INCIDENCE, PREVALENCE AND MANAGEMENT OF ROOT-KNOT NEMATODES (*Meloidogyne* spp.) ON SELECTED INDIGENOUS LEAFY VEGETABLES IN KISII AND TRANS-MARA COUNTIES, KENYA

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DECLARATION

I, Shem Bonuke Nchore, declare that this thesis is my original work and has not been presented for the award of a degree in any other University or for any other award.

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Signature…………………......................Date............................…………

Supervisors Approval

We confirm that the work reported in this thesis was carried out by the candidate under our supervision as university supervisors.

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DEDICATION

This work is dedicated to my lovely parents Mr. Joseph Nyakeramba Nchore Kerama and Mrs. Jane Kemunto Nchore, and my lovely aunt Yunika Kemuma Omae for their caring love, support and encouragement

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LIST OF ABBREVIATIONS AND ACRONYMS

Ac	*Amaranthus cruentus*
Ad	*Amaranthus dubius*
AEZ	Agro Ecological Zones
Ah	*Amaranthus hypochondriacus*
ANOVA	Analysis of Variance
a.s.l	Above sea level
Cg p	*Cleome gynandra* purple stemmed variety
CM	Cattle Manure
CRBD	Complete Randomized Block Design
DAP	Di ammonium phosphate
FAO	Food and Agricultural Organization
GM	Goat Manure
GoK	Government of Kenya
ILVs	Indigenous Leafy Vegetables
HIV/AIDS	Human Immune Deficiency Virus/Acquired Immune Deficiency Syndrome
IPGRI	International Plant Genetic Resources Institute
J2s	Second stage juveniles
KEPHIS	Kenya Plant Health Inspectorate Services
LH 1	Lower Highland Zones 1
LH 2	Lower Highland Zones 2
LM 1	Lower Midland Zones 1
LM 2	Lower Midland Zones 2
NARL	National Agricultural Research Laboratories

µm	Micrometer
OAs	Organic Amendments
P_f	Final Population
pH	Potential of Hydrogen ion concentration
P_i	Initial Population
PPN	Plant Parasitic Nematodes
Rf	Reproduction Factor
RKN	Root Knot Nematodes
Sng	*Solanum nigrum* green berried variety
Snp	*Solanum nigrum* purple berried variety
Svo	*Solanum villosum* orange berried variety
Td	*Tithonia diversifolia*
Trej	Tea rejects
Tres	Tea Residue
UM 1	Upper Midland Zones 1
UM 2-3	Upper Midland Zones 2-3
USDA	United States Department of Agriculture

ABSTRACT

Solanum nigrum L., *Cleome gynandra* L. and *Amaranthus* spp. are some of the indigenous leafy vegetables (ILVs) that contribute to food diet, income generation, good nutrition and health to resource-poor farmers in Kisii and Trans-Mara counties. The production of ILVs is constrained by inadequate land, diseases and pests of which, root-knot nematodes (RKN) are the most damaging pests to vegetable crops causing about 30 % yield losses globally. However, there is no information about the incidence, prevalence and management of RKN on ILVs in Kenya or worldwide. A survey was conducted in Kisii and Trans-Mara to determine the incidence and prevalence of RKN in ILVs and the available germplasms were screened for response to *Meloidogyne* spp. in greenhouse. Five organic amendments (OAs) commonly used in the areas of study for ILVs cultivation were also evaluated for their effects on RKN on *C. gynandra*, *S. nigrum*, *S. villosum* and *Amaranthus* spp. in greehouse and field tests. The amendments included: tea (*Camellia sinensis* (L.) Kuntze) residues (Tres) and rejects (Trej), decomposed cattle manure (CM), goat manure (GM) and *Tithonia diversifolia* manure (Td). The amendments were incorporated into the sterilized soil in micro-pots and the field at recommended rates. Unamended soils served as controls. After ninety (90) days, the disease and plant growth parameters were assessed. The study revealed that, 62.8 % of the farms surveyed were infected with RKN. The disease incidence was generally higher in the black nightshades from Kisii compared to those from Trans-Mara, while disease incidence in spider plants and amaranths was generally higher in Trans-Mara compared to Kisii Counties. Black nightshades were susceptible to RKN with green berried recording higher reproduction and galling index compared to susceptible check, while amaranths and spider plants had lower scores (<15.0 %) in the screening experiment. All OAs significantly (P<0.05) reduced final populations, rate of galling and reproduction of RKN relative to unamended soil. The reduction in such parameters greatly varied with the type of the OA and the host plant. Generally, Tres and Trej were most effective (P<0.05) against RKN galling followed by Td, while CM and GM were the least. However, corresponding decrease in ILV growth was observed in Tres and Trej amendment while, the other OAs showed significant growth increase under greenhouse conditions. As for managing RKN on ILVs, Tres and Trej were the most effective inhibitor to its build-up followed by Td manures. Percentage increase in black nightshades and amaranth shoot height and biomass was obtained in soils amended with Td, CM and GM compared to Trej and Tres in pots yet in the field Tres increased plant growth significantly. Further studies are imperative to correctly identify all the prevailing races of *Meloidogyne* spp. across various soil types in the study areas in addition to determination of the mechanisms of control by the OAs for proper nematode management.

CHAPTER ONE

INTRODUCTION

1.1 Background information of the study

Indigenous leafy vegetables (ILVs) have been part of the food systems in Southern Sub-Sahara Africa for generations (Chweya and Eyzaguirre, 1999; FAO, 1988; Smith and Eyzaguirre, 2007). In Kenya, over 220 indigenous plant species are used as leafy vegetables out of which, four have been fully domesticated, fifteen are semi domesticated while the majorities are wild (Maundu *et al.*, 1993).

The ILVs grown in Kenya includes; *Solanum villosum, S. nigrum, S. scubrum, Amaranthus dubius*, *A. hybridus*, *A. hypochondriacus*, *A. cruentus, A. blitum* and *Cleome gynandra* (Abukutsa-Onyango, 2002; Schippers, 2002). Vegetables are produced at farm gardens intercropped with other crops like maize, beans, tomatoes, kales and groundnuts or in place stands for rural and urban consumption (Abukutsa-Onyango, 2007). Vegetables are source of an affordable nutrition, vitamins and proteins to the rural population (IPGRI, 2003; Kokwaro, 1976), generate income, have medicinal properties (Mertz *et al.*, 2001) and form part of the traditional diets of many communities in Kenya (Grubben and Denton, 2004). The ILVs have been exploited in the management of the HIV/AIDS infected persons (Government of Kenya, 2002; Grubben and Denton, 2004) and healing stomach related ailments (Olembo *et al.*, 1995).

These vegetables have short growth periods and are ready for harvest within 3-4 weeks after establishment, respond well to organic fertilizers as well as tolerating biotic and abiotic stress (Abukutsa-Onyango, 2004). Their consumption has increased due to increased awareness of their nutritional value and the high cost of the vegetable substitutes. The average consumption of ILVs in Kenya is estimated at 147 kg $person^{-1}$ $year^{-1}$ in urban areas and 73 kg $person^{-1}$ $year^{-1}$ in the rural areas (Chweya and Eyzaguirre, 1999; Onim and Mwaniki, 2008). The high consumption may be attributed to among other factors commercialization of seed supply, rediscovery of ILVs by urban residents, move from kiosk to supermarkets where they are sold in fresh bundles as well as pre-processing which promotes their sale and consumption in urban areas.

The production of ILVs is constrained by among other factors inadequate seed production, lack of knowledge on growth and production of ILVs by farmers (Abuktsa-Onyango, 2007). Moreover, poor seed production and processing methods has resulted to low quality seeds preserved by farmers (Abuktsa-Onyango, 2007). Similarly, declining farm acreage, drought, poor marketing systems, infrastructure, neglect by researchers, educators, policy makers and agriculturalists constrain the production of ILV. In addition, viral, fungal and bacterial diseases as well as arthropod and nematode pests have been identified to be constraints in production of ILVs (Chweya and Eyzaguirre, 1999).

Nematodes are obligate parasites that are globally distributed with wide host range (Zarina, 1996). An estimated annual loss of about US 125 billion dollars in major crops globally is estimated to be caused by plant parasitic nematodes (PPN) (Zarina, 1996). They are great limiting factors in vegetable production globally and Kenya is no exception, a situation which in most cases is overlooked and goes unnoticed by majority of farmers (Kariuki *et al*., 2010; Zarina, 1996). Currently, scanty information is available on other PPN genera infecting ILVs. Among the PPN, root-knot nematode (RKN) (*Meloidogyne* spp.) causes greater losses of $ 78 billion per annum globally in a wide range of crops including vegetable crops (Zarina, 1996) and Kenya included (Kariuki *et al*., 2010) than any single group of PPN (Apple, 1985).

1.2 Problem statement and justification

Indigenous leafy vegetables plays significant role in the traditional diets (Grubben and Denton, 2004), have medicinal properties, generates income and are rich in micronutrients (IPGR, 2003; Olembo *et al*., 1995; Schippers, 2002). However, phytopathogens like fungi, bacteria, viruses and nematodes cause great reductions in vegetable yield (Chweya and Eyzaguirre, 1999; Gowen, 2005; Kariuki *et al*., 2010). Plant parasitic nematodes cause losses of up to 80 % on vegetables where soil fertility is low (Siddiq, 2000; Agrios, 2005; Kaskavalci, 2007). *Meloidogyne* spp. causes greatest yield losses ranging from 5 % to 60 % in vegetable crops and the losses are aggravated when they form complexes with *Fusarium* and *Ralstonia solanacearum* (Bala, 1984; Rivera and Aballay, 2008; Stirling *et al*., 1992). *Meloidogyne* spp. is ranked first in the world among the ten nematode genera considered as important pathogens hence a serious threat to vegetable production (Apple, 1985).

In Kenya, the RKN problem is more damaging because the country is located in the tropical region, where the climate is suitable for nematode reproduction and survival throughout the year (Kariuki *et al*., 2010; Zarina, 1996). Sandy-loam soils in warm rainy areas favour nematode infestation (Tariq, 2008). The availability of susceptible annual crops and continuous cultivation of susceptible crops in the same field often aggravate the disease problem (Sudirman, 1992; Zarina, 1996).

Although chemical nematicides are effective in managing RKN (Tariq, 2008), they cause serious threat to the ecosystem and are fatal to animals at high doses (Sharma and Pandey, 2009). Moreover, their use has been banned following their adverse effects (Kimenju *et al*., 2008; Wachira *et al*., 2009) hence, alternative eco-friendly methods such as use of organic amendments (OAs) have been recommended (Karuri *et al*., 2010; Waceke, 2001 & 2002). These OAs are useful alternatives of increasing yield (Abukutsa-Onyango, 2007) and minimizing incidence and prevalence of RKN (Zarina, 1996).

In Kenya, extensive research has been conducted using OAs for the management of RKN in vegetable crops (Waceke, 2001 & 2002). However, there is limited information concerning the use and efficacy of OAs for the management of RKN in ILV production systems. Information on the damage caused by RKN on ILVs is inadequate in Kenya, especially in farm areas of Kisii and Trans-Mara Counties. Hence, a study was conducted to ascertain the incidence and prevalence of this nematode pathogen in the two Counties. This study determines the association of RKN and ILVs commonly grown in these areas, screen the available local and commercial ILV germplasm for response to RKNs, and evaluate OAs commonly used for the production of ILVs for the management of RKN. The study provides data needed to develop sound management practices and control measures for RKN in the production of ILVs.

1.3 Research questions

i. Are RKN prevalent on commonly cultivated ILVs in Kisii and Trans-Mara Counties?

ii. How does the available local and commercial ILV germplasms in Kisii and Trans-Mara respond to RKN infection?

iii. What effects do locally used organic soil amendments have on RKN and yield of various varieties of *C. gynandra, S. nigrum* and *Amaranthus* spp.?

1.4 Hypotheses

i. There are no RKN associated with ILVs in Kisii and Trans-Mara Counties.

ii. The available local and commercial germplasms for *S. nigrum*, *C. gynandra* and *A. cruentus, A. dubius, A. hypochondriacus* are not resistant to RKN in Kisii and Trans-Mara Counties.

iii. Amending soils with cattle and goat manure, *Tithonia diversifolia*, tea rejects and residues does not influence infectivity of RKN and yields of various ILVs of *C. gynandra, S. nigrum* and *Amaranthus* spp.

1.5 Objectives

1.5.1 General objective

To determine the incidence and prevalence of RKN and their management using selected OAs commonly used for the production of ILVs in Kisii and Trans-Mara Counties.

1.5.2 Specific objectives

i. To determine the incidence and prevalence of the RKN on the commonly cultivated ILV crops in Kisii and Trans-Mara Counties.

ii. To screen the available local and commercial germplasm of ILVs for response to RKN.

iii. To determine the effect of cattle and goat manure, *T. diversifolia*, tea rejects and residues on RKN and yields of various ILVs of *C. gynandra, S. nigrum* and *Amaranthus* spp. in pots and field studies.

1.6 Significance of the study

These findings and knowledge are useful to ILV farmers in Kisii and Trans-Mara Counties of Kenya. It improves our understanding of RKN in the ILVs production systems and enhances management strategies. The findings lead to renewed interest in ILVs by the policy makers and the community as well as forming a basis for new research. In addition, it facilitates the future production of improved and resistant ILV germplasms; provide information and guidance for planning effective management strategies. This study creates awareness to growers about the incidence and prevalence of RKN infecting ILVs as well as an opportunity for generation of new technology that can be easily tapped and adopted into vegetable production system. The farmers will gain from cheap and readily available nematode management resources. This could lead to improved vegetable production and thus reduce malnutrition in children and improve on food security in the country.

