematode numbers. Standard farming practice had the least nematode numbers and nematode species diversity. The manure application farming practice is recommended because despite it having high nematode numbers as compared to the standard farm, it promotes rapid growth of the plant which counters effect of nematode attack leading to high yield of the tea bushes. The

farming practices influenced nematode species abundance and numbers in the nematode trophic levels across the agro ecological zones.

CHAPTER 4: INFLUENCE OF FARMING PRACTICES ON THE CHEMICAL PROPERTIES OF SOIL IN SMALL SCALE TEA FARMS IN KIRINYAGA AND THARAKA-NITHI COUNTIES OF KENYA

4.1 Abstract

Chemical properties of a soil are important in plant growth as they determine the nutrient availability for uptake for the plant. Experiments were set up in Kangaita, Kirinyaga County, and Weru, Tharaka-Nithi County using randomized complete bock design to establish the influence of farming practices on the chemical properties of soil. The study was carried out with the aim of understanding the role of the farming practices on the availability of soil nutrients, its effect on tea productivity and the abundance and diversity of soil nematodes. Each study site was divided into three zones depending on elevation and three farming practices identified within each zone namely neglected farms, manure applied farms and chemical fertilizer (NPK) applied farm. Soil samples were collected randomly from farms in each zone and analyzed for chemical properties and nematodes were extracted from each sample, quantified and identified. A correlation analysis for the nutrients and nematode species was conducted. The soil chemical analysis yielded results for both macro and micro nutrients, exchangeable acidity, total organic carbon and soil pH. Soil acidity increased from neglected farms through manure applied farms to NPK fertilizer applied (standard) farms. There was a significant positive correlation between the nematode trophic levels and the total nitrogen and total organic carbon. There was however a significant negative correlation between soil pH, exchangeable acidity, magnesium, sodium, potassium, calcium and other trace elements in the soil. The soils had generally low levels of potassium, magnesium and zinc due to rapid removal through harvesting of the young shoots and leaves. Increase in soil organic matter and soil nitrogen leads to increase in nematode trophic

groups. This means that an increase in total organic carbon or total nitrogen led to an increase in plant parasitic nematodes. It also led to an increase in nematode abundance and species diversity. However, increase in soil acidity, exchangeable acidity and other macro and micro nutrients led do decrease in nematode trophic groups. This means that increase in macro and micro nutrients leads to decrease in plant parasitic nematodes.

4.2 Introduction

Chemical properties of soil determine availability of nutrients for uptake by plants. The balance of both macro and micro nutrients in any soil plays a vital role in plant growth. The interactions of the nutrients also affect the availability of each other either positively or negatively (Hamid, 2006; Thenmonzi, 2012; Sultan *et al.* 2014). Various cultural practices including weeding, fertilizer application and even harvesting of farm produce affect the nutrient composition and balance in the soil which in turn affect the performance of crops in terms of productivity. Other factors like leaching and surface run off also play a role in soil physical and chemical composition.

Tea is cultivated using a number of cultural practices which are aimed at increasing the productivity of the tea plant. These cultural practices include weeding, pruning, fertilizer application and plucking/harvesting rounds (TBK, 2013). These practices greatly affect biodiversity in the soil (Wachira *et al.* 2014). Soil biodiversity is the variety of life below the ground and it's an indicator of sustainable land use (Wachira *et al.* 2014). Soil hosts a wide range of microbes (fungi and bacteria), macrobes (termites and earthworms) and mesofauna (acari, collembolan and nematodes) (Bardgett, 2005; Wachira *et al.* 2014). Wachira *et al.* (2014) noted that land use affects soil characteristics like organic carbon which was highest in least disturbed land. Wachira *et al.* (2014) further noted that soil nematodes were affected by land use types and

they were least reported in tea farms. This was attributed to low biological activity in tea husbandry and the monocrop husbandry characteristic in tea growing. Soil chemical properties, agro-ecological zones and land management levels also affect the distribution and abundance of nematode species (Nzesya *et al.* 2014). Nzesya *et al.* (2014) also noted that farms that are well managed had less plant parasitic nematodes. The amount of organic matter in the soil affects the health and performance of the plants. The organic matter acts to suppresses parasitic microorganisms like nematodes thus improving the health of the tea plants (TBK, 2003; Sultan *et al.* 2014).

Farmers use chemical fertilizers in the cultivation of tea, mainly Di ammonium phosphate (DAP) during nursery establishment and planting and nitrogen phosphorus potassium (NPK) for top dressing (TBK, 2003). Excessive application of fertilizer can cause imbalance in nutrient uptake and fix some nutrients leading to poor performance of the tea plant (Hamid, 2006; Thenmonzi, 2012; Sultan *et al.* 2014). NPK fertilizer application rate in Kenya's small scale holder tea farming is recommended at 50kgs per 700 bushes (TBK, 2003). The study was carried out to establish the influence of farming practices on soil chemical characteristic and the influence of the soil chemical characteristics on the abundance and diversity of soil nematodes.

4.3 Materials and methods

The study area, site selection, experimental design and soil sampling was done as described in sections 3.3.1, 3.3.2, 3.3.3 and 3.3.4 respectively. Two hundred grams of soil from the farms in each zone was analyzed for physical and chemical characteristics and this related to the nematode diversity and abundance. The analysis determined the soil pH, exchangeable acidity, total nitrogen (N), total organic carbon (TOC), available nutrient elements (phosphorus (P), potassium (K), sodium (Na), calcium (Ca), magnesium (mg) and manganese (Mn) and available

trace elements (Iron (Fe), zinc (Zn) and copper (Cu). Soil pH was determined in a 1:1 (w/v) soil – water suspension with a pH meter.

Exchangeable acidity was determined using the titration method. The soil was oven dried at 40^0 C. Five grams of the oven dried soil sample (< 2mm) was placed into a 50ml container. This was followed by addition of 125ml of 1 M KCl to the container and the contents were stirred using a clean glass rod. The mixture was allowed to stand for 30 minutes. The mixture was filtered through a funnel and leached with 5 successive 12.5ml aliquots of 1 M KCl. Three drops of phenolphthalein indicator solution were added and then titrated with 0.1 M NaOH to the first permanent pink color of the end point. The burette was read and the volume (ml) of NaOH used was recorded. The titration readings were corrected for a blank of titration of 75 ml KCl solution.

Total nitrogen was determined using Kjeldahl method. Two grams of the soil sample (< 0.5mm) was oven dried at 40^0 C and digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350^0C. Total nitrogen was determined by distillation followed by titration with diluted standardized 0.1 M NaOH.

Total organic carbon was determined using the calorimetric method. All the organic carbon in the oven dried soil sample (< 0.5mm) at 40^0C was oxidized by acidified dichromate at 150^0C for 30 minutes to ensure complete oxidation. Barium chloride was added to the cool digests. After mixing thoroughly, the digests were allowed to stand overnight. The carbon concentration was read on the spectrophotometer at 600nm.

Available nutrient elements (P, K, Na, Mg and Mn) were determined using the Mehlich Double Acid method. The oven dry soil samples at 40^0 C (< 2mm) were extracted in a 1:5 ratios (w/v)

with a mixture of 0.1 M HCl and 0.025 M H_2SO_4. Na, Ca and K were determined using a flame photometer. P, Mg and Mn were determined spectrophotometrically.

Available trace elements (Fe, Zn and Cu) were determined by the atomic absorption spectrophotometer (AAS). The oven dry (at 40^0 C) soil samples (<2mm) were extracted in a 1:10 ratio (w/v) with 0.1 M HCl. The elements were then determined with the AAS. A correlation analysis for soil pH, exchangeable acidity, total organic carbon, macro and micro nutrients and nematode trophic levels, abundance and diversity was conducted using Genstat edition 14.

4.4 Results

4.4.1 Soil chemical analysis

Soil chemical analysis conducted yielded results for soil pH, exchangeable acidity, total nitrogen, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper, iron, zinc and sodium. At Kangaita, the figures ranged as follows; pH 3.0-4.95, exchangeable acidity (me %) 0.3-0.5, total nitrogen (me %) 0.54-5.5, total organic carbon (%) 5.6-8.17, phosphorus (ppm) 50-180, potassium (me%) 0.2-2.79, (Table 4.1). At Weru, the figures ranged as follows; pH 4.0-5.2, exchangeable acidity (me%) 0.2-0.5, total nitrogen (me%) 0.14-0.4, total organic carbon (%) 1.3-3.95, phosphorus (ppm) 5-25, potassium (me%) 0.22-0.78 (Table 4.2).