CHAPTER TWO

LITERATURE REVIEW

2.1 Indigenous Leafy Vegetables

Vegetables form an important part of the diet and nutritional balance with different varieties grown all over the country depending on the rainfall and availability of irrigation (Ministry of Agriculture, 2007). The ILVs commonly grown in Nyanza, Western, Rift Valley and Coast provinces mainly for home consumption and urban markets include; amaranth, spider plant and black nightshade (Ministry of Agriculture, 2007).

Indigenous leaf vegetables form an integral part of agricultural systems in Africa (Adebooye and Opabode, 2004). An estimated 6,376 useful indigenous African plants of which 397 are vegetables have been reported (Smith and Eyzaguirre, 2007). Indigenous vegetables are grown in Eastern and Central Africa (ECA) for their important nutritional values among other benefits to the users (Onim and Mwaniki, 2008).

In Kenya, over 220 traditional leafy vegetables are used (Maundu *et al*., 1993) of which, ten ILVs are cultivated (Abukutsa-Onyango, 2007). The species identified include; *Solanum villosum, S. scubrum S. nigrum*, *Amaranthus dubius, A. blitum* and *Cleome gynandra* (Abukutsa-Onyango, 2002; Schippers, 2002). They are a source of income to the rural farmers in western Kenya with their popularity and local demand largely unsatisfied due to campaigns on their medicinal and nutritional value (Ministry of Agriculture, 2007).

A study by Maundu *et al*., (1999a) in Kisii indicated that, *C. gynandra*, *S. nigrum*, *S. villosum*, *A. cruentus*, *A. dubius*, *A. hypochondriacus*, *A. hybridus* and *A. blitum* are grown in home gardens for easy management. They have nutritional and medicinal attributes being rich in proteins, vitamins, carbohydrates and other mineral elements (Grubben and Denton, 2004).

2.2 Growth of indigenous leafy vegetables

Indigenous Leafy Vegetables occur in tropical and warm temperate regions from sea level to altitudes over 3500 m with Western Kenya, parts of Rift valley and coastal areas being the leading production sites (Edmonds and Chweya, 1997; Abuktsa-Onyango, 2007). They are drought tolerant, grow on a wide range of deep and well drained sandy to clay-loam soils, with pH 5.5- 7.0 (Waithaka and Chweya, 1991).

The seeds are either broadcast or planted in rows at a depth of 0.25-5.0 cm (Tindall, 1983) at a spacing of at least 15 to 50 cm between plant and 30-60 cm between rows (FAO, 1988). Germination occurs 10-15 days after sowing (Edmonds and Chweya, 1997). The optimum germination temperature ranges from15 to 30^{o} C (Rogers and Ogg, 1981). Manure and phosphate fertiliser may be applied before planting or top dressing with nitrogenous fertilizers to encourage vigorous growth and leaf production (Abukutsa-Onyango, 2007). They are ready for harvesting three weeks after sowing (Waithaka and Chweya, 1991).

2.2.1 Spider plant

The spider plant (*Cleome gynandra* L.), cat's whiskers (English) or Chinsaga (Ekegusii) grows to a height of 1.0 m (Naples, 2005). It belongs to the family

Cleomaceae comprising of 150-200 species, of which 50 of them occurs in Africa (Chweya and Eyzaguirre, 1999). The existing varieties for spider plant in Kenya are purple and green/white stemmed.

They contribute to food security, income generation (Olembo *et al*., 1995) and increase mineral nutrition (Schippers, 2002; Tindall, 1983). The edible leaves have a bitter taste due to polyphenolics (Leung *et al*., 1968; Naples, 2005). They are used in traditional and marriage ceremonies (IPGRI, 2003), replenish blood in people with anaemia and are given to women in labour (Mathenge, 1997; Naples, 2005). So far, limited information is available on nematode infection on this crop (Chweya and Eyzaguirre, 1999).

2.2.2 Amaranth

Amaranth (English), mchicha (Kiswahili) or emboga (Ekegusii) is an herbaceous annual belonging to the family Amaranthaceae with thirteen species reported in Kenya (Maundu *et al*., 1999a). Of these, *A. thunbergii*, *A. sparganiocephallus, A. blitum* and *A. graecizans* are probably indigenous to the country (Maundu *et al*., 1999a). However, ototo (*A. hybridus*), emboga yekegusii, omotego (*A. hypochondriacus*) and riboroche (*A. cruentus*) are reported to exist in Kisii and Trans-Mara (Chweya and Eyzaguirre, 1999). They are differentiated by their leaves, colour of seeds, growth height and occurrence of thorns (Maundu *et al*., 1999a, b; Schippers, 2004).

Amaranths have been reported to host *Meloidogyne* spp. in a survey conducted in Pakistan (Ateeq-ur-Rehman, 2009; Zarina and Shahid, 2002). Similar findings were reported by other workers in Spain (Castillo *et al*., 2008) and in Fiji on *Amaranthus viridis* (Khurma *et al*., 2008). However, little information is available on host suitability of other *Amaranthus* varieties to RKN.

2.2.3 Black nightshade

Black nightshade (English), *Solanum nigrum* L., rinagu (Ekegusii), is an erect herb belonging to the Solanaceae family which is widely distributed in the tropics (IPGRI, 1997). Five varieties belonging to *S. nigrum* (green and purple berried) and *S. villosum* (yellow, orange and red berried) varieties are commonly used in Kenya (Edmonds and Chweya, 1997; Schippers, 2002). They play an important role in traditional medicine for treatment of ailments (Manoko and Van der Weerden, 2004), and as tonic for babies. Its potential is being considered by the Government of Kenya for use in the management of HIV/AIDS in infected persons (Government of Kenya, 2002). Seeds are used for pigment extraction (Edmonds and Chweya, 1997). So far, 13 nematodes including RKN have been reported to attack black nightshades and other ILVs (Castillo *et al*., 2008; Rogers and Ogg, 1981).

2.3 Root-knot nematodes (*Meloidogyne* spp.)

Among the biotic factors (fungi, bacteria, viruses and nematodes) that are obstacles to getting high yields of ILVs, *Meloidogyne* spp. are widespread, destructive and the most difficult pathogen of ILVs (Fontem and Schippers, 2004). Root-knot nematodes greatly reduce both quality and quantity of vegetables by living within plant roots or inhabits the rhizosphere soil around plant roots and root hairs (Agrios, 2005).

Meloidogyne spp. are polyphagous PPN with marked sexual dimorphism where the males are vermiform and active, while the females are pyriform or saccate and sedentary (Tariq, 2008). Mature females measure between 0.5 – 1.5 mm in length and 0.33 – 0.7 mm in width (Beije *et al*., 1984; Taylor and Sasser, 1978). They are host specific with wide host ranges (Abu-Gharbieh *et al*., 2005; Yeates *et al*., 1993) of more than 2000-3000 plant species including almost all cultivated crops (Abad *et al*., 2003; Ateeq-ur-Rehman, 2009; Okeniyi *et al*., 2009). These nematodes inflict great losses to various vegetable crops and fruit trees (Tariq, 2008). Infected roots produce galls that interfere with the uptake of water and mineral salts hence affecting foliar growth on many host plants (Anwar and McKenry, 2010; Wallace, 1978).

More than 70 *Meloidogyne* species have been described (Eisenback and Triantaphyllou, 1991; Karssen, 2002) of which, four have been recognized as the major and widely distributed in Kenya (Beije *et al*., 1984). These are *Meloidogyne incognita* (Kofoid and white) Chitwood, *M*. *javanica* Treub, *M*. *arenaria* Neal and *M*. *hapla* Chitwood (Sasser, 1980). These species are responsible for atleast 90 % of all damage caused on plants by RKN (Ateeq-ur-Rehman, 2009). Plant parasitic nematodes cause annual yield losses of about $ 100 billion worldwide, with 70 % of the damage attributed to RKN (*Meloidogyne* spp.) thus making RKN nematode of major concern (Chaudhary *et al*., 2011).

2.3.1 Life cycle of root-knot nematode

The RKN have a short life cycle consisting of the egg, four juvenile stages and the adult male and female, ranging from six to eight weeks (Pakeerathan *et al*., 2009) that can lead to high reproduction and survival rates resulting to severe crop losses in warmer tropical countries (Ateeq-ur-Rehman, 2009). Root-knot nematodes may reproduce by mitotic parthenogenesis or by amphimixis and have many generations on one crop (Triantaphyllou, 1962; Ladner *et al*., 2008; Tariq, 2008).

Mature female lay between 1000 and 3000 eggs into a gelatinous matrix that are completely or partially embedded into the root of host plant (Maggenti and Allen, 1960; Sudirman, 1992). The eggs develops into first juvenile (J1) within the egg membrane before they moult forming infective stage (J2). The J2 moves through the soil towards the root tip, penetrating and migrating to the zone of elongation where they drain the plant's photosythates and nutrients before becoming sedentary (Bird, 1974). They increase in size and undergo the second and third moult forming J3 and J4 respectively. The J4 develops into either female or male. The male leaves the root system and becomes free living in the soil while mature female lay eggs and the cycle is repeated again. The eggs are not laid at temperature below 14.2^{o} C or higher than 31.7^{o} C and a new generation can arise within 25 days although under less favourable conditions, the time may be prolonged to 30 to 40 days (Beije *et al*., 1984).

2.3.2 Disease cycle of root-knot nematode

The infective stage is guided by plant exudates to move through the soil to the growing root tips and penetrates it using its stylet and enzymes behind the root cap (Beije *et al*., 1984). This penetration process occurs between 10 and 35^{o} C with the optimum being at about 27^{o} C depending on the species (Beije *et al*., 1984). The enzymes dissolve the middle lamella interrupting the cell division (Bird, 1974).

The J2 migrates intracellularly through the cortex where it becomes sedentary (Bird, 1974). It secretes growth regulators as well as induces the host plant to produce ethylene and auxin that causes hypertrophy and hyperplasia around its head forming giant cells (Bird, 1974). Formation of giant cells interferes with vascular vessels in infected crops causing water deficiency, loss in vigour, chlorosis, stunting, reduced yields and plant death during hot dry weather (Agrios, 2005; Bala, 1984; Sasser and Carter, 1985; Wilcox-Lee and Loria, 1987). A short life cycle, existence of different species, ability to inhabit and attack underground parts of plants and high reproductive rates makes the control and management of RKN difficult (Sikora and Fernandez, 2005; Stirling, 1991). The RKN are the most destructive and difficult pest to control in tropical and subtropical countries (Simpson and Starr, 2001) with an estimated amount of US$ 500 million being spent on their control globally (Keren-Zur *et al*., 2000).

Meloidogyne spp. are pests of major economic importance associated with vegetable crops globally (Jacquet *et al*., 2005). They cause severe damage to crops, resulting to substantial yield losses ranging between 5 % and 12 % globally (Kaskavalci, 2007; Sikora and Fernandez, 2005; Zaki, 2000) and in some instances crop failure in susceptible hosts in developing countries (Jacquet *et al*., 2005; Sudirman, 1992). Taylor, (1967) and Siddiqi, (1986 & 2000) reported suppression of vegetable yields by RKN ranging from 10 to 80 % causing great economic losses in vegetables (Cetintas and Yarba, 2010).

The RKN attack on vegetables may greatly intensify severity of bacterial (*Ralstonia solanacearum*), *Fusarium* and *Verticillium* wilt diseases resulting in greater yield loss in vegetable crops (Bala, 1984; Beije *et al*., 1984; Rivera and Aballay, 2008) in soils with low soil moisture and fertility (Hillocks, 2002). They have been reported in *C. gynandra* (Naples, 2005), *S. nigrum* (Zancada *et al.*, 1998) and *Amaranthus* spp. (Zarina and Shahid, 2002; Van den Heaver and Alleman, 2004). These nematodes are spread by transplanting infested seedlings, soil, sticking on farm implements and farm workers as well as via irrigation water (Beije *et al.*, 1984).

2.3.3 Incidence and reproduction of root-knot nematode in vegetable crops

Studies have been conducted in various parts to determine RKN disease incidence and reproduction in vegetable genotypes. Anwar and McKenry, (2010) conducted an extensive survey study in 16 major vegetable production areas in Punjab, Pakistan and found out that RKN (*M. incognita* and *M. javanica*) incidence was ranging from 5.4 % to 94.4 % in infested fields. In a separate study in Pakistan, disease incidence ranging from 75-100 % was reported in tomato (Shahid *et al.*, 2007). However, such studies on incidence of RKN in ILVs have not been conducted in Kenya or elsewhere.

2.3.4 Management of root-knot nematodes

2.3.4.1 Use of resistant genotypes

Plant resistance to PPN is among the most effective and eco-friendly components of integrated pest management that results to increased crop yield (Devran, *et al.*, 2010). Host plant resistance has been prioritized over chemical, biological, cultural and regulatory control components as a major goal for pest management. It provides an effective, sustainable and economical method for managing PPN in both high and low value cropping systems (Anwar and McKenry, 2010). Establishment of new diseases and new races of existing pathogens threatens crop production, thus, screening for response to RKN becomes a major goal to solving this problem.

Resistant varieties exhibits reduced nematode reproduction and low populations in the rhizosphere zone compared to susceptible hosts (Medina-Filho and Tanksley, 1983). Crop cultivars with high degree of resistance are recommended for nematode-infested fields either as a routine crop or in a rotational sequence of the crops (Starr *et al*., 2001). They are also compatible to the environment, requires less specialised applications and low input costs (Starr *et al*., 2001). Root-knot nematode resistant rootstocks have been used by tomato growers to control RKN (Devran *et al*., 2010).