11. Table 4.1: Soil chemical properties in different farming practices across the agro ecological zones in Kangaita

Zone	Upper			Medium			Lower				
Farming practice	Standard	Manure	Neglected	Standard	Manure	Neglected	Standard	Manure	Neglected	LSD	C.V%
Soil pH	3.00a	4.05d	4.07d	3.80c	3.32b	4.25e	3.02a	4.01d	4.08d	0.15	2.4
EA me%	0.50a	0.50a	0.50a	0.50a	0.50a	0.50a	0.50a	0.50a	0.50a	-	-
TN %	0.56a	0.65bc	0.60b	0.65bc	0.65bc	0.56a	0.79e	0.69cd	0.70d	0.04	3.8
TOC %	5.86a	6.81bc	6.61b	6.62b	6.69b	5.73a	8.14e	7.06cd	7.25d	0.33	2.9
P ppm	125.00d	140.00e	80.00b	150.00f	145.00ef	50.00a	178.30g	95.00c	85.00b	5.36	2.7
K me%	0.40cd	2.72f	0.26b	0.42d	0.30b	0.20a	0.28b	1.50e	0.36c	0.05	4.1
Ca me%	3.00a	10.67g	3.67b	5.00d	4.00c	3.00a	6.00e	9.30f	5.00d	0.31	3.3
Mg me%	1.67c	3.63e	0.56a	0.95b	1.95d	0.93b	0.95b	3.80f	0.93b	0.02	0.9
Mn me%	0.82f	0.43d	0.41d	0.44d	0.30c	0.60e	0.28c	0.20b	0.11a	0.02	3.9
Cu ppm	3.81b	0.66a	0.64a	0.54a	1.12a	1.02a	0.40a	0.57a	4.90b	2.1	79.9
Fe ppm	122.00f	56.63d	38.00c	24.40a	145.00h	34.43b	137.00g	40.70c	68.70e	3	2.3
Zn ppm	3.52c	8.62d	3.95c	2.20b	9.98e	3.48c	1.11a	13.10f	2.00b	0.67	7.3
Na me%	0.22cd	1.22f	0.14a	0.20c	0.17b	0.16ab	0.20c	1.04e	0.24d	0.02	3.5

Means followed by different letters within the same column are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million, Upper - LH0, Medium - LH1, Lower - UM1

12. Table 4.2: Soil chemical properties in different farming practices across the agro ecological zones in Weru

Zone	Upper			Medium			Lower				
Farming practice	Standard	Manure	Neglected	Standard	Manure	Neglected	Standard	Manure	Neglected	LSD	C.V%
Soil pH	4.33b	4.12a	4.12a	5.16e	5.02d	4.42bc	4.47c	4.10a	4.16a	0.11	1.5
EA me%	0.40a	0.50a	0.50a	0.20a	0.30a	0.40a	0.40a	0.50a	0.50a	-	-
TN %	0.38e	0.35d	0.38e	0.22b	0.24c	0.25c	0.21c	0.14a	0.15a	0.01	2.8
TC %	4.05g	3.46f	3.93g	2.26cd	2.46de	2.65e	2.01bc	1.34a	1.81b	0.36	7.9
P ppm	10.00b	23.33d	20.00c	6.67a	23.33d	10.00b	10.00b	5.00a	10.00b	3	13.2
K me%	0.40d	0.51e	0.22a	0.28c	0.75f	0.24ab	0.26bc	0.52e	0.24ab	0.02	3.1
Ca me%	8.23fg	8.26g	5.40d	6.20e	12.20h	8.00f	5.00c	8.26g	4.16a	0.24	2.1
Mg me%	0.46ab	0.81b	0.50ab	1.76c	1.50c	0.50ab	0.17a	0.47ab	0.57ab	0.4	31.3
Mn me%	0.71f	0.30c	0.18a	0.46e	0.21b	0.41d	0.71f	0.44e	0.88g	0.02	2.9
Cu ppm	1.71ab	1.82ab	1.00a	2.89b	15.67e	1.00a	9.18d	23.46f	4.80c	1.36	11.5
Fe ppm	49.20h	53.27i	34.10d	44.67g	23.90c	35.13e	13.97b	39.50f	11.60a	0.45	0.8
Zn ppm	5.51h	2.22f	1.08a	2.08e	1.70b	3.22g	1.75c	2.07e	2.00d	0.05	1.2
Na me%	0.21c	0.40e	0.16ab	0.18b	0.35d	0.18b	0.14a	0.36d	0.15a	0.02	5.6

Means followed by different letters within the same column are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million, Upper - LH0, Medium - LH1, Lower - UM1

There was a significant (P<0.05) difference in the three farming practices for soil pH, exchangeable acidity, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper zinc and sodium (Table 4.3 and 4.4). There was no significant difference for total nitrogen, and iron in the two sites.

13. Table 4.3: Effect of farming practices on soil pH, exchangeable acidity, total organic carbon and micronutrients at Kangaita

Parameter	Manure	Standard	Neglected	LSD	C.V%
pH	3.95b	3.11a	4.44c	0.24	6.2
EA me%	0.40a	0.50b	0.38a	0.04	9
T N %	0.66a	1.17a	0.67a	0.953	114.3
TOC %	6.80b	6.15a	7.24c	0.24	3.6
P ppm	126.70b	151.10b	71.70a	26.14	22.5
K me%	1.51b	0.37a	0.28a	0.61	84.5
Ca me%	7.99b	4.67a	3.89a	1.93	35
Mg me%	3.13b	1.19a	0.81a	0.56	33
Mn me%	0.31a	0.52b	0.38ab	0.14	34.7
Cu ppm	5.77b	2.25a	2.19a	1.89	55.6
Fe ppm	80.80a	94.50a	47.00a	51.55	69.6
Zn ppm	10.57b	2.28a	3.15a	1.73	32.5
Na me%	0.81b	0.21a	0.18a	0.28	70.1

Means followed by different letters within the same row are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

14. Table 4.4: Effect of farming practices on soil pH, exchangeable acidity, total organic carbon and micronutrients at Weru

Parameter	Manure	Standard	Neglected	LSD	C.V%	P Value
pH	4.41b	4.23a	4.66c	0.18	4	<.001
EA me%	0.43b	0.46b	0.34a	0.05	11.8	<.001
TN %	0.24a	0.27a	0.26a	0.03	9.3	0.07
TOC %	2.567b	2.22a	2.87c	0.19	7.6	0.015
P ppm	17.22b	8.89a	13.33ab	5.79	44.1	0.025
K me%	0.60b	0.32a	0.24a	0.09	22.7	<.001
Ca me%	8.36b	6.48a	5.86a	1.65	24	0.015
Mg me%	0.93a	0.80a	0.52a	0.44	58.4	0.168
Mn me%	0.32a	0.63b	0.50b	0.16	34.3	0.004
Cu ppm	13.65b	4.60a	2.27a	4.4	64.4	<.001
Fe ppm	38.90a	35.90a	26.90a	11.17	33	0.091
Zn ppm	7.00b	3.11a	3.43a	1.14	25.3	<.001
Na me%	0.37b	0.18a	0.17a	0.02	8.8	<.001

Means followed by different letters within the same row are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

4.4.2 Influence of soil chemical properties on the abundance and diversity of soil nematodes

There was a positive correlation between the soil pH, total organic carbon, exchangeable acidity and micronutrients and total nematode numbers (nematode abundance) and nematode species diversity in the two study sites (Table 4.5, Table 4.6,).

At Kangaita (Table 4.5), there was a positive correlation between soil pH and total nematode numbers/nematode abundance (r = 0.7927). This means that the nematode numbers decreased

with increase in soil acidity. The nematode trophic levels PPN, BF, FF, PR and OM had a positive correlation (r = 0.5567, 0.9191, 0.3942 0.79 and 0.20 respectively) with soil pH. This means that the nematode numbers increased with decrease in soil acidity. For OM (omnivorous) nematodes, the positive correlation was not significant. There was a negative correlation between exchangeable acidity and total nematode numbers, nematode diversity, PPN, BF, FF and PR nematodes. This means that the nematode numbers decreased with increase in exchangeable acidity. The negative correlation between exchangeable acidity and OM nematodes was not significant. Total nitrogen had a positive correlation with nematode abundance, species diversity, PPN, BF and PR nematodes. However, total nitrogen had a negative correlation with FF and OM. There was a negative correlation between total organic carbon and total nematodes, species diversity, PPN, BF, FF and PR nematodes. There was a negative correlation between phosphorus and nematode abundance, species diversity, PPN, BF, and PR nematodes. There was a negative correlation between potassium and species diversity, PPN, BF, PR and OM nematodes. There was a positive correlation between potassium and FF nematodes. There was a negative correlation between calcium and nematode abundance, species diversity, OM, PPN, BF, and PR nematodes. There was however a positive correlation between calcium and FF. For magnesium, there was a negative correlation with nematode abundance, species diversity, PPN, OM, BF and PR nematodes. There was however a positive correlation between magnesium and FF nematodes. Sodium levels had a negative correlation with PPN and OM nematodes nematode abundance, species diversity and BF, and a positive correlation with FF nematodes and no significant correlation with predatory nematodes.

There was a positive correlation between total organic carbon and PPN, BF, FF, PR, OM, nematode abundance as well as nematode species diversity. This means that an increase in total organic carbon leads to an increase in nematode populations and species diversity.

15. Table 4.5: Correlation analysis between nematode trophic levels, nematode abundance, nematode species diversity, and soil pH, exchangeable acidity, macro and micro nutrients at Kangaita

	PPN	BF	FF	PR	OM	A	SD	pH	EA	TN	TOC	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na
PPN	-																			
BF	0.73	-																		
FF	-0.01	0.32	-																	
PR	0.71	0.92	0.25	-																
OM	0.36	0.26	-0.53	0.26	-															
A	0.92	0.92	0.27	0.87	0.26	-														
SD	0.84	0.93	0.09	0.90	0.41	0.93	-													
pH	0.56	0.92	0.39	0.79	0.20	0.79	0.81	-												
EA	-0.40	-0.81	-0.45	-0.62	-0.18	-0.66	-0.64	-0.91	-											
TN	0.13	0.27	-0.20	0.35	0.24	0.18	0.21	0.13	-0.08	-										
TOC	0.42	0.62	0.52	0.61	0.05	0.61	0.54	0.54	-0.55	0.10	-									
P	-0.56	-0.78	-0.19	-0.81	-0.27	-0.71	-0.81	-0.73	0.52	-0.15	-0.36	-								
K	-0.63	-0.07	0.46	-0.10	-0.48	-0.35	-0.29	0.13	-0.18	-0.12	0.00	0.15	-							
Ca	-0.63	-0.15	0.48	-0.15	-0.50	-0.38	-0.37	0.06	-0.12	-0.08	0.21	0.26	0.91	-						
Mg	-0.73	-0.20	0.60	-0.24	-0.62	-0.44	-0.45	0.01	-0.12	-0.20	0.00	0.13	0.87	0.83	-					
Mn	-0.20	-0.29	-0.54	-0.23	0.21	-0.33	-0.14	-0.35	0.43	-0.04	-0.78	-0.07	-0.11	-0.42	-0.14	-				
Cu	-0.33	-0.07	0.72	-0.06	-0.66	-0.13	-0.26	-0.03	-0.11	-0.23	0.19	0.14	0.50	0.46	0.68	-0.29	-			
Fe	-0.19	-0.39	-0.02	-0.46	-0.13	-0.29	-0.42	-0.53	0.28	-0.15	-0.05	0.58	-0.25	-0.21	-0.05	0.04	0.27	-		
Zn	-0.45	0.02	0.63	-0.09	-0.55	-0.18	-0.27	0.22	-0.34	-0.07	0.07	-0.04	0.59	0.57	0.86	-0.25	0.64	-0.03	-	
Na	-0.66	-0.07	0.53	-0.08	-0.50	-0.35	-0.30	0.14	-0.19	-0.12	0.10	0.06	0.96	0.94	0.93	-0.20	0.53	-0.27	0.69	-
	PPN	BF	FF	PR	OM	A	SD	pH	EA	TN	TOC	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na

PPN- Plant parasitic nematodes, BF – Bacterial feeders, FF – Fungal feeders, PR – Predatory OM – Omnivores, A – Abundance (Total nematodes), SD – Species diversity, pH – Soil pH, EA – Exchangeable acidity, TN – Total nitrogen, TOC – Total organic

carbon, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na - Sodium

At Weru, (Table 4.6), there was a positive correlation between soil pH and total nematode numbers/nematode abundance (r = 0.3855). This means that the nematode numbers decreased with increase in soil acidity. The nematode trophic levels PPN, BF, FF, PR and OM has a positive correlation with soil pH. This means that the nematode numbers increased with decrease in soil acidity. There was a negative correlation between exchangeable acidity and total nematode numbers, nematode diversity, PPN, OM, BF, FF and PR nematodes. This means that the nematode numbers decreased with increase in exchangeable acidity. There was a negative correlation between potassium and species diversity, PPN, PR, BF and OM nematodes. There was a positive correlation between potassium and FF nematodes. There was a negative correlation between calcium and nematode abundance, species diversity, PPN, BR, OM and PR nematodes while FF had a negative correlation with calcium. For magnesium, there was a negative correlation with PPN, BF, PR, OM nematode abundance and species diversity. There was however a positive correlation between magnesium and FF. Sodium had a negative correlation with nematode abundance, species diversity, PPN, PR and OM nematodes. The correlation between sodium and BF and FF was positive.

There was a positive correlation between total organic carbon and PPN, BF, FF, PR, OM, nematode abundance as well as nematode species diversity. This means that an increase in total organic carbon lead to an increase in nematode populations and species diversity.

16. Table 4.6: Correlation analysis between nematode trophic levels, nematode abundance, nematode species diversity, and soil pH, exchangeable acidity, macro and micro nutrients at Weru

	PPN	BF	FF	PR	OM	A	SD	pH	EA	TN	TOC	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na
PPN	-																			
BF	0.59	-																		
FF	-0.21	0.57	-																	
PR	0.84	0.66	0.03	-																
OM	0.90	0.71	0.00	0.75	-															
A	0.99	0.69	-0.10	0.85	0.92	-														
SD	0.98	0.67	-0.10	0.88	0.93	0.98	-													
pH	0.35	0.28	0.09	0.41	0.42	0.39	0.36	-												
EA	-0.41	-0.25	0.02	-0.47	-0.43	-0.42	-0.42	-0.94	-											
TN	-0.03	-0.03	-0.19	-0.20	0.07	-0.02	0.01	-0.16	0.08	-										
TOC	0.23	0.37	0.05	0.06	0.34	0.28	0.29	0.02	-0.09	0.85	-									
P	0.00	0.39	0.22	0.02	0.17	0.09	0.03	0.19	-0.13	0.55	0.61	-								
K	-0.62	0.12	0.73	-0.41	-0.40	-0.52	-0.56	0.10	0.05	-0.01	0.00	0.46	-							
Ca	-0.37	-0.01	0.30	-0.26	-0.19	-0.31	-0.33	0.53	-0.43	0.36	0.30	0.59	0.71	-						
Mg	-0.32	-0.20	0.07	-0.39	-0.24	-0.30	-0.35	0.32	-0.25	-0.06	0.05	0.18	0.37	0.46	-					
Mn	0.10	-0.37	-0.43	0.04	-0.19	0.01	0.02	-0.29	0.34	-0.38	-0.55	-0.61	-0.43	-0.49	-0.37	-				
Cu	-0.39	0.09	0.66	-0.16	-0.30	-0.35	-0.38	-0.06	0.15	-0.62	-0.56	-0.17	0.60	0.01	0.03	-0.09	-			
Fe	-0.43	-0.08	0.20	-0.47	-0.25	-0.39	-0.33	-0.28	0.22	0.56	0.55	0.07	0.20	0.24	0.21	-0.40	-0.24	-		
Zn	-0.41	0.41	0.84	-0.21	-0.16	-0.30	-0.30	-0.01	0.13	0.15	0.25	0.37	0.82	0.53	0.07	-0.40	0.43	0.48	-	
Na	-0.56	0.32	0.80	-0.33	-0.30	-0.45	-0.46	-0.08	0.18	0.04	0.14	0.43	0.86	0.49	0.24	-0.50	0.50	0.46	0.91	-
	PPN	BF	FF	PR	OM	A	SD	pH	EA	TN	TOC	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na

PPN- Plant parasitic nematodes, BF – Bacterial feeders, FF – Fungal feeders, PR – Predatory OM – Omnivores, A – Abundance (Total nematodes), SD – Species diversity, pH – Soil pH, EA – Exchangeable acidity, TN – Total nitrogen, TOC – Total organic

carbon, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na - Sodium

4.5 Discussion

The study investigated the influence of farming practices on the soil chemical properties and the relationship between the soil chemical properties and the abundance and diversity of soil nematodes. The different farming practices influenced soil chemical properties differently. The soil chemical properties had both positive and negative relationship with nematode abundance, species diversity and nematode numbers in their various trophic levels.