The susceptibility of ILVs has important implications on the yield and economic returns. Therefore, information on susceptibility to RKN can be useful to farmers (Khan, 1994). Host plant resistance is a potential component of a solution to many nematode problems of tropical agriculture especially, for the low input, small-scale farmers when used in combination with cultural techniques and traditionally grown crops (Luc *et al*., 2005). There is need therefore, to screen the ILVs for response to RKN.

2.3.4.2 Chemical Nematicides

The control and management of PPN is remarkably a hard task (Simpson and Starr, 2001). Due to their worldwide distribution, disease complexes with fungi and bacteria and serious destruction to vegetables and field crops, it is imperative to find out the most effective and feasible management of RKN (Ateeq-ur-Rehman, 2009). Of the different nematode management strategies, chemical control has proved generally effective in managing PPN on a number of crops in the tropics (Wachira *et al*., 2009; Odour-Owino and Waudo, 1994; Waudo and Waceke, 1987). Mocap nematicide has been used in the control of PPN in vegetable and perennial crops. However, they have adverse effects to the environment such as depleting the ozone layer (UNEP, 1995) and interacting with human and non-target organisms in the soil (Schneider *et al*., 2003).

Nematicides reduce the populations of beneficial antagonistic micro-organisms in the soil (Hasabo and Noweer, 2005). Furthermore, they are costly and unaffordable to the small scale rural resource-poor farmers. Therefore, the development and implementation of alternative control strategies is needed (Waceke and Waudo, 1993 & 2001; Waceke, 2001& 2002). These include crop rotation, use of resistant varieties and organic amendments (OAs) (Kaskavalci, 2007; Oka *et al*., 2000).

2.3.4.3 Organic Amendments (OAs)

Amending soil with OAs is the most feasible and eco-friendly practice of managing RKN and other PPN (Agbenin, 2004). Management of PPN has been effectively conducted in various parts of the world using OAs of animal and plant origin (Agbenin, 2004). In Africa, an increasing interest in the use of OAs for the management of nematodes has been reported (Gaur and Prasad, 1970; Agbenin, 2004; Langat *et al*., 2008). Organic amendments have been incorporated into the soil as alternative sources for the management of PPN and adding nutrients to the soil for improved crop production (Hasabo and Noweer, 2005; Oka *et al*., 2000; Wachira *et al*., 2009).

The incorporation of organic material into the soil reduces RKN populations (Muller and Gooch, 1982). These amendments increases antagonistic organisms in the soil (Akhtar and Malik, 2000; Kimenju *et al*., 2004), improving drainage, aeration and water/moisture retention in the soil which is reported to increase plant tolerance to PPN (Wachira *et al*., 2009). Cherr, (2004) reported increased populations of predatory nematodes, availability of fungal and bacterial grazing nematodes on using saw dust mulch. Incorporation of animal manure and agro-based industrial wastes (Korayem, 2003) to the soil for the management of RKN has also been reported (Magdoff and Van Es, 2000).

Studies conducted in Florida, USA reported an increase in population of saprophytic, omnivorous and predatory nematodes on soils with organic matter (Gonzalez, 1991) as well as enhancing nematode-trapping fungi (Wang *et al*., 2002). The materials used for amending soil for this study were selected on the basis of their availability and traditional usage by farmers in the areas of study.

Soil amendment is a more realistic way of managing and suppressing RKN, increasing vegetable yields and plant tolerance (Kimenju *et al*., 2004). Animal manure like CM and GM have been used in managing RKN as well as in sustainable agricultural systems to improve soil structure and fertility (Agbenin, 2004). There is limited data on the effect of these materials in Kenya on *Meloidogyne* spp. infecting ILVs. Application of chemical fertilizers to soils may pose leachate problems. Moreover, naturally occurring substances like green manure, animal manure and agro-industrial wastes help reduce cost over chemical methods and posses nematicidal properties for control of PPN (Buena *et al*., 2006).

2.3.4.4 Animal manures

Animal manures have been used over time in the management of PPN in addition to adding soil fertility and improving its texture (Agbenin, 2004; Korayem, 2003). The animal manures used include, CM, poultry litter and GM. It has been found that CM and GM stimulate soil flora and fauna which are antagonistic to PPN through various mechanisms. Korayem, (2003) revealed that CM effectively reduces RKN (*M. incognita*) in tomato in both greenhouse and field trials in Egypt. Wachira *et al*., (2009) evaluated the use of CM on the management of RKN in vegetable production in Kenya and found it effective in suppressing nematode population.

2.3.4.5 Green manure

Green manures are incorporated into the soil to increase soil organic matter, structure, microbial biomass and reduce Nitrogen leaching (Bath 2000, Wivstad 1997). Moreover, they improve nutrient retention and N-uptake efficiency, reduces erosion, suppresses weeds and PPN through physical, biotic, allelopathic and adaptive interactions (Cherr, 2004; Ross *et al*., 2001). Addition of green manure of cabbage, cauliflower leaves, chopped pineapple leaves, rye and cotton to soil reduced RKN disease incidence in field studies in Sri Lanka (Pakeerathan *et al*., 2009). Moreover, green manure has additional benefits not only by enriching the soil, changing soil physical and chemical properties, but also reduces soil borne pathogens like *Rhizoctonia*, *Fusarium*, *Ralstonia* and *Phytium* population (Pakeerathan *et al*., 2009). Green manures may have effects on populations of PPN, improves soil fertility and crop productivity (Cherr, 2004; Pakeerathan *et al*., 2009; Pyndji *et al*., 1997).

Tithonia diversifolia (Td) is a shrub belonging to the family Asteraceae that is widely distributed along farm boundaries in the humid and sub-humid tropics of Africa (Jama *et al*., 2000). It is used to improve soil fertility while it is being considered as a good component of green manure and amendment in banana, tomato and maize crop production in Kenya (Jama *et al*., 2000) and in Papua New Guinea (Igua and Huasi, 2009). *Tithonia diversifolia* has been used in biomass transfer, eradicating striga and as a pesticide for management of nematodes in the production of maize in western Kenya (Jama *et al*., 2000). On the other hand *T. diversifolia* has been used in *in vitro* experiments to manage PPN (Akinyemi *et al*., 2009). However, the use of Td manure for management of RKN in ILVs has been under utilized as there is no information available on their use in managing these nematodes in ILVs.

2.3.4.6 Agro-industrial wastes

Agro-industrial wastes are an important source of OA at low and affordable cost to rural resource-poor farmers. They are effective and eco-friendly relative to chemical nematicides (Ayazpour *et al*., 2010). Composted agro-industrial wastes have been used as nutrient sources in crop production as well as management of PPN in Nigeria (Hassan *et al*., 2010). Therefore, incorporating these materials into soil is not only a possible solution to their disposal (D'Addabbo and Sasanelli, 1996) but also a feasible way of managing PPN.

Natural products from plants reduce PPN population in the soil (Insuaza, 1988). Korayem, (2003) reported that Egyptian farmers incorporated animal and crop residues into the soil to improve its fertility and structure as well as control PPN. Use of agro-based industrial residues for the management of PPN has been reported

(D'Addabbo and Sasanelli, 1996). Tea residues (Tres) and rejects (Trej) are used in amending soil to manage RKN and improving soil fertility in perennial crops (Rivera and Aballay, 2008). However, their use in managing RKN in ILVs has not been reported in Kenya or elsewhere.

2.3.4.6.1 Tea (*Camellia sinensis* (L.) Kuntze) dust residue

Kenya is a major tea producer and exporter in the world. Tea residues and Trej are piled up in most factories. Disposal of these materials has been done through burning them to generate steam without considering possible alternative uses. In the recent past, some workers and farmers residing within and around the factory premises in Kisii have been incorporating these materials into the soil for the production of vegetables in home gardens (Nchore *et al*., 2012). The use of Tres for the management of PPN has been effectively carried out in Chile (Rivera and Aballay, 2008) and Egypt (Montasser, 1991) but in Kenya, such studies have not been reported.

2.3.5 Mechanisms of organic soil amendment

The mode of action of OAs in the management of PPN involves several mechanisms including stimulation of antagonistic organisms, increases soil fertility and structure and the level of plant resistance to PPN (D'Addabbo and Sasanelli, 1996; Korayen, 2003; Stirling, 1991). Undecomposed dry plant residue and materials are reported to release nematoxic chemicals when incorporated into the soil (Ragasa *et al*., 2007; Rich *et al*., 1989). Moreover, during decomposition nematoxic gases like ammonia and enzymes like collagenase and chitinase acting on the cuticle of nematodes and their eggs are released (Bello, 1997; Galper *et al*., 1990). Increased temperature during decomposition may inactivate, kill, degrade or render PPN susceptible to other control agents in the soil (Chen and Katan, 1980; Hasin, 2002; Stapleton, 1991).

This research seeks to survey and screen the available local and commercial ILV germplasms for response to RKN and assess the efficacy of locally available OAs commonly used for the production of ILVs in Kisii and Trans-Mara Counties on RKN infection.

CHAPTER THREE

MATERIALS AND METHODS

3.1 GENERAL METHODOLOGY

3.1.1 Description of sampling sites and procedures

The roots and soil samples of ILVs were collected only from those farms where vegetable production occurred in Sameta and Kilgoris Divisions for the production of ILVs in Kisii and Trans-Mara Counties, respectively. These areas grow large amounts of ILVs for subsistence and commercial purposes.

Kisii County lies between 1400 m and 2000 m above sea level (a.s.l) with rainfall amount of 1100-2000 mm (Chweya and Eyzaguirre, 1999) and lies between latitudes of 00300 and 00580 south and longitude of 340420 and 35000 west (Figure 3.1). The land allocated to the production of ILVs in Kisii is 25 % or more of the 0.5 - 5 hectares owned by a single farmer (Abukutsa-Onyango, 2007).

The County has three AEZs zones; Lower Highland Zone one and two (LH 1 and LH 2) and Upper Midland Zone one (UM 1) known for vegetable production (Jaetzold and Schmidt, 1983). Sampling was done in farms from UM 1 and LH 1 in Sameta area (altitude of 1980 m a.s.l,) in Kisii. Upper Midlands one (UM 1), also referred to as the Coffee-Tea Zone, while LH 1 is referred to as Tea-Daily Zone and lies between 1980-2280 m above sea level (Jaetzold and Schmidt, 1983). Both zones are characterized by permanent cropping, very good yield potential, moderate to high fertile red volcanic (Ferralsols, Nitosols and Phaeozems) soils, and bimodal rainfall (1400-1800 mm/year) and annual average temperature range of 14.8-16.6^{o} C (Jaetzold and Schmidt, 1983). Crops such as finger millet, beans, potatoes, cabbages, spinach, maize, pyrethrum, black nightshades (rinagu), and kales among others are grown (Jaetzold and Schmidt, 1983).

Trans-Mara is located on the altitude of 2200 m a.s.l. It is divided into two parts; the highland (Kilgoris division mostly for crop production) and plateau (mostly for livestock production). The study site (Kilgoris) is located at an altitude of 1950 m a.s.l with annual rainfall of between 1336-1600 mm evenly distributed throughout the year (Jaetzold and Schmidt, 1983) (Figure 3.2).

Trans-Mara has three AEZs (LH 1, LH 2 and UM 2-4) where vegetable farming is practiced (Jaetzold and Schmidt, 1983). Lower highland one (LH 1) is an extension from Kisii as described earlier, Lower Highland two (LH 2) also known as Maize/Wheat-Pyrethrum Zone occurs between an altitude of 1980 m and 2280 m with mean annual temperature range of 14.8-16.6^{o} C and rainfall of between 1000-1300 mm/year. The soil fertility is low to very low for growth of maize, wheat, peas, potatoes, carrots, and kales among others. Upper Midland two to four (UM 2-4) is also referred to as Coffee-Maize Zone is located at an altitude of between 1720-1880 m with mean annual temperature and rainfall range of 17.5-19.7^{o} C and 1000-1400 mm/year respectively (Jaetzold and Schmidt, 1983). The soil has moderate fertility for growth of Maize, cabbage, tomatoes, spinach and kales among others (Jaetzold and Schmidt, 1983).