The farming practices had a significant effect on the soil pH. The soil acidity was highest in inorganic fertilizer applied farms (Standard) followed by manure applied farms and lowest in neglected farms. Tea grows well in acidic soils of pH between 4.5 and 5.6 (Njogu *et al.* 2013). However, as this study revealed and as noted by Sultan *et al.* (2014), continuous use of nitrogenous fertilizer increases the soil acidity. The farmers tend to use the recommended fertilizers non-judiciously with the hope of increasing yield but this instead leads to increase in soil acidity, pollution of water masses and poses a challenge to the sustainability of the tea production (Tabu *et al.* 2015). The acidified soils tend to adversely affect the soil microorganisms (Thenmonzi *et al.* 2012). The applied manure plays an important role in reducing soil acidity which is increased by continuous application of nitrogenous fertilizers (Sultan *et al.* 2014).

There was a significant difference among the three farming practices in soil pH, exchangeable acidity, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper zinc and sodium. There was no significant difference for total nitrogen, and iron in the two sites. This can be attributed to the interaction of both macro and micro nutrients in the soil (IPCC, 1999; IPCC, 2000) and application of the fertilizers affecting soil pH (Sultan *et al.* 2014).

The study revealed a correlation between soil nutrients, soil pH, total organic carbon, exchangeable acidity, nematode abundance and nematode species diversity. The interaction of these factors affected each other either positively or negatively. Where there was a decrease in soil pH leading to soil acidity there was observed a decline of both nematode abundance and species diversity. Thenmonzi *et al.* (2012) also noted that increase in soil acidity leads to decrease in soil microorganisms. Soil pH was also affected by the farming practice due to the type and intensity of fertilizer application. High rates of inorganic nitrogenous fertilizers led to increased soil acidity (Sultan *et al.* 2014) while application of manure led to decrease in soil acidity.

Nelson (2006) noted that deficiency of zinc in the soil can be induced by a buildup of phosphorus resulting from excessive application of phosphate fertilizers. Kitundu *et al.* (2006) noted that high levels of iron in the soil led to copper deficiency and that even though iron was found to be sufficient in the soil, it was poorly reflected in the leaves due to high levels of zinc in the leaves. Nath, (2013b) noted that high soil pH results to retention of micronutrients in the soil. Nath, (2013b) also noted that the concentration of Mn, Cu, Fe and Zn increases with the increase in organic content in the soil. Jessy (2010) noted that where potassium is not matched with nitrogen, there is depletion of starch reserves in the roots, degeneration of feeder roots characterized by die back and buildup of nitrates in the soil. Phosphorus is affected by soil acidity. Hamid (2006) reported that phosphorus availability to plants is highest when there is moderate pH of about 5.5 – 7 and becomes exceedingly unavailable at pH above 7 and below 5.5. Hamid (2006) further noted that in very acidic soils, phosphorus combines with hydroxides of iron and aluminum to form compounds that are unavailable to plants.

The availability of nitrogen in the soil is affected by other nutrients and it also affects the availability of other nutrients in the soil. IPCC, (1990) reported that increase in nitrogen leads to decrease in mature leaf P, K, Ca and Mg due to the acidification of the soil by ammonia in the fertilizer. A decrease in mature leaf potassium can be attributed to leaching (IPCC, 1990).

Soil chemical properties of a farm depend on the type of agricultural practice employed. Use of inorganic fertilizer led to increase in soil acidity. Increased soil acidity was responsible for decline in nematode numbers and species diversity. For a better balance of soil nematodes in the soil in their trophic levels, manure application in tea farms is recommended.

CHAPTER 5: EFFECT OF ROOT KNOT NEMATODE ON THE GROWTH AND PRODUCTIVITY OF TEA CLONES IN MERU COUNTY OF KENYA

5.1 Abstract

Nematodes have been reported in tea plantations in Kenya and have been associated with death of tea plants in some areas. Nematodes associated with tea have been found to be well distributed in Ngere catchment of Murang'a County, Kangaita catchment of Kirinyaga County and Imenti catchment of Meru County. This study was conducted in Kionyo, Meru county, to establish the effect of the root knot nematodes on the growth and productivity of the common tea clones and the recently released, high yielding clones in Kenya. These clones include TRFK 31/8, TRFK 301/4, TRFK371/3, TRFK430/90, and TRFK 306/1 (purple tea). The experiment was set up in a randomized complete block design. Two thousand eggs of *Meloidogyne spp* were inoculated in each potted plant and one potted plant was not inoculated to act as control. Growth parameters like stem girth, length of internode (internode space) and number of new leaves were recorded. The data was recorded fortnightly for a period of twenty-four weeks. The data was analyzed using Genstat edition 14. The nematodes affected significantly the growth parameters and yield of the high yielding, newly released clones TRFK 301/4, TRFK371/3, TRFK 430/90 and TRFK 306/1. Tea clone TRFK 31/8 was least affected and therefore considered resistant to the nematode attack while clone TRFK 430/90 was the most affected and therefore susceptible to nematode attack. Clone TRFK 430/90 is unsuitable for cultivation in areas infested with root knot nematodes while clone TRFK 31/8 is the most suited clone in areas infested with root knot nematodes.

5.2 Introduction

Tea is a major cash crop in Kenya contributing up to 26% of total exports in the country. Tea originated in China (Tapan, 2004). Tea is cultivated in Kenya mainly through small scale holder system. It is mainly grown in Mt. Kenya region, the Aberdares, nandi hills, Kericho, Kisii highlands and along the Nyambene hills (TBK, 2003). Otieno *et al.* (2002) documented the outbreak of root knot nematodes in Kenya's Kerugoya and Imenti areas. Otieno *et al.* (2002) recorded that areas which were previously under coffee or forests were severely affected by the nematode infestation leading to decline in plant health and die back. Kamunya *et al.* (2008) conducted a study and reported that root knot nematodes were responsible for death of some tea clones in nursery conditions.

Nematodes have been reported in tea plantations in Kenya and have been associated with loss of tea plants in some areas (TBK, 2013). A study conducted by Wachira *et al.* (2014) in Ngere catchment of Murang'a County found out that nematode species associated with tea were well distributed in tea farms. Other studies conducted by Kamunya *et al.* (2008) found out that nematodes were well distributed in Kangaita, Kirinyaga County and Imenti, Meru County and were responsible for the declining population of tea in the areas. The study also reported that *Meloidogyne* spp. was responsible for total death of tea plants of clone TRFK 303/577 under nursery conditions. Nematodes have also been found to be responsible for declining populations of tea in other parts of the world. In India, root knot nematode species (*Meloidogyne javanica*, *Meloidogyyne incognita* and *Meloidogyne brevicauda*) have been found to be well distributed in tea farms and have been linked to declining populations of tea plants in farms (Glover, 1961).

Plant parasitic nematodes cause injury to plants as they feed on them. The nematodes have a hollow feeding structure, with a stylet and a pharynx that have undergone morphological and

physiological adaptations to suit the nematode's mode of feeding (Lee, 2002). They feed by forming diverse and sometimes complex feeding relationships with their host plants (Davis et al. 2004; Luc *et al.* 2005).

In general, PPNs use their stylet to mechanically injure plants through piercing as they withdraw and ingest nutrients from plants (Bilgrami *et al.* 2004; Guagler *et al.* 2004). In the process of feeding or in the attempt to obtain food from plants, the nematodes may also inject secretions into the plant cells weakening or modifying those plants (Gheysen *et al.* 2006).

Root knot nematodes are best controlled using resistant tea clones (TBK, 2003). Studies by Kamunya *et al.* (2008) showed that various tea clones have varying degrees of resistance to root knot nematode attack. Clone TRFK 303/577 was reported to be the most susceptible to root knot nematode attack. TRI carries out research and develops new tea clones which are resistant to pests and diseases and are high yielding (TBK, 2003). This study was conducted with the aim of evaluating the susceptibility of commonly grown and recently released tea clones to root knot nematode and the effect of the nematode of the clones' productivity.

5.4 Materials and method

5.4.1 Experimental design

The experiment was set up in a randomized complete block design. Potted tea plants were used in the experiment. The plants were two years old when the experiment started. Five different clones were used in the study. These were TRFK 31/8, TRFK 301/4, TRFK 371/3, TRFK 430/90 and TRFK 306/1 (Purple Tea).