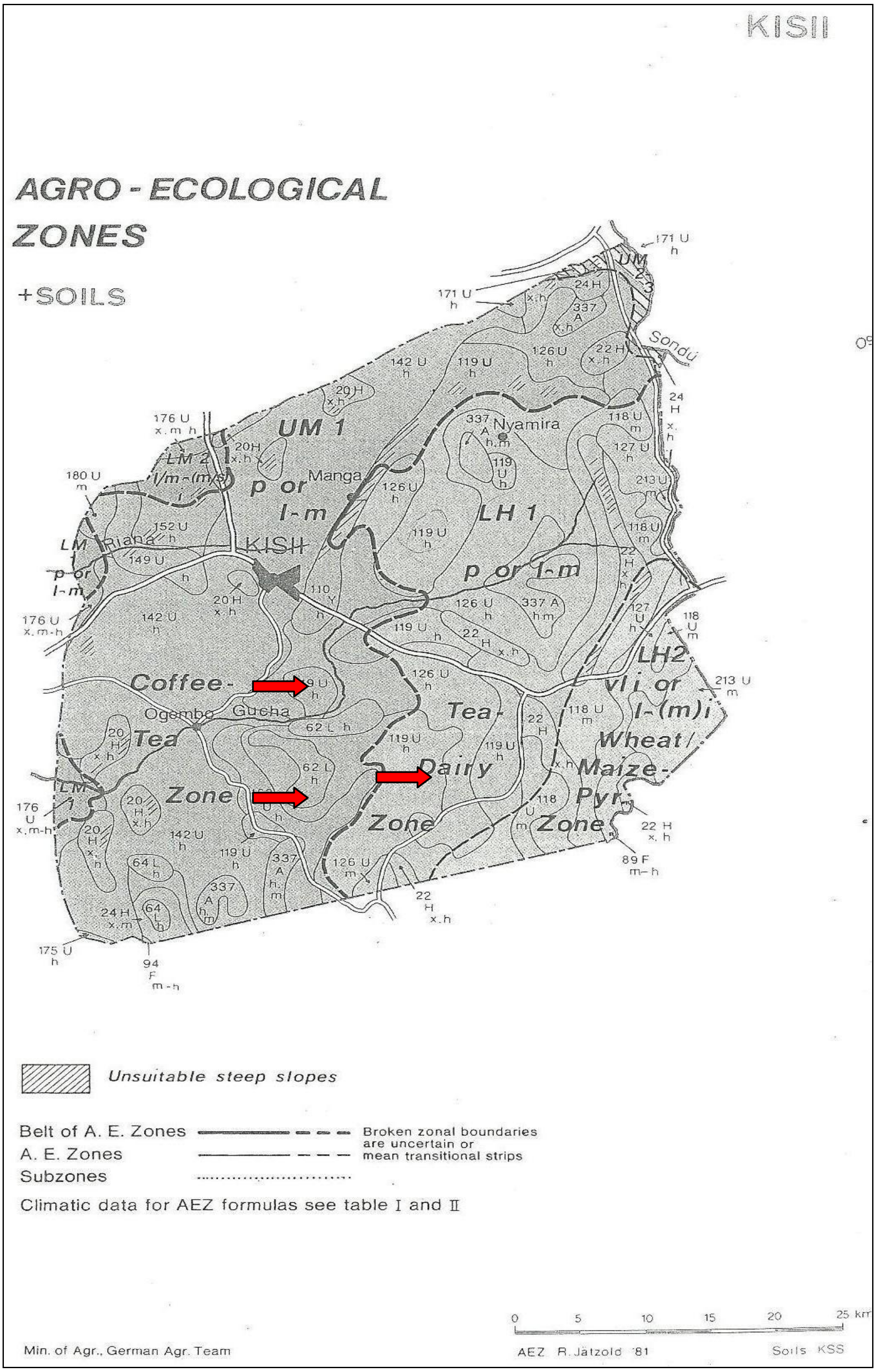

Figure 3.1: Map of Kisii County showing the AEZs where sampling was done as indicated by the arrows (Adopted from Jaetzold and Schmidt, 1982).

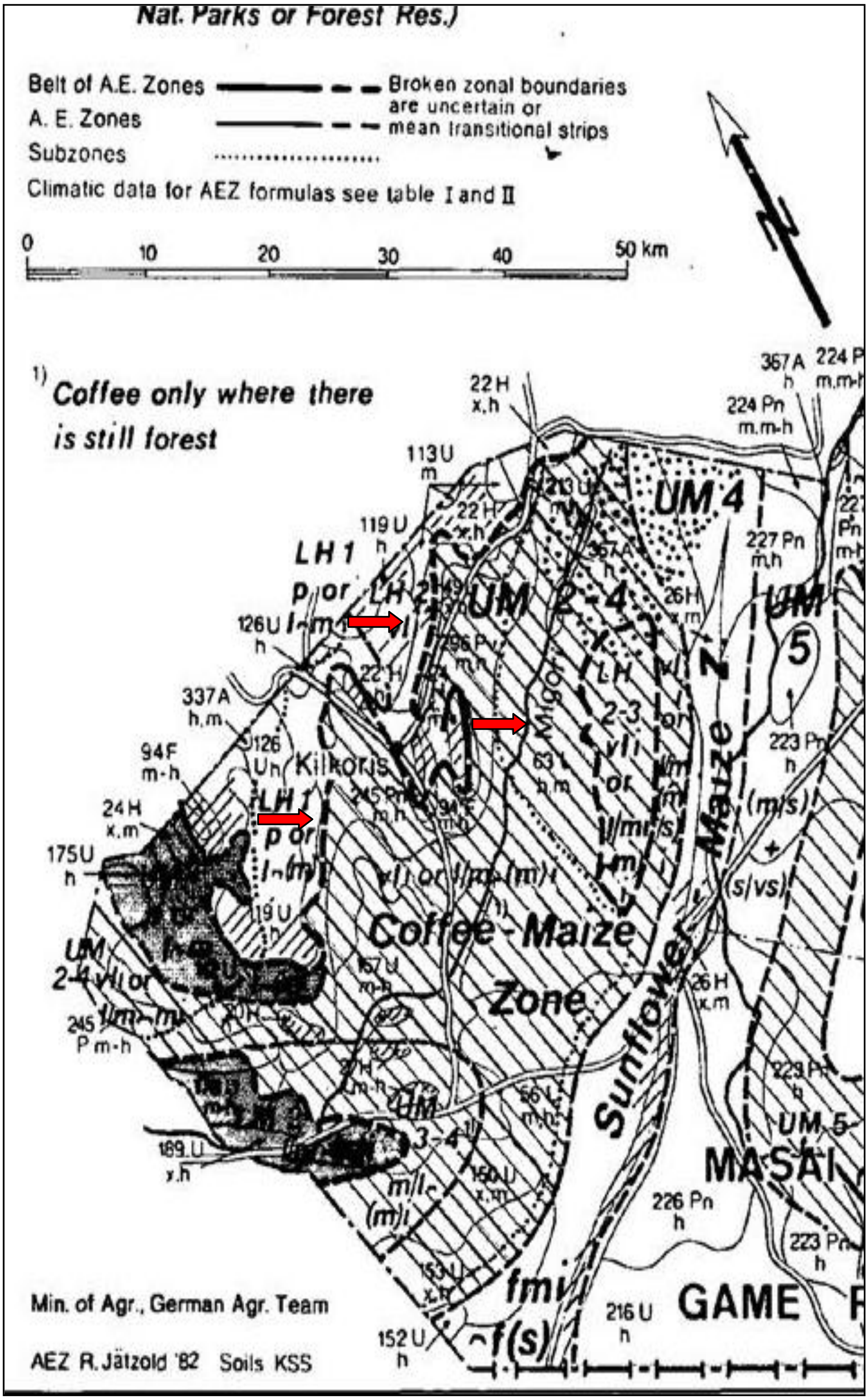

Figure 3.2: Map of Trans-Mara County showing the AEZs where sampling was done as indicated by the arrows (Adopted from Jaetzold and Schmidt, 1983).

3.1.2 Sampling procedures

To assess the incidence and prevalence of selected ILVs to RKN infection, rhizosphere soil and root samples were randomly taken from a total of 20 different farms (approximately 500 m apart) in Sameta and Kilgoris farm areas. The most popular varieties of *S. nigrum*, *S. villosum*, *C. gynandra* and *Amaranthus* spp. grown in the study area were sampled.

Ten samples of each ILV roots and soil from each farm (approximately ½ acre) were randomly selected in a zigzag pattern and dug out gently using a hand trowel, to a depth of 20 cm. The rhizosphere soil adhering to root systems was gently shaken off from the roots, combined and mixed gently before taking a 1 kg sub-sample. The roots and soil samples were placed separately in polythene bags, tightly sealed and labelled with details of host, locality and date of collection. The samples were thereafter placed in a cool box and taken to the laboratory where they were stored at 10^{o} C until processed. Data on crop type, cropping system, source of planting materials, planting season, pest management, diseases, farm history and farmer's practices were recorded for each farm during the survey using a structured questionnaire as indicated in Appendix I.

3.1.3 Initiation of root-knot nematode culture and inoculation procedure

Root-knot nematode egg-masses used in this study were obtained from knotted ILV roots sampled from the study sites by hand picking them with a hand needle (Abu-Gharbieh *et al*., 2005). Visible knots were carefully dissected with a sharp needle and egg-masses picked without damaging them (Sudirman, 1992; Ateeq-ur-Rehman, 2009). The egg-masses were placed into depressions made on the rhizosphere of a susceptible three weeks old (5-6 leaves) tomato (*Solanum lycopersicum* L. cv. Money maker) grown on autoclaved sand: soil (2: 1) mixture in the greenhouse at Kenyatta University at (21 ± 3^{o} C) and maintained for 45 days. The depressions were gently covered with soil and the plants were gently watered to prevent loss of nematodes through leaching or excessive drying.

Nematode inoculum was prepared by extracting egg-masses from knotted tomato roots with a hand needle (Abu-Gharbieh *et al*., 2005; Anwar and McKenry, 2010), placed in a sterile petri dish with 1 ml distilled water. Ten egg-masses were placed into 2-cm-depressions made around the twenty one (21) day old ILV rhizosphere using a 10 ml teat pipette, covered gently with soil (Anwar and McKenry, 2010) as described earlier and maintained for seventy five days. The plants were watered gently as required to prevent loss of nematodes through leaching or excessive drying.

3.1.4 Preparation of test plants and growth media

The seeds of the test ILVs commonly grown by farmers with better yields than the other varieties were collected from farmers during the field survey or purchased from Kenya Seed Company. Selected varieties of *S. nigrum* green berried (Appendix II A), *S. nigrum* purple berried, *S. villosum* orange berried (Appendix II B), *Amaranthus dubius*, *A. hypochondriacus* and *A. cruentus, Cleome gynandra* (purple stemmed) and tomato (*Solanum lycopersicum* L. cv. Money-maker) were raised on sterile sand: soil (2: 1) mixture in 12-cm-diameter plastic pots. One week after germination, the seedlings were thinned and transplanted two weeks thereafter (5-6 leaves stage). One day before transplanting, the pots were not watered. Seedlings were carefully removed from the pots with the adhering soil to avoid damaging the roots and transplanted into a 12-cm-diameter pot with sterilised soil medium and watered as required to avoid loss of J2s and leachates.

Soil and sand was sieved through a 3 mm pore size sieve to remove large particles and then mixed in the ratio of 2: 1 (sand: soil) to improve soil texture, before it was sterilized by autoclaving at 121^{o} C for fifteen minutes. The mixture was spread on polythene sheet for aeration for 7 days after which it was thoroughly mixed with 2 grams of phosphate fertilizer/pot (DAP 300 kg ha^{-1}) and thereafter placed into a 12-cm-diameter plastic pot (area of 0.011 m^2) leaving a space on the top for watering the seedlings.

3.1.5 Collection and preparation of organic amendments (OAs)

The OAs were collected from various sites. Tea rejects (Trej) and residues (Tres) (Plate I) were collected from Kiamokama and Njunu tea factories and buying centres, while *T. diversifolia* (Td) tender shoots were cut from the hedge, dried under shade and ground (for greenhouse experiment) (Plate I) or cut and incorporated into the soil as green manure (for field experiment) (Plate II). Well decomposed cattle manure (CM) and goat manure (GM) (Plate I) were collected from the farmers, sun dried and then incorporated into the soil.

In greenhouse test 2, the soil was treated by incorporating Trej (28.5 g pot^{-1} or 25 tons ha^{-1}), Tres (28.5 g pot^{-1} or 25 tons ha^{-1}), CM (6 g pot^{-1} or 5 tons ha^{-1}), GM (6 g pot^{-1} or 5 tons ha^{-1}), Td (5 g pot^{-1} or 4 tons ha^{-1}) amendments. The sand: soil mixture was mixed thoroughly with each amendment. The pots into which manure was not incorporated served as control. Thereafter, the pots were watered regularly to facilitate decomposition of the materials (Edmonds and Chweya, 1997).

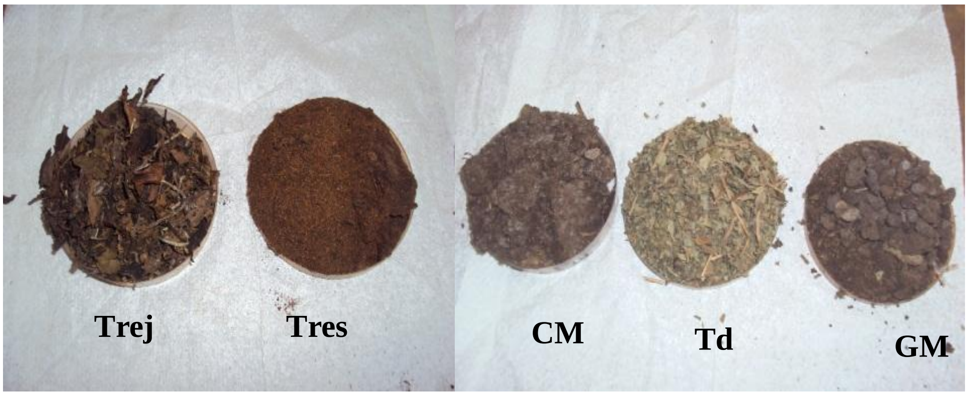

Plate I: Various organic amendments (From L-R); Trej, Tres, CM, Td and GM used in greenhouse and field tests

Plate II: *Tithonia diversifolia* (Td)

3.1.6 Preparation and treatment of seedbed

The treatment combinations mentioned in section 3.1.5 in greenhouse test 2 were used in the field experimental area (37 × 5 m) infested with RKN at a concentration of 106

J2s/200cm^3 soil. The field was cleared, cultivated, ploughed and divided into 48 seedbeds each measuring 1.2 × 3.2 m. A total of twelve plots per block were used.

3.1.7 Pest and Disease control

Most common pests encountered in the greenhouse and field attacking ILVs included white flies (*Bemisia tabaci*), scale insects, black aphids and red spider mites. Similarly, powdery mildew disease was observed to attack amaranth and black nightshade. Both the pests and diseases were controlled through application of Thiovit, a fungicide and miticides which is compatible with the agronomic conditions and practices of the study area.