5.4.2 Establishment of experimental plants

Tea plants were obtained from a tea nursery at Kionyo tea factory in Meru. The plants had been propagated in the nursery for two years. They were mature enough for transplanting. Fifteen plants per clone were obtained. Pots were filled with steam sterilized soil and the tea was planted in the pots, one plant per pot. The tea plants were then raised for two years until they reached bearing level. Three plants per clone were randomly selected and placed in a plot as an experimental unit. The experiment was replicated three times.

5.4.3. Preparation of nematode inoculum and inoculation

Spinach plants (*Spinacia oleracea*) was used as a bioassay plant. The spinach plants were raised in Kionyo tea factory in a place infested with the root knot nematode. The plants were raised for two months and the roots harvested for extraction of nematode eggs and J_2s. The nematode eggs were extracted from the two months old plant roots in the laboratory using 1% sodium hypochlorite solution technique as described by Hussey and Barker (1973). The number of eggs per milliliter was determined by counting over a microscope in a counting slide as described by Ravichandra (2010). Two thousand eggs were inoculated to each potted plant. The egg masses and J_2s were inoculated on the plants by placing them under the roots of the tea plant. Un inoculated plants served as control.

5.4.4 Data collection and analysis

Growth parameters including stem girth, internode length and number of new leaves were measured at an interval of fourteen days for twenty-four weeks. Stem girth was meant to monitor the lateral growth of the tea plant. Internode length was meant to monitor the growth of the tea plant in height (apical growth). Number of new leaves was meant to measure productivity of the plant. The number of new leaves were the shoots comprising of at least two leaves and a bud;

which is the harvestable part of the tea plant. These new shoots were harvested and counted per plant. Tea plants were also observed for physical symptoms like chlorosis, wilting, drooling of leaves, stunting and die back. The symptoms were assigned numbers in a scale of 0-9 to denote severity of the effect of RKN infestation. Where 0 - dead plant, 1-3 –wilting and drooling of leaves, 4-6 - plants showing chlorosis, 7 - stunted plants 8-9 – healthy plants. The obtained data was analyzed using Genstat edition 14.

5.5 Results

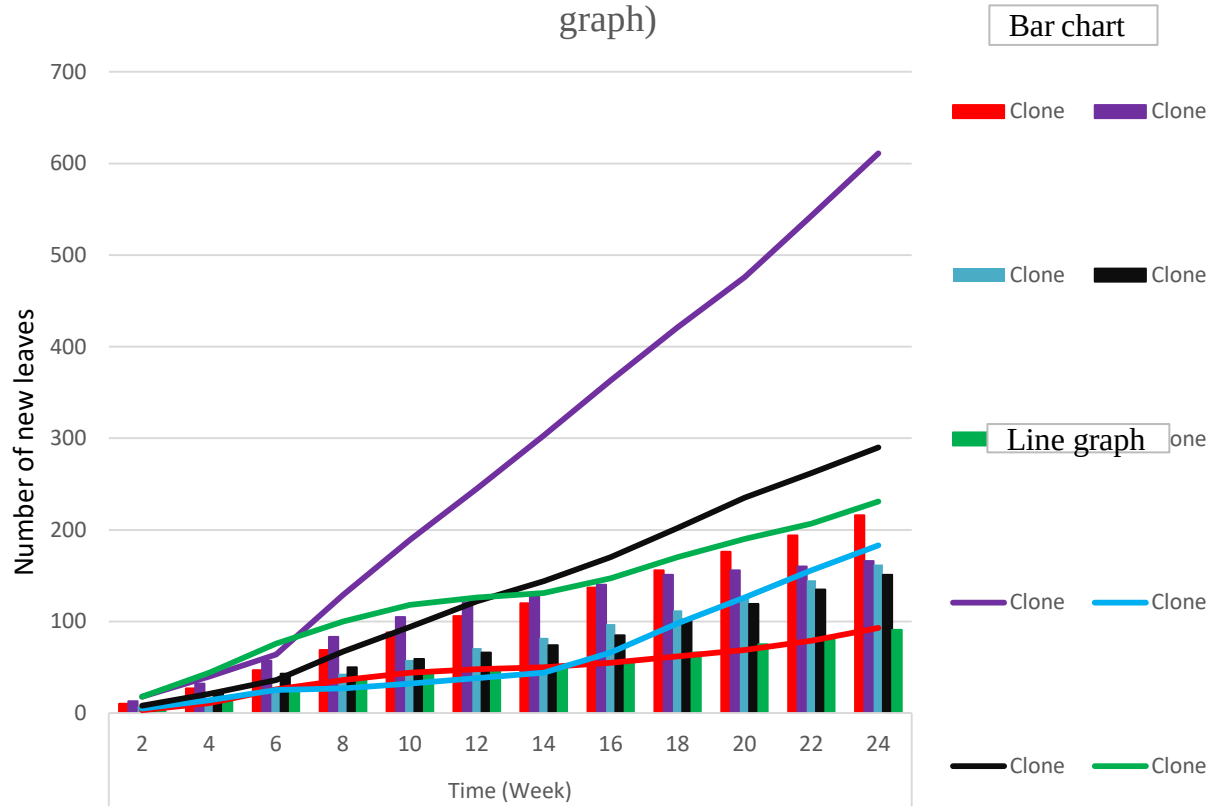
Root knot nematodes had no significant impact on the growth parameters of tea clone 31/8 (Table 5.1). In tea clone 301/4, the root knot nematodes had a significant reduction effect on the number of new leaves while the internode length and stem girth were not significantly affected (Table 5.1). This means that there was no notable physical difference between an infested tea plant and a healthy one but there was reduction in yield in the infested plants. This is because the new leaves are the yield forming parts of the plant. In tea clone 371/3, only the stem girth was negatively affected by the root knot nematode while the internode space and number of new leaves suffered an insignificant reduction (Table 5.1). For clone 430/90, there was a significant reduction in all the growth parameters in the plants infested with the root knot nematode (Table 5.1). This means that the tea clone's growth is susceptible to the nematode attack. For tea clone 306/1 (purple tea), the nematode had a significant reduction on the number of new leaves while the effect on the other two parameters was not significant (Table 5.1).

17. Table 5.1: Effect of root knot nematode on the stem girth, internode length and number of new leaves (growth parameters) of tea clones TRFK 31/8, TRFK 301/4, TRFK 371/3, TRFK 430/90 and TRFK 306/1

Clone	Parameter	A	B	Control	LSD	C.V%	P Value
	SG	9.35a	10.72a	11.02a	2.78	15.5	0.36
TRFK 31/8	IL	18.2a	15.1a	11.2a	9.61	37.5	0.28
	NL	214a	104a	93a	121	51.1	0.092
	SG	5.35a	5.28a	6.10a	1.16	12	0.47
TRFK 301/4	IL	15.93a	16.10a	19.90a	4.43	14.8	0.12
	NL	166.20a	170.70a	610.50b	66	12.1	<.001
	SG	5.93a	6.03a	9.20b	2.08	17	0.013
TRFK 371/3	IL	34.80a	29.50a	25.90a	19.22	38	0.403
	NL	160.00a	140.00a	183.00a	70	25.1	0.376
	SG	4.375a	4.750a	6.80b	1.43	15.6	0.012
TRFK 430/90	IL	4.78a	5.20a	13.50b	1.89	13.9	<.001
	NL	146.20a	145.00a	290.00b	114.6	34.2	0.033
	SG	6.85a	7.05a	7.50a	2.97	24	0.863
TRK 306/1	IL	18.10a	16.40a	16.40a	14.98	55.4	0.656
	NL	88.00a	99.80a	231.00b	24.44	10.1	<.001

Means followed by different letters within the same row are significantly different. SG – Stem girth, IL- Internode length, NL – New leaves, Treatments A and B – inoculated with 2,000 eggs of *Meloidogyne spp.*, Control – Free of nematodes

Figure 5.1: Cummulative leaf production of tea clones infested with RKN (bar chart) as compared with uninfested ones (line graph)



In un infested clones, Clone TRFK 31/8 had the highest production in terms of number of leaves followed by clone TRFK 430/90 (figure 5.1). Clone TRFK 31/8 had the least leaf production followed by clone TRFK 371/3 (figure 5.1).

5.6 Discussion

The study was conducted with an aim of establishing the reaction of tea clones to infestation with root knot nematodes. It was aimed at establishing and recommending the most suitable clones to be grown in areas infested with root knot nematodes.