3.1.8 Physicochemical analysis of soil and organic amendments

Representative soil and OA sub-samples in each case were taken to the National Agricultural Research Laboratories (NARL), Kabete for physicochemical analyses. Amount of nitrogen (N) was determined using Kjedahl method, organic carbon (C) was estimated through calometric method, while phosphorous (P) was analyzed by colorimetry. Amount of potassium (K) and sodium (Na) were determined by flame emission spectro-photometry, while magnesium (Mg) and calcium (Ca) was by atomic absorption spectro-photometry (Gallaher *et al*., 1975) as indicated in Tables 3.1 - 3.3.

Properties[♦]	Ks1	Ks2	Ks3	Ks4	Ks5	Ks6	Ks7	Ks8	Ks9	Ks10
Soil pH	5.77	5.63	5.82	5.73	5.54	5.83	5.47	5.28	6.31	6.18
Total Nitrogen %	0.18	0.19	0.18	0.15	0.20	0.19	0.22	0.15	0.27	0.21
Org. Carbon %	1.65	1.53	2.15	2.37	1.42	1.71	1.85	1.92	1.98	1.95
Phosphorus ppm	42	45	48	47	44	45	87	86	101	98
Potassium me%	1.44	1.24	1.18	1.80	1.38	1.84	1.58	1.46	0.29	0.58
Calcium me%	5.5	5.38	5.20	5.32	5.48	8.4	8.94	8.57	3.10	2.9
Magnesium me%	4.26	4.18	4.21	4.81	4.57	4.24	4.36	4.08	4.31	4.21
Manganese me%	1.97	2.12	2.37	2.28	2.59	2.00	2.27	2.82	1.54	1.47
Copper ppm	1.72	1.75	1.18	1.08	2.40	4.95	4.06	3.63	0.68	0.76
Iron ppm	86.8	94.2	96.7	94.3	96.4	104	97.2	95.4	92.6	94.0
Texture	C	C	CL	CL	CL	C	C	CL	CL	CL

Table 3.1: Physical-chemical properties of soils from upper mid-land 1 (KS1-5) and lower highlands 1 (KS6-10) Sites in Kisii (Sameta) County

KS = Kisii, **C** = Clay **CL** = Clay Loam **ppm =** parts per million **me** = milliequivalents

[♦] Physical-chemical analysis done at National Agricultural Research Laboratories (KARI-NARL) in Kenya

Properties♦	Kg1	Kg2	Kg3	Kg4	Kg5	Kg6	Kg7	Kg8	Kg9	Kg10
Soil pH	6.81	6.20	6.77	6.83	6.54	6.40	7.20	7.32	6.81	7.18
Total Nitrogen %	0.22	0.24	0.18	0.19	0.28	0.17	0.21	0.19	0.27	0.18
Org. Carbon %	2.02	2.09	2.15	1.31	2.02	1.38	1.95	1.52	1.48	1.87
Phosphorus ppm	134	129	132	45	114	43	98	84	121	118
Potassium me%	1.18	1.20	1.24	0.84	1.38	0.62	0.58	0.46	1.22	1.50
Calcium me%	6.5	5.94	6.25	3.42	3.50	3.3	2.90	2.57	3.14	2.24
Magnesium me%	5.18	5.21	5.26	2.85	2.18	2.75	4.21	4.18	4.70	3.51
Manganese me%	1.52	1.57	1.67	1.30	1.60	1.21	1.47	1.52	1.71	1.72
Copper ppm	0.20	0.26	0.31	0.95	0.40	0.46	0.76	0.68	0.36	0.74
Iron ppm	58.4	54.1	56.8	54.4	56.4	53.2	94.0	95.4	52.9	97.6
Texture	SCL	SCL	SCL	SCL	SCL	SCL	CL	CL	SCL	CL

Table 3.2: Physical-chemical properties of soils from lower highlands 2 (Kg1-5), upper mid-lands 2-4 (Kg6-9) and lower highlands 1 (Kg10) sites in Trans-Mara County

Kg = Kilgoris (Trans-Mara) **C** = Clay **CL** = Clay Loam **SCL =** Sandy Clay Loam **ppm =** parts per million
me = milliequivalents
♦ Physical-chemical analysis done at National Agricultural Research Laboratories (KARI-NARL) in Kenya

Organic Amendment Analysis Data (Test results)					
Sample description	GM	CM	Trej	Tres	Td
pH-water (1:2.5)	7.77	7.34	6.96	5.83	6.30
Org. Carbon %	3.15	3.70	3.81	3.91	4.26
Nitrogen %	1.05	1.05	4.20	4.10	5.25
C/N ratio	3:1	3.5:1	0.91:1	0.95:1	0.81:1
Phosphorus %	0.27	0.21	0.25	0.52	0.28
Potassium %	1.58	1.58	1.92	0.13	1.65
Calcium %	4.36	0.96	2.09	2.13	0.59
Magnesium %	0.33	0.08	0.34	0.26	0.19
Iron mg/kg	3767	1397	1315	1297	2033
Copper mg/kg	15.0	3.3	3.67	3.58	8.33
Manganese mg/kg	2083	892	1020	1026	1040
Zinc mg/kg	307	85	82	79	78

Table 3.3: Physical-chemical properties of plant tissue and animal manure used for amending soil in greenhouse and field experiments

GM = goat manure **CM** = cattle manure **Trej** = tea rejects **Tres** = tea residue **Td** = *Tithonia diversifolia*

♦ Physical-chemical analysis done at National Agricultural Research Laboratories (KARI-NARL) in Kenya

3.1.9 Data collection

3.1.9.1 Determination of plant growth parameters

Plant growth (plant height, fresh shoot, fresh root and dry shoot weights) parameters were determined. The plant height was measured from the first basal node to the shoot apex with a cotton thread at the end of the experiment. The plants were gently uprooted and the shoots separated from roots and their fresh weight taken (Ateeq-ur-Rehman, 2009). The shoots were oven dried at 60^o C until a constant mass was achieved and their dry weight determined as described by Arim *et al*., (2006). The roots were gently washed, blotted dry as described before and their fresh weights determined.

3.1.9.2 Assessment of root-knot nematode damage on indigenous leafy vegetables

i. Determination of the Galling Index. The entire root systems were gently but thoroughly washed to get rid of adhering soil under a gentle stream of tap water, blotted dry and then thoroughly examined for the presence of galls using a 0-5 galling scale as described by Quesenberry *et al*., (1989) where; 0= no galls; 1= 1-2; 2= 3-10; 3= 11-30; 4= 31-100 and 5= > 100 galls per root system.

ii. Egg-mass index. The roots were divided into four sub-samples of 10 grams each. The first sub-sample was immersed in 0.15 g/litre of Phloxine B solution as described by Holbrook *et al*., (1983) to stain the egg-masses red (Plate III). Stained roots were then rinsed with running tap water and blotted dry. Egg-masses were visually counted on a stereo microscope, enumerated with a hand counter and scored using a 0-5 egg-mass rating index according to Quesenberry *et al*., (1989) where; 0= no egg-masses; 1= 1-2; 2= 3-10; 3= 11-30; 4= 31-100 and 5= > 100 egg-masses per root system.

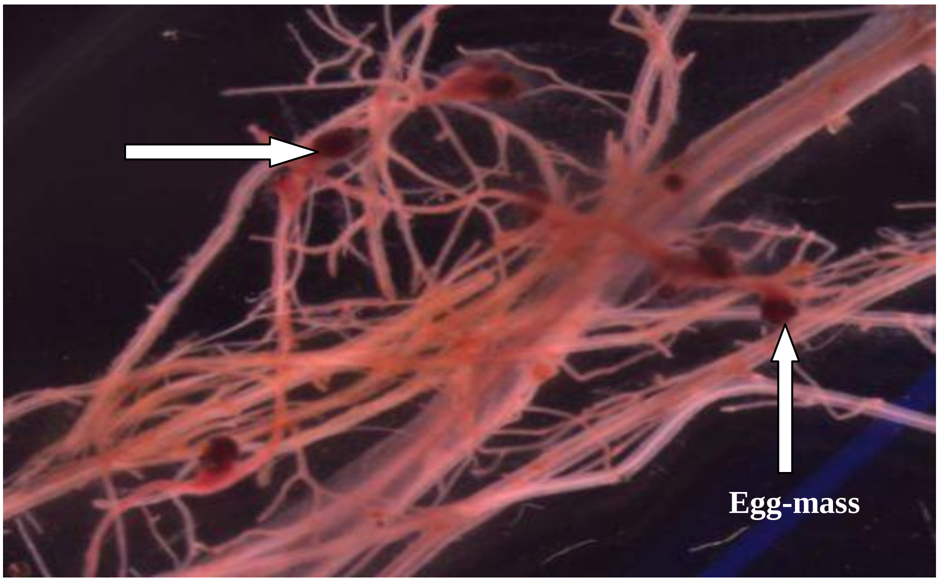

Plate III: Stained egg-masses using Phloxine B on *Solanum nigrum* roots

iii. Number of females within the roots. A five-gram sub-sample per plant was chopped into 1-cm long segments and then transferred into 50 ml of tap water in a 150 ml beaker. Thereafter, 20 ml of commercial bleach (5.25 % sodium hypochlorite) was added and the roots left for four minutes with occasional agitation to clear the roots (Byrd *et al*., 1983).

The roots were then removed from the bleach and thoroughly rinsed through a 100 µm aperture sieve with running tap water for 30 seconds to remove all traces of the bleach, and then the roots were allowed to soak in tap water for at least 15 minutes. Longer soaking period was required for *Amaranthus* spp. roots due to their thickness. The cleared roots were then transferred to a 150 ml beaker with 50 ml water and 1 ml of Acid fuchsin solution (875 ml of lactic acid, 63 ml of glycerol, 62 ml of water, 0.1 g of Acid fuchsin) added.

The content in the beaker was boiled over a hot plate for 30 seconds to stain nematodes (Hooper *et al*., 2005). The roots were allowed to cool in the stain to room temperature and then transferred to a sieve 100 µm aperture, to wash off excess stain gently in running tap water. The stained roots were then boiled for 30 seconds in 30 ml of acidified glycerine according to Byrd *et al*., (1983), viewed under a Leica MZ5 Stereo microscope for RKN and scored according to Taylor and Sasser, (1978). Where; 0=0; 1=1-2; 2=3-10; 3=11-30; 4=31-100 and
5= >100 RKNs.

iv. Number of J2 in roots and soil. The root system was cut into small pieces of 2 cm long and then macerated in water in an electric macerator for 30 seconds as described by Dropkin, (1980). The macerated roots were then placed on a double paper towel supported by a plastic sieve placed on a shallow extraction tray. Water was then added gently to wet the roots and the J2 recovered using modified extraction-tray method (Plate IV) according to Thomas (1959) and enumerated with a hand counter and quantified under dissecting microscope 40 × magnifications.

Plate IV: Extraction of J2 from the roots (I) and soil sample (II) using modified extraction-tray method

The soil was thoroughly but gently mixed and a 200 cm^3 sub-sample taken for assessing nematode population. The soil was placed on a double layer of paper towel supported by a plastic sieve and placed over a shallow extraction tray. Water was gently added to the tray until the soil was just wet and thereafter the set-up left for 24 hours. The nematodes were harvested (extracted) twice at a duration of 12 hours by pouring the contents of the tray through a 38 µm sieve, backwashed with water from a wash bottle onto a 50 ml beaker and enumerated over a Leica MZ5 stereo microscope as described above.

v. Determination of RKN reproduction factor (Rf). The nematode reproduction factor was calculated as R = Pf/Pi, where Pf = (number of egg-masses per root system) and Pi = 10 egg-masses pot^{-1} where R is Rf, Pf is final egg-masses, Pi is initial egg-mass inoculum.

Classification of ILVs resistance and susceptibility was done based on percentage reproduction of RKN in susceptible tomato cultivar (*S. lycopersicum* L. c.v Money-maker). Normal reproduction of RKN i.e. 100 % was considered in susceptible check. Percentage nematode reproduction on test plants was calculated as Egg-masses in Test Plant x 100/ Egg-masses in Susceptible Check (Tomato) (Khan, 1994; Zhang and Schmitt, 1994). Host suitability (Susceptibility and resistance) was categorized according to Zhang and Schmitt, (1994) as susceptible when $Pf/Pi > 5.0$, moderately resistant if $5.0 \geq Pf/Pi > 1$, poor if $1 > Pf/Pi > 0$, and resistant when $Pf/Pi = 0$.

Root-knot disease severity was rated using the following key developed by Taylor and Sasser (1978) based on the galling index.

Severity scale	**Disease intensity**
0	Disease free
1-2	Very mild
3	Mild
4-5	Moderate
6-8	Severe
9-10	Very severe

3.2 SPECIFIC METHODOLOGY

3.2.1 Nematode survey

Seven indigenous leafy vegetables grown in different fields in Kisii and Trans-Mara Counties were assessed to determine the disease incidence and prevalence of RKN infection. A hundred and forty (140) infected root systems and sixty (60) rhizosphere soil samples were randomly taken from a total of 60 different farms from Kisii and Trans-Mara Counties respectively for the presence of RKN. The sampling procedures are as described in section 3.1.2.

Root-knot nematode galls on the entire root system from each farm for each ILV were enumerated and thereafter the roots rated for galling on a 0 to 5 scale according to Quesenberry *et al*., (1989). The prevalence and incidence of the disease in each farm was calculated using a method adopted from Khan, (2009);

$$\text{Prevalence} = \frac{\text{Number of farms with root-knot nematode infection}}{\text{Number of farms surveyed}} \times 100$$

$$\text{Incidence} = \frac{\text{Number of plants with root-knot nematode galls}}{\text{Total number of plants sampled}} \times 100$$

The number of plants galled was determined by visually examining the plant roots characteristic root knots. In addition to the prevalence and incidence of RKN, the severity of RKN infection was also determined by observing and scoring the extent of galling on the root system. The root systems from each farm were pooled together and then divided into two sub-samples. The first sub-sample was used to assess the presence of egg-masses on a 0-5 scale as described in section 3.1.9.2 while the second sub-sample was cut into 2-cm-long segments and thereafter, used to assess endoparasitic nematodes (EN) as described before in section 3.1.9.2. The total egg-masses and endo-parasitic J2s were expressed per entire root system.

3.2.2 Screening indigenous leafy vegetables for response to root-knot nematodes in greenhouse test 1

Selected varieties of the most preferred ILVs were screened for their response to RKN infection in the greenhouse. The ILVs screened were *Solanum nigrum* green and purple berried, *S. villosum* orange berried, *Amaranthus dubius*, *A. hypochondriacus*, *A. cruentus*, *Cleome gynandra* purple stemmed and money-maker tomato (*Solanum lycopersicum*) as a positive control.

A three-week-old ILV seedling of each type was transplanted into a 12-cm-diameter pot with sterilized soil as described in section 3.1.4. Seven days later the seedlings were inoculated with ten egg-masses as described in section 3.1.3. Uninoculated plants served as negative control while inoculated tomato served as a positive control. The treatments were labelled and arranged in Completely Randomized Block Design (CRBD) with four replications in the greenhouse bench at a temperature of 21 ± 3^{o} C. The plants were watered regularly to facilitate hatching of juveniles from the egg-masses (Agbenin *et al*., 2005). Thereafter, regular disease symptoms were observed and recorded. The experiment was terminated 75 days after inoculation and plant growth and disease parameters evaluated as described earlier in section 3.1.9.

3.2.3 Efficacy of selected organic amendments on reproduction of root-knot nematodes on indigenous leafy vegetables

Selected OAs commonly used for the production of ILVs in the areas where sampling was done were evaluated to determine their efficacy against RKN in a greenhouse test. The OAs evaluated included cattle manure (CM), goat manure (GM), tea residue (Tres), tea rejects (Trej) and *T. diversifolia* (Td). The amendments were mixed with the sand: soil (2: 1) media as described in section 3.1.5. The OAs that were used for this study were selected on the basis of their availability and traditional usage by potential farmers in the study area.

Three-week-old seedling of each ILV and tomato was planted in each pot and watered regularly for seven days. Two pots from each OA were selected and into one of the pots, ten egg-masses were placed at the rhizosphere zone while the other one was not inoculated. Unamended and un-inoculated pots served as controls. The treatments were labelled and arranged in CRBD with four replications in the greenhouse.

The initial RKN population was determined by randomly sampling ten points from each plot in a zigzag pattern with a field trowel before the ILVs were sown. The final RKN population was determined by sampling around the rhizosphere of each ILV from each plot 90 days after planting. In each case, the soil samples were composited and mixed thoroughly after which a 1 kg sub-sample soil was taken for nematode bioassays as described in section 3.1.9.2. (iv). The J2s were extracted from 200 cm^3 using modified extraction-tray method according to Thomas (1959) as described in section 3.1.9.2 (iv).

The seedbeds (described in section 3.1.6) were then treated as;

i. No manure,
ii. Tres (9 kg $plot^{-1}$ or 25 t ha^{-1}),
iii. Trej (9 kg $plot^{-1}$ or 25 t ha^{-1}),

iv. CM (2 kg plot^{-1} or 5 t ha^{-1}),

v. GM (2 kg plot^{-1} or 5 t ha^{-1}),

vi. Td (1.5 kg plot^{-1} or 4 t ha^{-1}),

vii. Mocap nematicide (M) (36 g plot^{-1} or 100 kg ha^{-1}) as a reference control,

viii. CM + M,

ix. GM + M,

x. Tres + M,

xi. Trej + M,

xii. Td + M at their respective rates in a CRBD with four replications.

The amendments were applied on the surface of each respective plot through broadcast and then incorporated to a depth of 10 cm of soil with a hoe. Amended and unamended plots with Mocap nematicide served as positive control while plots where plants were planted directly without amendment served as negative controls. All plots were planted 14 days after incorporation of OAs with three seeds of *S. nigrum* (green berried), *S. villosum* (orange berried), *A. dubius*, *A. hypochondriacus* and tomato (*S. lycopersicum*) a susceptible host to RKN as a positive control. Di-ammonium phosphate (DAP) fertilizer was used at the rate of 120 g per plot (300 kg ha^{-1}) during planting. Two weeks after germination, the seedlings were thinned to one plant per depression. Each plot had 10 rows with each row having 6 plant units at a spacing of 15 x 30 cm giving a total of 60 plants per plot (156,250 plants per hectare equivalent). Mechanical weeding was done to ensure the plots were weed free.

Ten plants from each of the plots were randomly selected and uprooted gently and data on plant growth and disease parameters obtained as described in section 3.1.9.

Ten soil samples were randomly collected from the rhizosphere of each ILV and composited before taking 1 kg sub-sample for nematode bioassays as described in section 3.1.9.2. The nematode reproductive factor (R_f) was determined by expressing the final nematode population (P_f) as a ratio of initial population (P_i). The P_f population was determined by finding the total number of nematodes recovered from both the roots and soil and the nematode reproduction factor ($Rf= P_f/P_i$) was calculated as mentioned earlier.

3.2.4 Data analysis

All experiments were carried out in completely randomized block design. All the data were subjected to Analysis of Variance (ANOVA) using Statistica, Minitab and MS Excel computer programs. Prior to statistical analyses, numerical data were transformed using logarithmic transformation (Log_{10} [X+1] where X = nematode population per 200 cm^3 soil or egg-masses or galls or their indices in a single sample) and then subjected to one way ANOVA followed by LSD post ANOVA test to sort out treatments producing significant effects at probability level of 5%. However, untransformed arithmetic means are presented in tables and other presentations of results. Other sets of data were carried out using two-way ANOVA to test for main treatment effects using Statistica and Minitab. Correlation and regression analyses were carried out to determine the relationship between RKN galling index/Rf/J2 populations with fresh shoot weight and fresh root weight.

CHAPTER FOUR

RESULTS

4.1 Cultivation of indigenous leafy vegetables in Kisii and Trans-Mara Counties

This study revealed that 50 % of vegetables cultivated in the two Counties were ILVs, while 45 % were exotic. The other leafy vegetables including *Basela alba* and pumpkins though not cultivated, were growing naturally and were used as vegetables consisted of the remaining 5 %. The study also revealed that all the four varieties of *Solanum* spp. (green, orange, yellow and purple berried) are cultivated in the two Counties, with the green berried variety being the most preferred as indicated in Table 4.1. Two varieties of *Cleome* spp. (purple and green stemmed) and four of *Amaranthus* spp. (*A. dubius, A. hybridus, A. hypochondriacus* and *A. cruentus*) were also cultivated in the study area (Table 4.1). The most preffered spider plant was purple stemmed while that of amaranth was *A. dubius*.

The study revealed that most of the farmers were using CM and a few of them chicken manure for the production of ILVs (Figure 4.1). Although a large proportion of farmers did not use manure, they applied inorganic fertilizer (DAP) during planting and top dressing (urea) as depicted in Figure 4.1.

Farmer	Indigenous leafy vegetables and other crops															
	Sng	Sp	Svo	Svy	Ad	Ac	Ah	Ahy	Cgg	Cgp	B	M	T	B.a	Spi	Pum
1	-	-	+	-	+	-	-	-	-	+	+	+	-	+	-	+
2	-	+	-	-	+	-	+	-	-	+	+	+	-	-	-	+
3	-	-	+	+	-	+	-	+	-	-	+	+	-	-	-	-
4	+	-	-	-	+	-	-	-	-	+	-	+	-	-	-	-
5	+		-	-	+	-	-	+	+	+	-	+	-	-	-	-
6	+	+	-	-	-	-	-	-	-	+	-	+	-	-	-	-
7	+	+	-	-	-	-	-	+	+	-	-	+	+	-	-	-
8	+	+	-	-	-	-	+	-	-	-	+	+	-	-	+	+
9	+	-	-	-	-	+	-	-	-	+	+	+	-	+	+	-
10	+	-	-	+	-	-	+	-	-	-	+	+	+	-	-	-
11	-	+	-	-	-	+	-	-	-	+	+	+	+	-	-	-
12	-	-	+	+	-	+	-	-	-	+	+	+	+	-	+	-
13	-	-	+	-	+	-	-	-	+	-	-		-	-	-	+
14	+	-	-	-	+	-	+	-	-	+	+	+	+	-	-	+
15	+	-	-	-	-	+	-	+	-	+	-	+	+	-	-	-
16	+	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-
17	+	-	-	-	+	-	+	-	+	-	-	+	+	-	-	-
18	+	-	-	-	+	-	-	-	-	+	-	-	+	-	-	-
19	+	-	-	-	+	-	-	-	-	+	+	+	-	-	-	-
20	+	-	-	-	+	-	-	+	-	+	+	+	-	-	-	-
Total	14	5	4	3	10	5	5	5	4	14	11	18	8	2	3	5
%	70	25	20	15	50	25	25	25	20	70	55	90	40	10	15	25

Table 4.1 Proportion of farmers growing indigenous leafy vegetables and other crops in Kisii and Trans-Mara Counties

+ cultivated on the farm, - not cultivated, Sng= *Solanum nigrum* green berried, Sp= *S. nigrum* purple berried, Svo= *S. villosum* orange berried, Svy= *S. villosum* yellow seeded, Ad= *Amaranthus dubius*, Ac= *A. cruentus*, Ah= *A. hypochondriacus*, Ahy= *A. hybridus*, Cgg= *Cleome gynandra* green petioled, Cgp= *C. gynandra* purple petioled, B= beans, M= maize, T= tomato, B.a= *Basela alba*, Spi= spinach, Pum= pumpkin

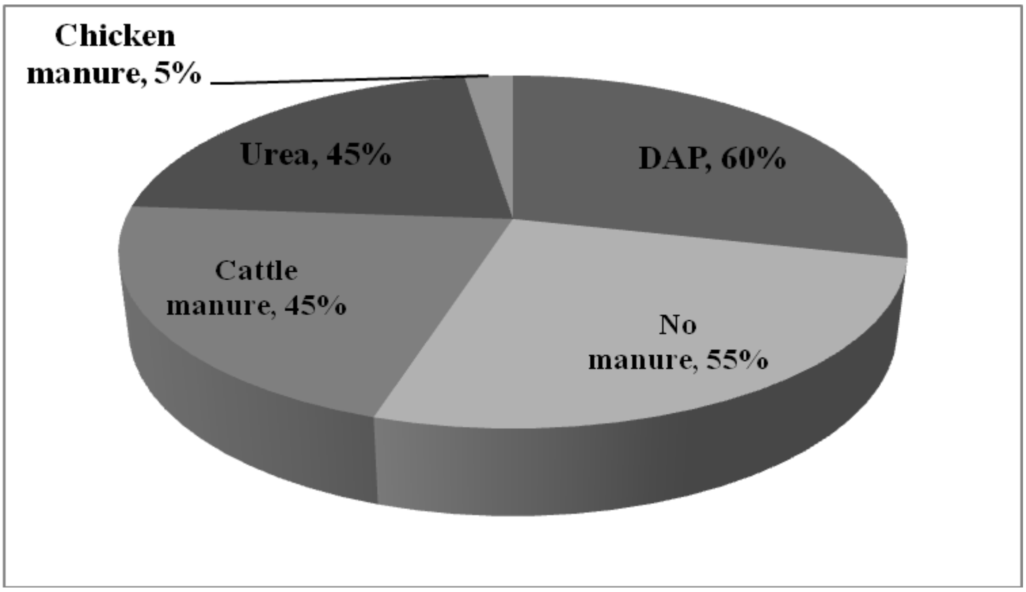

Figure 4.1: Percentage of farmers using different soil fertility treatments for indigenous leafy vegetable production in Kisii and Trans-Mara Counties.

The size of farms dedicated for cultivation of ILV varied from < ¼ acre to > ½ acre with the largest proportion of farmers in Kisii using ¼ acre land and Trans-Mara having ½ acre and few grew ILVs on > ½ acre land in both Counties (Figure 4.2).

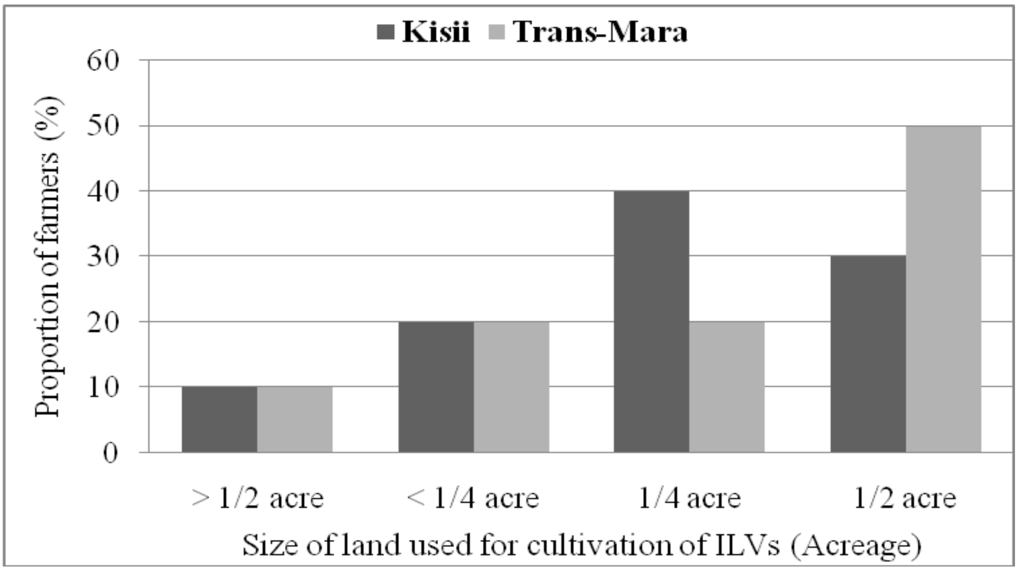

Figure 4.2: Proportion of land used for indigenous leafy vegetables production in Kisii and Trans-Mara Counties.