Clone TRFK 31/8 was observed to resist attack by the nematode since it had high yield despite the nematodes attack and by the fact that it did not exhibit any sign of physical disorders like chlorosis, wilting and die back. The nematode *Meloidogyne* spp did not have any significant effect on the clone's stem girth, internode length and number of new leaves. This makes this clone resistant to nematode attack. This resistance/tolerance to nematode attack can be used by farmers as a method of cultural control of the nematodes as noted by Gnapragasam *et al.* (2005). Resistance/tolerance coupled with other cultural methods like use of organic matter, soil cultivation and inorganic fertilizer application will greately help in reducing the negative effects of nematodes on tea plants Gnapragasam *et al.* (2005).

Clones TRFK 301/4, TRFK371/3 and TRFK 430/90 suffered most in terms of loss in number of harvestable new leaves and showing physical disorders. Clone 430/90 exhibited the most severe above ground symptoms. This renders these clones susceptible to the nematode attack. *Meliodogyne* spp affected different growth parameters of these clones thus affecting their performance and productivity. The nematode significantly reduced the stem girth and number of new leaves produced by the tea plants. The new leaves are the harvestable product that is of interest to the tea farmers. The reduction on number of leaves means reduction in productivity and decline in production per area leading to direct loss to the farmers.

These findings are consistent with studies carried out by Kamunya *et al.* (2008) in nematode infested areas of Kenya. Kamunya *et al.* (2008) noted that the tea plants of clone TRFK 31/8 infested with nematode *Meloidogyne* spp did not show any above ground symptoms and the effect of the nematode on the plant was insignificant. The study by Kamunya *et al.* (2008) also established that clone 301/4 and 303/577 were most affected and showed severe above ground symptoms and galling of the roots. Gnanapragasam (2002), also indicated that there have been several instances of slow decline leading to death of tea bushes in Sri Lanka caused by plant parasitic nematodes. Orisajo (2012) in a study conducted in Nigeria also found that, *Meloidogyne* significantly reduced stem girth and leaf area of tea plants. Sivipalan (1957) and Venkata (1963) also reported that tea of all ages were susceptible to attack by *Meloidogyne brevicauda*. It was also noted that, root knot nematodes were causing loss in tea plants in fields (Otieno *et al.* 2002). The survey by Otieno *et al.* (2002) further indicated that, *Meloidogyne* spp attacked young plants of clone TRFK 303/577 leading to the death of the plants.

Root knot nematodes (RKN) also affect many other plants and have been found to reduce yield and even cause death of the plants. Other plants affected by RKN include common beans, tomato (*Solunum lycopersicum* L.), tobacco, cantaloupe, bananas, among others. The nematodes have been reported to affect growth parameters of the plants, reducing yield and even causing death of the plants (Kimenju *et al.* 1999; Kankam *et al.* 2014). The inoculum levels also play a major role in the effect of the nematodes on the plants as the plants have varying rates of tolerance or resistance (Vitro *et al.* 1983; El-Sherif *et al.* 2007).

In terms of performance in productivity, the five clones can be ranked, from best performing, as TRFK 31/8, TRFK 301/4, TRFK 371/3, TRFK 430/90 and TRFK 306/1. Clone TRFK 31/8 is recommended for propagation in areas infested by the root knot nematode.

CHAPTER 6: GENERAL DISCUSSION CONCLUSION AND RECOMMENDATIONS

6.1 Discussion

This study showed that nematode abundance and diversity varied depending on the farming practice adopted by farmers. Neglected farms had the highest nematode numbers and species diversity. The neglected farms are characterized by long-term freedom from human interference in terms of cultivation/weeding, fertilizer application, plucking and other cultural practices associated with tea farming. As a result, these farms end up having high above ground plant diversity and high organic matter. The standard farming practice involves regular weeding and application of inorganic fertilizer once or twice every year. The manure applied farms follow the same cultural practice as Standard farming practice with an additional application of animal manure and/or other organic mulch. Due to application of manure in these farms, the use of organic fertilizer is minimized.

This study agrees with other studies conducted earlier which revealed that increased disturbance in an ecosystem in terms of intensity of cultivation leads to decrease in nematode abundance, species richness and species composition (Bloemers *et al.* 1997; Bongers and Bongers. 1998; Yeates *et al.* 1999). This in the long run interferes with the functions of an ecosystem (Giller *et al.* 1997). Human interference in an agro ecosystem alters both the density and heterogeneity of plant communities (Kimenju *et al.* 2005). This in turn plays a role in restructuring nematode communities, which depend on the plants (Yeates, 1999). It has also been revealed that destruction of natural forests to pave way for establishment of a single species plantation results in the decline in nematode abundance and species richness (Kimenju *et al.* 2005).

From the survey, it was observed that the nematodes in genus *Meloidogyne* are well distributed in the tea farms in the two study sites. This is constistent with a research carried earlier in India which concluded that root knot nematodes, *Meloidogyne javanica, Meloidogyne incognita and Meloidogyne brevica,* are widely distributed in tea plants (Glover, 1961).

Five trophic groups of nematodes were recovered in the study areas. These are herbivores, bacteriovores, fungivores, omnivores and predators. This is in line with many research findings which have indicated that the five trophic levels are represented in almost every soil sample (Freckman and Baldwin, 1990; Kibet *et al.* 2013). Nematodes of *Aphelenchus* spp. were wide spread in the tea fields of both Kangaita and Weru. These findings agree with studies previously conducted in tea fields (Kibet *et al.* 2003; Kimenju *et al.* 2009).

Farming practices had a significant effect on the soil pH. Soil acidity was highest in inorganic fertilizer applied farms (standard) followed by manure applied farms and lowest in neglected farms. Tea grows well in acidic soils of pH between 4.5 and 5.6 (Njogu *et al.* 2013). However, as this study revealed and as noted by Sultan *et al.* (2014), continuous use of nitrogenous fertilizer increases soil acidity. Farmers tend to use the recommended fertilizers non-judiciously with the hope of increasing yield but this instead leads to increase in soil acidity, pollution of water masses and poses a challenge to the sustainability of tea production (Tabu *et al.* 2015). The acidified soils tend to adversely affect the soil microorganisms (Thenmonzi *et al.* 2012). The applied manure plays an important role in reducing soil acidity which is increased by continuous application of nitrogenous fertilizers (Sultan *et al.* 2014).

There was a significant difference among the three farming practices in soil pH, exchangeable acidity, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper

zinc and sodium. There was no significant difference for total nitrogen, and iron from the two sites. This can be attributed to the interaction of both macro and micro nutrients in the soil (IPCC, 1999; IPCC, 2000) and application of the fertilizers affecting soil pH (Sultan *et al.* 2014).

The study demonstrated a correlation between soil nutrients, soil pH, total organic carbon, exchangeable acidity, nematode abundance and nematode species diversity. The interaction of these factors affected each other either positively or negatively. Decrease in soil pH leading to soil acidity led to the decline of both nematode abundance and species diversity. Thenmonzi *et al.* (2012) also noted that increase in soil acidity leads to decrease in soil microorganisms. Soil pH was also affected by the farming practice due to the type and intensity of fertilizer application. High rates of inorganic nitrogenous fertilizers lead to increased soil acidity while application of manure leads to decrease in soil acidity (Sultan *et al.* 2014).

Nelson (2006) noted that deficiency of zinc in the soil can be induced by a buildup of phosphorus resulting from excessive application of phosphate fertilizers. Kitundu *et al.* (2006) noted that high levels of iron in the soil led to copper deficiency and that even though iron was found to be sufficient in the soil, it was poorly reflected in the leaves due to high levels of zinc in the leaves. Nath, (2013b) noted that, high soil pH results to retention of micronutrients in the soil. Nath, (2013b) also noted that the concentration of Mn, Cu, Fe and Zn increases with the increase in organic content in the soil. Jessy (2010) noted that where levels of potassium are not matched with those of nitrogen, there is depletion of starch reserves in the roots, degeneration of feeder roots characterized by die back and buildup of nitrates in the soil. Phosphorus is affected by soil acidity. Hamid (2006) reported that phosphorus availability to plants is highest when there is moderate pH of about 5.5 – 7 and becomes exceedingly unavailable at pH above 7 and

below 5.5. Hamid (2006) further noted that in very acidic soils, phosphorus combines with hydroxides of iron and aluminum to form compounds that are unavailable to plants.

The availability of nitrogen in the soil is affected by other nutrients and it also affects the availability of other nutrients in the soil. IPCC, (1990) reported that increase in nitrogen leads to decrease in mature leaf P, K, Ca and Mg due to the acidification of the soil by ammonia in the fertilizer. A decrease in mature leaf potassium can be attributed to leaching triggered by Ammonium nitrate in NPK fertilizer (IPCC, 1990).