ILVs = Indigenous leafy vegetables.

Similarly, a large proportion of farmers grew or intercropped ILVs with beans and tomatoes on the same parcel of land with more farmers in Kisii growing beans than Trans-Mara while more tomatoes were grown in Trans-Mara than Kisii (Figure 4.3). These two crops are highly susceptible to RKN.

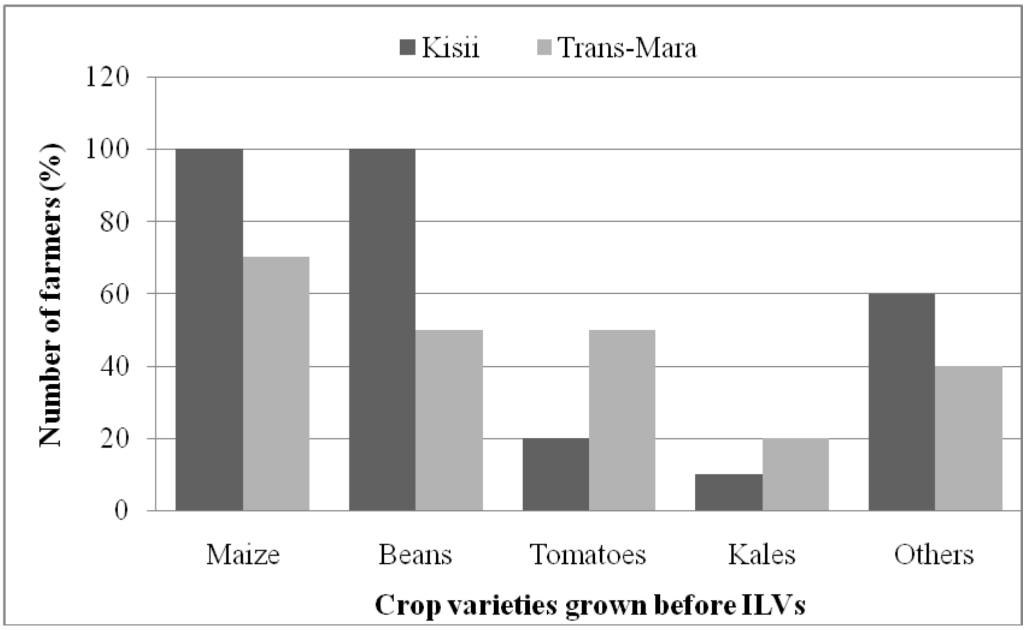

Figure 4.3: Crop varieties grown before indigenous leafy vegetables by farmers in Kisii and Trans-Mara Counties.

ILVs = Indigenous leafy vegetables.

All (100 %) the respondent farmers grew black nightshade, 30.1 % grew amaranth and 80.0 % grew spider plant while 10.0 % grew other ILVs. The study revealed that a large proportion of the farmers (70.0 %) grew ILVs mainly for commercial purposes while 30.0 % grew them for both subsistence and commercial use. Growth of ILVs in the two counties differed significantly ($\chi 2$ = 3.810, P<0.05). Similarly, the study revealed a decline in cultivation of ILVs in Kisii County while in Trans-Mara County it was noted to be on the increase (χ^2 = 11.00, P<0.05). In Kisii County 70.0 % of the respondents noted a decrease in ILV production, while 90.0 % of the respondents from Trans-Mara County noted an increase.

Major pests on the ILVs reported by 55.0 % of the sampled farmers were scale insects, 30.0 % respondents noted aphids attack and 15.0 % reported nematode attack on the crops. Twenty percent (20.0 %) of farmers in Kisii and (10 %) in Trans-Mara, reported nematode attack on ILVs. Of these, 60.0 % of farmers were aware of nematodes, while 40.0 % were not (Figure 4.4). Only 25 % of the farmers, who were aware of nematodes, knew how to look for symptoms of attack while 75.0 % did not.

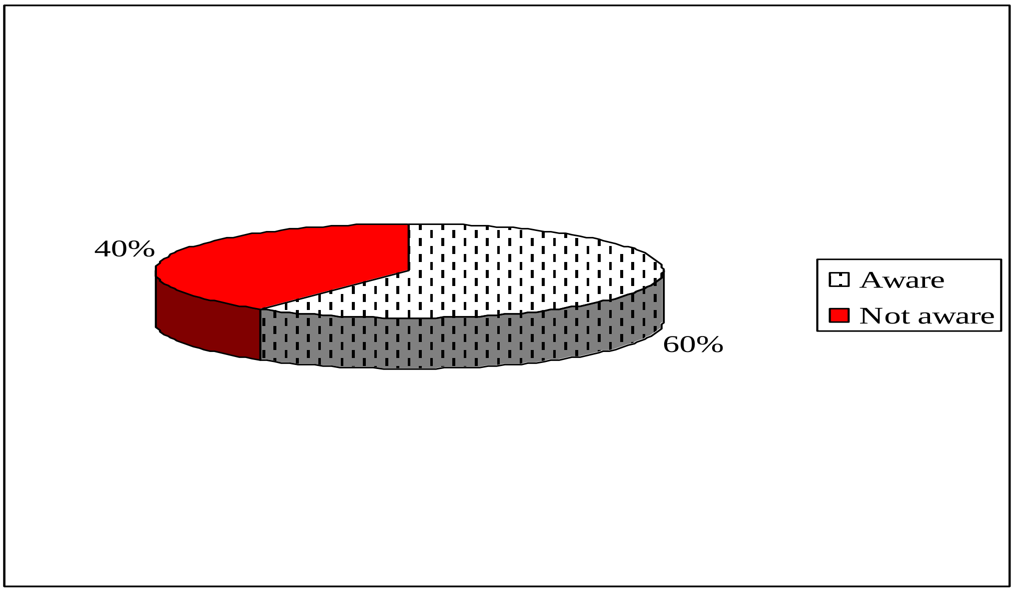

Figure 4.4: Percentage farmers aware/not aware of the great loss caused by nematodes on indigenous leafy vegetables.

4.2 Incidence and prevalence of the root-knot nematodes on indigenous leafy vegetables in Kisii and Trans-Mara Counties

4.2.1 Incidence of root-knot nematodes on indigenous leafy vegetables

This study revealed significant differences ($P<0.05$) in the RKN incidence among the crops sampled (Figure 4.5). Although there was no significant difference ($P>0.05$) in

RKN incidence among the crops in Kisii and Trans-Mara, those of *A. cruentus* (Ac), *A. dubius* (Ad) and *A. hypochondriacus* (Ah), were found to differ significantly (P<0.05) between the two Counties (Figure 4.5). Highest RKN incidence occurred on *S. nigrum* green berried (Sng), followed by *S. villosum* orange berried (Svo) in Kisii relative to Trans-Mara, while Ad, Ah and *C. gynandra* green stemmed (Cgg), recorded low RKN incidence (Figure 4.5). Generally, RKN incidence was higher in Kisii (78 %) compared to Trans-Mara (62 %) for the black nightshades, (30 % and 60 %) in spider plants and (1 % and 2 %) in amaranths for Kisii and Trans-Mara respectively (Figure 4.5).

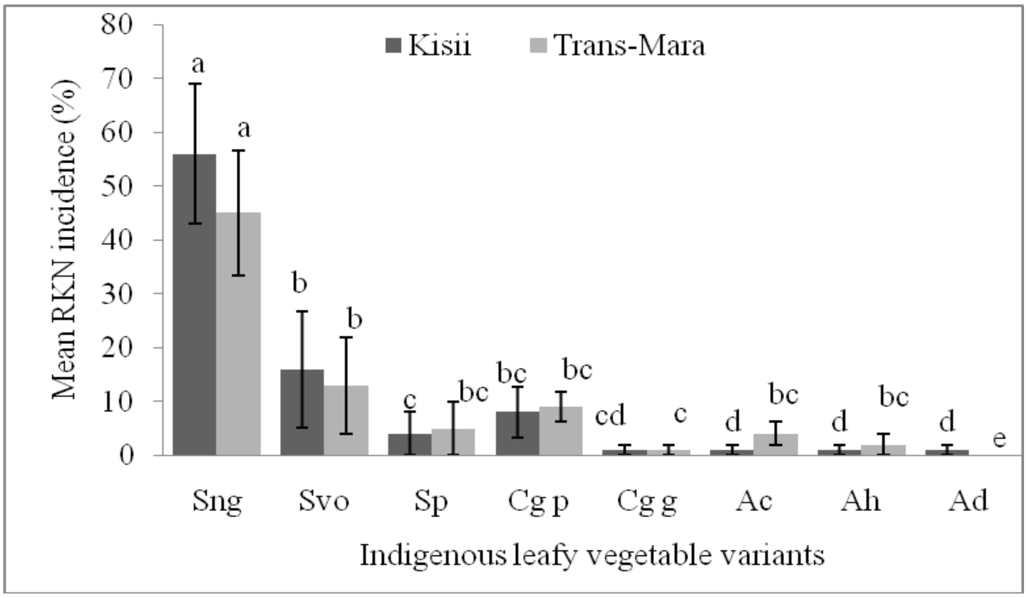

Figure 4.5: Incidence of root-knot nematode in indigenous leafy vegetables from Kisii and Trans-Mara Counties*.

Data are means ± SE of ten root systems/farm obtained from the survey study.
*Bars with similar letters are not statistically different (P>0.05) with LSD test.
Sng = *Solanum nigrum* green berried, Svo = *S. villosum* orange berried, Sp = *S. nigrum* purple berried, Cgp = *Cleome gynandra* purple stemmed, Cgg = *C. gynandra* green stemmed, Ac = *A. cruentus*, Ah = *Amaranthus hypochondriacus*, Ad = *A. dubius*.

4.2.2 Disease prevalence

The disease prevalence was detected on 62.75 % of the farms surveyed. The disease prevalence between the ILVs in the sampled farms from the two Counties, differed significantly (P<0.05) as depicted in Figure 4.6. However, there was no significant difference (P>0.05) established between the two Counties (Figure 4.6). Generally, higher disease prevalence was recorded in Sng, followed by Cgp, Ac and lowest in Ad in both counties (Figure 4.6).

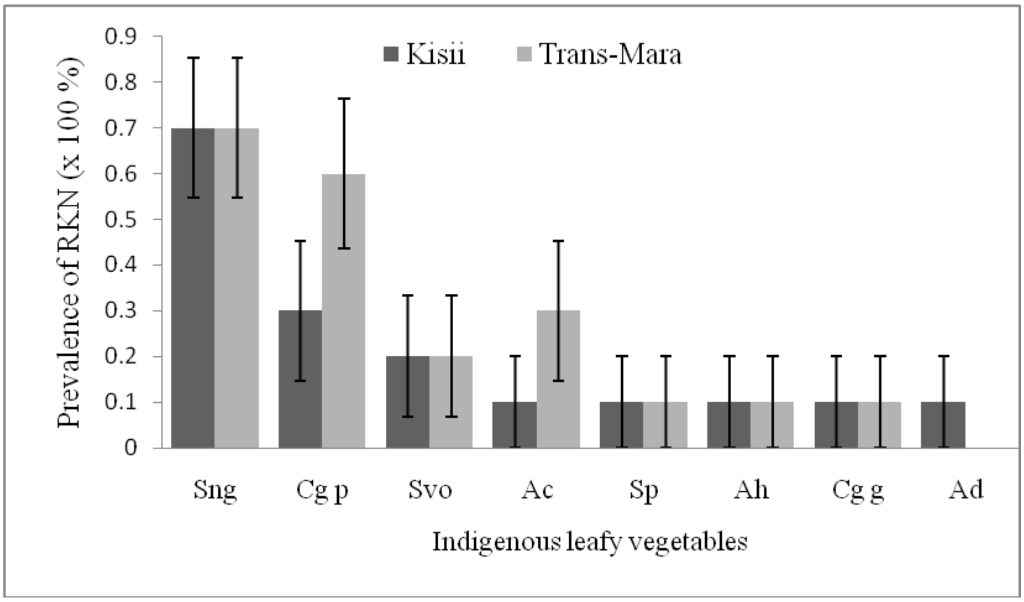

Figure 4.6: Prevalence of root-knot nematodes on indigenous leafy vegetables in Kisii and Trans-Mara Counties*.

*Data is the mean ± SE of root systems obtained from the survey study.
Sng = *Solanum nigrum* green berried, Cgp = *Cleome gynandra* purple stemmed, Svo = *S. villosum* orange berried, Ac = *Amaranthus cruentus*, Sp = *S. nigrum* purple berried, Ah = *A. hypochondriacus*, Cgg = *C. gynandra* green stemmed, Ad = *A. dubius*.

The prevalence of RKN in black nightshade did not differ significantly (P>0.05) in the two Counties. Higher prevalence was recorded in Sng farms, followed by Svo while those with Sp had the least prevalence (70 %, 20 % and 10 % respectively) in both Counties. The prevalence of RKN in farms with *Amaranthus* species in Trans-Mara differed significantly (P<0.05). Farms with Ac recorded the highest prevalence (30 %), followed by Ah (10 %), while those with Ad recorded none (0 %). In Kisii, the prevalence of RKN in farms with *Amaranthus* species (10 % each) was not significantly different (P>0.05) (Figure 4.6). The prevalence in Cgp farms was significantly (P<0.05) higher in Trans-Mara compared to Kisii (60 % and 30 % respectively) while Cgg recorded the lowest (10 % each) in the two Counties respectively (Figure 4.6).