Meloidogyne spp affect different growth parameters of tea plants thus affecting the performance and productivity of the tea plant. The nematode significantly reduced the stem girth and number of new leaves produced by the tea plants. New leaves are the harvestable product that is of interest to farmers. Its reduction means reduction in productivity and decline in production per area leading to direct loss to the farmer. Clone TRFK 31/8 was observed to resist attack by the nematode since it had high yield despite the nematodes attack and by the fact that it did not exhibit any sign of physical distress like chlorosis, wilting and die back. The nematode *Meloidogyne* spp did not have any significant effect on the clone's stem girth, internode space and number of new leaves. Clones TRFK 301/4, TRFK371/3 and TRFK 430/90 suffered most in terms of loss in number of harvestable new leaves and showing physical distress like plant chlorosis, stunted growth and die off. Clone 430/90 exhibited the most severe above ground symptoms. This makes these clones susceptible to nematode attack. These findings are consistent with studies carried out by Kamunya *et al.* (2008) in nematode infested areas of Kenya. Kamunya *et al.* (2008) noted that the tea plants of clone TRFK 31/8 infested with nematode *Meloidogyne* spp did not show any aboveground symptoms and the effect of the nematode on the plant was insignificant. The study also established that clone 301/4 and 303/577 were most

affected and showed severe above ground symptoms and galling of the roots (Kamunya *et al.* 2008). Gnanapragasam, (2002) also reported that there have been several instances of slow decline leading to death of tea bushes in Sri Lanka caused by plant parasitic nematodes. Orisajo (2012) in a study conducted in Nigeria also found that *Meloidogyne* significantly reduced stem girth and leaf area of tea plants. Sivipalan (1957) and Venkata (1963) also reported that tea of all ages were susceptible to attack by *Meloidogyne brevicauda*. *Meloidogyne brevicauda* was also recorded to be well distributed in fields of mature tea in Sri Lanka (Loos, 1953). Otieno *et al.* (2002) reported that *Meloidogyne* spp were found to be distributed in areas of Kerugoya in Kirinyaga county and Imenti in Meru county of Kenya. It was also noted that root knot nematodes were causing losses of tea plants (Otieno *et al.* 2002). The survey by Otieno *et al.* (2002) further indicated that *Meloidogyne* spp attacked young plants of clone TRFK 303/577 leading to death of the plants.

6.2 Conclusion

The findings of the study reveal that soil nematodes are well distributed in tea growing fields. PPNS and total nematode numbers vary with the cultural practices applied in tea production. Nematode numbers are highest in neglected farms while they are lowest in manure applied farms.

Root knot nematodes affect various tea clones differently and lead to reduction in tea productivity from farms. The most susceptible clones were TRFK 301/4, TRFK371/3 and TRFK 430/90 while clone TRFK 31/8 was the most resistant cultivar.

The various farming practices have an effect on the soil pH, exchangeable acidity, total organic carbon, total nitrogen, phosphorus, and potassium and micro nutrients in the soil. There was also

correlation between the farming practice employed and the nematode abundance, nematode species diversity, soil pH, total organic carbon and various soil nutrients. Increase in soil acidity leads to decline of both nematode abundance and species diversity. Increase in total organic carbon in the soil leads to increase in nematode communities and nematode numbers (species diversity and nematode abundance).

6.3 Recommendations

- Due to increased soil acidity resulting from the non-judicious use of inorganic fertilizers, farmers are advised to follow the recommended application rates to reverse the trend.
- Manure should also be applied to the tea bushes at the recommended rate per bush per year to lower soil acidity.
- There is need for further research to investigate the effect of nematode damage on the quality of tea produced by nematode infested clones.
- Further research should also be carried out to investigate the seasonal variation of nematode numbers and community structures in the tea farms in various tea growing ecological zones.
- There is also need for further research to identify the species of the root knot nematode responsible for severe damage on the tea plants in Kenya.
- Clone TRFK 31/8 can be recommended for growth in areas infested with root knot nematodes.

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APPENDICES

Appendix 1: Soil test results for Kangaita study site

Zone	Farming Practice	Replication	Soil pH	EA me%	TN me%	TOC %	P ppm	K me%	Ca me%	Mg me%	Mn me%	Cu ppm	Fe ppm	Zn ppm	Na me%
Upper	Standard	1	3.00	0.50	0.56	5.68	125.00	0.40	3.00	1.68	0.82	3.85	122.00	3.52	0.22
Upper	Manure	1	4.00	0.40	0.65	6.81	140.00	2.79	11.00	3.68	0.43	5.67	56.70	8.62	1.22
Upper	Neglected	1	4.95	0.30	0.68	6.94	80.00	0.28	3.60	0.56	0.42	0.64	38.00	3.95	0.14
Upper	Standard	2	3.01	0.50	0.54	5.66	120.00	0.38	3.00	1.68	0.78	3.80	120.00	3.52	0.22
Upper	Manure	2	3.95	0.40	0.65	6.80	135.00	2.68	10.00	3.60	0.44	5.65	56.50	8.62	1.22
Upper	Neglected	2	4.25	0.40	5.50	6.94	80.00	0.20	4.00	0.54	0.42	0.64	36.00	3.95	0.14
Upper	Standard	3	3.00	0.50	0.58	5.60	130.00	0.42	3.00	1.66	0.86	3.80	124.00	3.52	0.22
Upper	Manure	3	4.20	0.40	0.65	5.96	145.00	2.70	11.00	3.62	0.43	5.67	56.70	8.62	1.22
Upper	Neglected	3	4.80	0.30	0.59	6.82	80.00	0.30	3.40	0.58	0.40	0.64	40.00	3.95	0.14
Medium	Standard	1	3.32	0.50	0.65	5.73	150.00	0.42	5.00	0.95	0.44	1.55	24.40	2.87	0.20
Medium	Manure	1	3.80	0.40	0.65	6.62	145.00	0.30	4.00	1.95	0.30	6.12	150.00	9.98	0.18
Medium	Neglected	1	4.25	0.40	0.56	6.69	50.00	0.20	3.00	0.93	0.61	1.03	34.60	3.48	0.16
Medium	Standard	2	3.32	0.50	0.65	5.73	150.00	0.42	5.00	0.95	0.42	1.55	24.00	2.83	0.22
Medium	Manure	2	3.78	0.40	0.65	6.62	145.00	0.30	4.00	1.95	0.30	6.10	140.00	10.00	0.18

EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

Appendix 1: Soil test results for Kangaita study site 'continued'

Zone	Farming Practice	Replication	Soil pH	EA me%	TN me%	TOC %	P ppm	K me%	Ca me%	Mg me%	Mn me%	Cu ppm	Fe ppm	Zn ppm	Na me%	
Medium	Neglected	2	4.20	0.50	0.56	6.69	50.00	0.20	3.00	0.93	0.60	1.00	34.20	3.48	0.16	
Medium	Standard	3	3.32	0.50	0.65	5.73	150.00	0.42	5.00	0.95	0.46	1.52	24.80	0.92	0.18	
Medium	Manure	3	3.82	0.40	0.65	6.62	145.00	0.30	4.00	1.95	0.30	6.14	145.00	9.96	0.14	
Medium	Neglected	3	4.30	0.40	0.56	6.69	50.00	0.20	3.00	0.93	0.61	1.05	34.50	3.50	0.16	
Lower	Standard	1	3.02	0.50	0.79	7.07	180.00	0.28	6.00	0.95	0.29	1.40	137.00	1.08	0.20	
Lower	Manure	1	4.01	0.40	0.69	7.27	95.00	1.50	9.30	3.80	0.20	5.58	40.70	13.10	1.04	
Lower	Neglected	1	4.90	0.30	0.70	8.14	85.00	0.36	5.00	0.93	0.11	0.70	68.70	2.00	0.24	
Lower	Standard	2	3.00	0.50	0.78	7.02	175.00	0.26	5.80	0.95	0.28	1.42	136.00	1.04	0.22	
Lower	Manure	2	4.00	0.40	0.66	7.22	100.00	1.48	9.00	3.80	0.20	5.57	40.40	12.90	1.04	
Lower	Neglected	2	4.20	0.40	0.70	8.11	85.00	0.40	5.00	0.93	0.10	7.00	68.70	2.00	0.22	
Lower	Standard	3	3.04	0.50	0.81	7.09	180.00	0.30	6.20	0.95	0.29	1.38	138.00	1.22	0.18	
Lower	Manure	3	4.02	0.40	0.73	7.28	90.00	1.52	9.60	3.80	0.20	5.58	41.00	13.30	1.04	
Lower	Neglected	3	4.15	0.40	0.70	8.17	85.00	0.34	5.00	0.93	0.13	7.00	68.70	2.00	0.26	

EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

Appendix 2: Soil test results for Weru study site

Zone	Farming Practice	Replication	pH	EA me%	TN Me%	TOC %	P ppm	K me%	Ca me%	Mg me%	Mn me%	Cu ppm	Fe ppm	Zn ppm	Na me%
Upper	Standard	1	4.11	0.50	0.38	3.04	10.00	0.40	8.20	0.20	0.70	1.60	49.40	5.50	0.20
Upper	Manure	1	4.13	0.50	0.34	3.46	25.00	0.52	8.30	0.80	0.30	2.00	53.30	7.20	0.40
Upper	Neglected	1	4.20	0.40	0.38	3.93	20.00	0.24	5.40	0.50	0.20	1.00	34.20	3.10	0.20
Upper	Standard	2	4.11	0.50	0.36	3.00	10.00	0.40	8.30	0.20	0.70	1.60	49.00	5.40	0.20
Upper	Manure	2	4.10	0.50	0.34	3.44	20.00	0.50	8.20	0.80	0.30	2.00	53.10	7.20	0.40
Upper	Neglected	2	4.50	0.40	0.38	3.90	20.00	0.22	5.60	0.50	0.20	1.00	34.00	3.10	0.20
Upper	Standard	3	4.10	0.50	0.40	3.10	10.00	0.42	8.20	1.00	0.70	2.00	49.20	5.60	0.20
Upper	Manure	3	4.12	0.50	0.36	3.48	25.00	0.52	8.30	0.80	0.30	1.50	53.40	7.20	0.40
Upper	Neglected	3	4.30	0.40	0.38	3.95	20.00	0.22	5.20	0.50	0.20	1.00	34.10	3.10	0.20
Medium	Standard	1	4.35	0.40	0.22	2.26	5.00	0.28	6.20	1.70	0.50	5.60	44.70	2.10	0.20
Medium	Manure	1	5.01	0.30	0.24	2.46	25.00	0.76	12.00	0.80	0.20	16.00	23.90	6.70	0.40
Medium	Neglected	1	5.18	0.20	0.25	2.65	10.00	0.24	8.00	0.50	0.40	1.00	35.20	4.20	0.20
Medium	Standard	2	4.50	0.40	0.22	2.25	10.00	0.26	6.00	1.80	0.50	1.50	44.40	2.10	0.20
Medium	Manure	2	5.04	0.30	0.24	2.45	20.00	0.72	12.00	1.80	0.20	15.00	23.70	6.70	0.30

EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na - Sodium, me – milli equivalents, ppm – parts per million

Appendix 2: Soil test results for Weru study site 'continued'

Zone	Farming Practice	Replication	pH	EA me%	TN Me%	TOC %	P ppm	K me%	Ca me%	Mg me%	Mn me%	Cu ppm	Fe ppm	Zn ppm	Na me%
Medium	Neglected	2	5.11	0.20	0.25	2.60	10.00	0.24	7.80	0.50	0.40	1.00	35.00	4.20	0.20
Medium	Standard	3	4.40	0.40	0.22	2.27	5.00	0.30	6.40	1.80	0.50	1.60	44.90	2.10	0.20
Medium	Manure	3	5.00	0.30	0.24	2.47	25.00	0.78	12.00	1.80	0.20	16.00	24.10	6.70	0.40
Medium	Neglected	3	5.20	0.20	0.25	2.70	10.00	0.24	8.20	0.50	0.40	1.00	35.20	4.20	0.20
Lower	Standard	1	4.14	0.50	0.21	1.34	10.00	0.26	5.00	0.20	0.70	9.20	13.90	1.80	0.10
Lower	Manure	1	4.00	0.50	0.14	1.56	5.00	0.52	4.60	0.50	0.40	24.00	39.50	7.10	0.40
Lower	Neglected	1	4.50	0.40	0.15	2.28	10.00	0.24	4.20	0.60	0.90	4.80	11.60	3.00	0.20
Lower	Standard	2	4.18	0.50	0.21	1.30	10.00	0.26	4.80	0.20	0.70	9.20	14.40	1.70	0.10
Lower	Manure	2	4.20	0.50	0.14	2.30	5.00	0.50	4.60	0.50	0.40	23.00	39.00	7.10	0.30
Lower	Neglected	2	4.50	0.40	0.15	2.26	10.00	0.22	4.10	0.60	0.90	4.80	11.20	3.00	0.10
Lower	Standard	3	4.16	0.40	0.21	1.38	10.00	0.26	5.20	0.20	0.70	9.20	13.60	1.80	0.20
Lower	Manure	3	4.10	0.50	0.14	1.50	5.00	0.54	4.60	0.50	0.40	24.00	40.00	7.10	0.40
Lower	Neglected	3	4.40	0.50	0.15	1.57	10.00	0.26	4.20	0.60	0.90	4.80	12.00	3.00	0.20

EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

Appendix 3: Nematode trophic levels, abundance and species diversity and their distribution in different farming practices across the zones in Kangaita and Weru study sites

			Kangaita							Weru						
Zone	Farming Practice	Replication	PPN	BF	FF	PR	OM	Total	Species	PPN	BF	FF	PR	OM	Total	Species
Upper	Standard	1	27	28	23	0	2	80	12	36	13	9	1	0	59	12
Upper	Manure	1	21	55	41	2	1	120	14	33	42	14	2	1	92	13
Upper	Weedy	1	101	83	18	5	4	211	21	258	49	9	6	5	327	23
Upper	Standard	2	29	26	23	0	2	80	12	35	14	7	1	0	57	12
Upper	Manure	2	21	57	38	3	1	120	14	32	46	13	2	1	94	13
Upper	Weedy	2	93	89	22	7	3	214	20	241	45	8	3	7	304	22
Upper	Standard	3	32	25	27	0	3	87	12	31	14	8	0	0	53	11
Upper	Manure	3	27	53	38	2	0	120	13	31	43	11	2	2	89	13
Upper	Weedy	3	107	90	23	4	4	228	22	242	48	8	3	6	307	22
Medium	Standard	1	61	23	27	0	1	112	12	40	11	6	1	0	58	12
Medium	Manure	1	78	54	36	1	0	169	13	32	40	15	2	1	90	11
Medium	Weedy	1	112	80	29	5	1	227	22	237	42	8	5	5	297	22
Medium	Standard	2	60	30	21	0	2	113	12	50	11	3	0	0	64	10
Medium	Manure	2	82	56	42	2	1	183	14	36	32	12	2	2	84	12

PPN – plant parasitic nematodes, BF – bacterial feeders, FF – fungal feeders, PR – predators, OM – Omnivores, Total – nematode abundance, Species – Species diversity

Appendix 3: Nematode trophic levels, abundance and species diversity and their distribution in different farming practices across the zones in Kangaita and Weru study sites 'continued'

			Kangaita							Weru						
Zone	Farming Practice	Replication	PPN	BF	FF	PR	OM	Total	Species	PPN	BF	FF	PR	OM	Total	Species
Medium	Weedy	2	112	73	29	5	2	221	20	221	47	11	5	5	289	23
Medium	Standard	3	67	24	23	0	2	116	12	19	6	8	1	0	34	11
Medium	Manure	3	81	53	42	1	1	178	14	42	36	17	2	1	98	12
Medium	Weedy	3	114	83	29	6	2	234	20	208	44	10	6	6	274	22
Lower	Standard	1	51	30	19	0	2	105	12	56	11	6	2	0	75	12
Lower	Manure	1	28	53	44	1	1	127	13	38	41	17	3	1	48	13
Lower	Weedy	1	114	93	48	5	3	263	21	268	45	8	6	4	331	23
Lower	Standard	2	54	29	25	0	2	110	12	53	11	4	3	0	71	12
Lower	Manure	2	22	49	44	2	1	118	13	45	44	19	2	1	111	13
Lower	Weedy	2	115	81	40	5	1	242	22	257	50	9	5	3	324	21
Lower	Standard	3	49	26	20	0	2	97	12	54	9	4	2	0	69	12
Lower	Manure	3	22	45	40	3	1	111	13	51	43	17	2	2	115	13

PPN – plant parasitic nematodes, BF – bacterial feeders, FF – fungal feeders, PR – predators, OM – Omnivores, Total – nematode abundance, Species – Species diversity