4.2.3 Disease severity of root-knot nematodes on indigenous leafy vegetables

4.2.3.1 Root-knot nematode galling index and egg-mass index

Root-knot nematode GI was scored and means for all ILVs compared. A significant difference (P<0.05) was found for the GI in the various ILVs in Kisii and Trans-Mara Counties. Generally, the GI was significantly (P<0.05) higher on Sng plants relative to the other ILVs except on Svo from Kisii where the GI was higher though not significantly different. The GI was generally low in Ad, Cgg, Ac and Ah with GI ranging from 0 to 0.2 in both Kisii and Trans-Mara respectively. However, there was no significant (P<0.05) difference established (Figure 4.7).

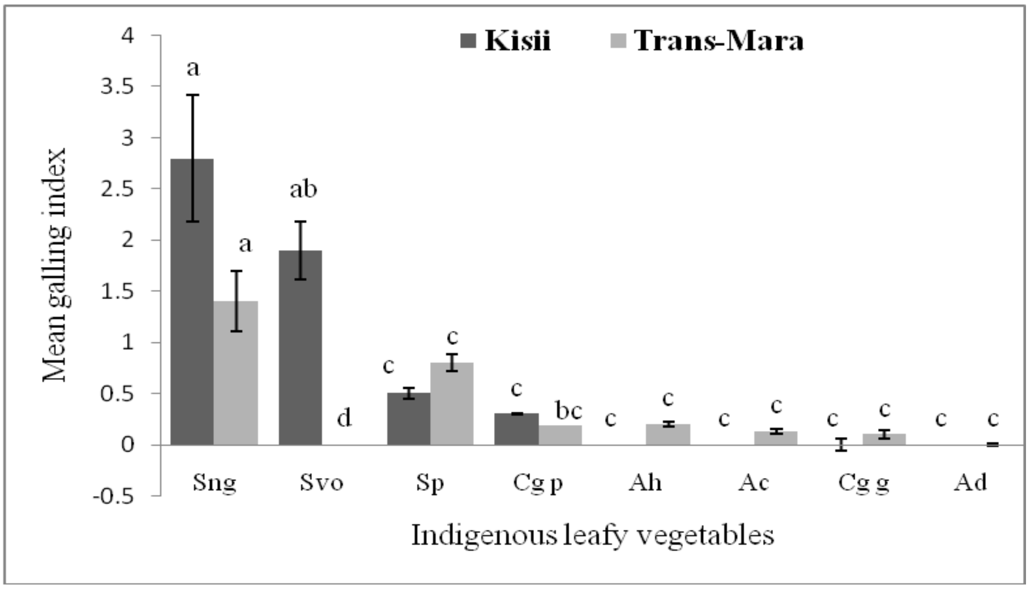

Figure 4.7: Root-knot nematode galling indices on indigenous leafy vegetables in the Kisii and Trans-Mara Counties*.

Data are mean ± SE of ten root systems per ILV obtained from the survey study on a 0-5 scale according to Quesenberry *et al*., (1989).
*Bars followed by the same letter (s) are not significantly different (P>0.05).
Sng = *Solanum nigrum* green berried, Svo = *S. villosum* orange berried, Sp = *S. nigrum* purple berried, Cgp = *Cleome gynandra* purple stemmed, Ah = *Amaranthus hypochondriacus*, Ac = *A. cruentus*, Cgg = *C. gynandra* green stemmed, Ad = *A. dubius*.

Egg-mass indices differed significantly (P<0.05) among the ILVs in the two Counties with Sng recording significantly (P<0.05) higher egg-mass index in Kisii relative to Trans-Mara (Figure 4.8). Although the egg-mass index in Svo was higher in Kisii, there was no significant difference (P>0.05) established with Trans-Mara. However, Ad, Ah, Ac, Cg p and Cg g ILVs recorded higher egg-mass index in Trans-Mara compared to Kisii (Figure 4.8).

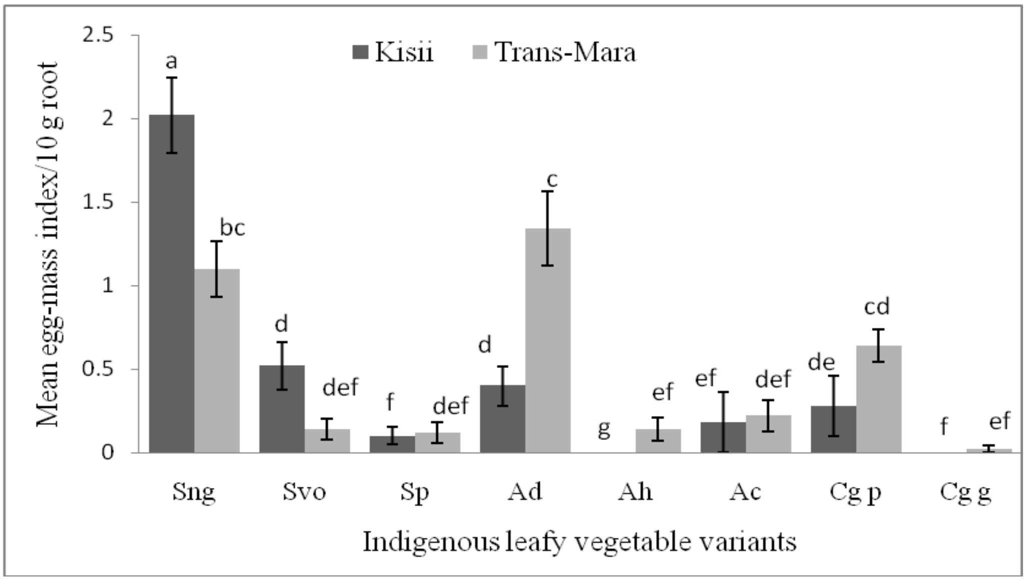

Figure 4.8: Root-knot nematode egg-mass indices on indigenous leafy vegetables in Kisii and Trans-Mara Counties*.

Data are mean ± SE of egg-mass indices of 10 g of dry roots/ILV obtained from the field on a 0-5 scale according to Quesenberry *et al*., (1989).
*Means followed by the same letter (s) are not significantly different at P>0.05. Sng = *Solanum nigrum* green berried, Svo = *S. villosum* orange berried, Sp = *S. nigrum* purple berried, Ad = *Amaranthus dubius*, Ac = *A. cruentus*, Ah = *A. hypochondriacus*, Cgp = *Cleome gynandra* purple stemmed, Cgg = *C. gynandra* green stemmed.

4.2.3.2 Root-knot nematodes within the roots of indigenous leafy vegetables

The roots of ILVs were positive for the presence of endo-parasitic nematode (EN). The RKN in the sampled ILVs in farms from the two Counties differed significantly (P<0.05) (Figure 4.9). The EN in Sng in Kisii was significantly higher (1.5) compared to Svo (0.4) and Sp (0.17). However, there was no significant difference (P>0.05) established from that of Trans-Mara County although Sng had higher value (1.4) than Svo (0.13) and Sp (0.2). The EN for Sp was higher in Trans-Mara than that in Kisii. However, Cgg, Ah and Ac (0.03, 0.07 and 0.13 respectively) had lower EN in Trans-Mara compared to Kisii where no EN was recorded (Figure 4.9).

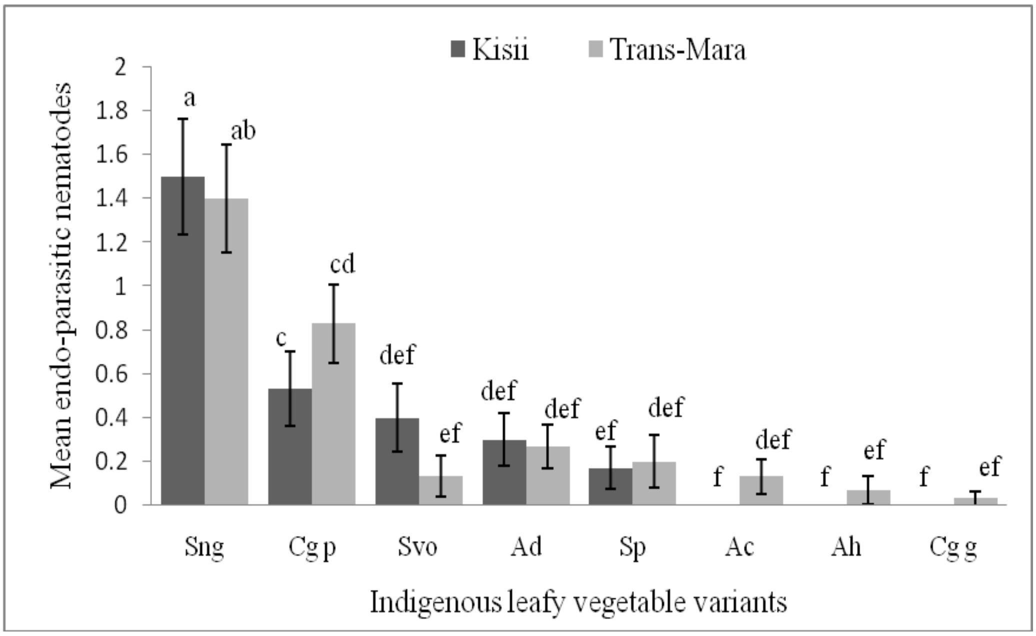

Figure 4.9: Root-knot nematode indices on indigenous leafy vegetables in Kisii and Trans-Mara Counties*.

Data are means ± SE of endo-parasitic nematodes per 10 g of dry roots obtained from the survey study on a scale of 0-5 according to Quesenberry *et al*., (1989).
*Means followed by the same letter (s) are not significantly different (P>0.05) with LSD test.
Sng = *Solanum nigrum* green berried, Cgp = *Cleome gynandra* purple stemmed, Svo = *S. villosum* orange berried, Ad = *Amaranthus dubius*, Sp = *S. nigrum* purple berried, Ac = *A. cruentus*, Ah = *A. hypochondriacus*, Cgg = *C. gynandra* green stemmed.

4.3 Response of indigenous leafy vegetables to root-knot nematode inoculation in the greenhouse test 1

4.3.1 Root-knot nematode reproduction factor on indigenous leafy vegetables

Seven ILVs; *Solanum nigrum* green (Sng) and purple (Sp) berried, *S. villosum* orange berried (Svo), *Amaranthus cruentus* (Ac), *A. dubius* (Ad), *A. hypochondriacus* (Ah), and *Cleome gynandra* purple stemmed (Cgp) were screened in the greenhouse for response to *Meloidogyne* spp. relative to susceptible *S. lycopersicum* (To) as a positive check.

The response of ILVs to RKN varied significantly (P<0.05) from resistant to susceptible (Table 4.2). Of the seven ILVs screened, Ah, Cg p and Ac were moderately resistant, Ad was tolerant, while Sp, Svo and Sng were found to be susceptible relative to the susceptible check plant (Table 4.2). Percentage Rf was lower in resistant and moderately resistant ILVs compared to the susceptible ILVs and the check (Table 4.2).

ILVs	**Rf**	**% Rf¶**	**GI***	**J2/200 cm^3 soil**	**Response****
Solanum nigrum (g)	7.69^{b}	69.58	3.75^{ab}	493.5^{ab}	Susceptible
S. nigrum (p)	7.66^{b}	48.35	3.25^{ab}	498.5^{ab}	Susceptible
S. villosum (o)	7.23^{bc}	46.34	3.25^{ab}	600.0^{ab}	Susceptible
Amaranthus dubius	3.25^{d}	14.98	2.0^{bc}	1118.5^{a}	Tolerant
A. cruentus	1.59^{d}	9.55	1.0^{c}	275.0^{b}	Moderately resistant
Cleome gynandra (p)	1.53^{de}	4.72	1.0^{c}	203.5^{b}	Moderately resistant
A. hypochondriacus	0.9^{e}	2.12	0.5^{c}	537.0^{ab}	Moderately resistant
S. lycopersicum (positive control)	13.0^{a}	100	5.0^{a}	740.3^{ab}	Very susceptible (Check plant)
P-Value	0.000	0.000	0.000	0.308	

Table 4.2 Response of indigenous leafy vegetables to root-knot nematode infection in the greenhouse test 1.

Mean on the same column denoted by similar letter (s) are not significantly different (P>0.05).
¶Reproduction factor based on Rf of ILV/Rf of check plant × 100 %
*GI on a 0-5 galling scale where; 0= no galls; 1= 1-2; 2= 3-10; 3= 11-30; 4= 31-100 and 5= > 100 galls per root system (Quesenberry *et al*., 1989).
**Host response (Susceptibility and resistance) was categorized as susceptible when Rf > 5.0, tolerant if 5.0 ≥ Rf > 1, moderately resistant if 1 > Rf > 0, and resistant when Rf ≤ 0 (Zhang and Schmitt, 1994).

Although Sng, Sp and Svo were susceptible to RKN with higher Rf that ranged from 7.23 to 7.69, there was no significant difference (P>0.05) established among them

(Table 4.2). Lower Rf ranging from 0.9 to 1.59 was obtained in moderately resistant ILVs (Table 4.2). Root-knot nematode Rf was lowest in Ah followed by Cg p and highest in Sng compared to the rest of the ILVs and tomato (Table 4.2). On further analysis, a significant positive correlation (r=0.992, P<0.05) was established between nematode galls and Rf in Svo plants (Figure 4.10).

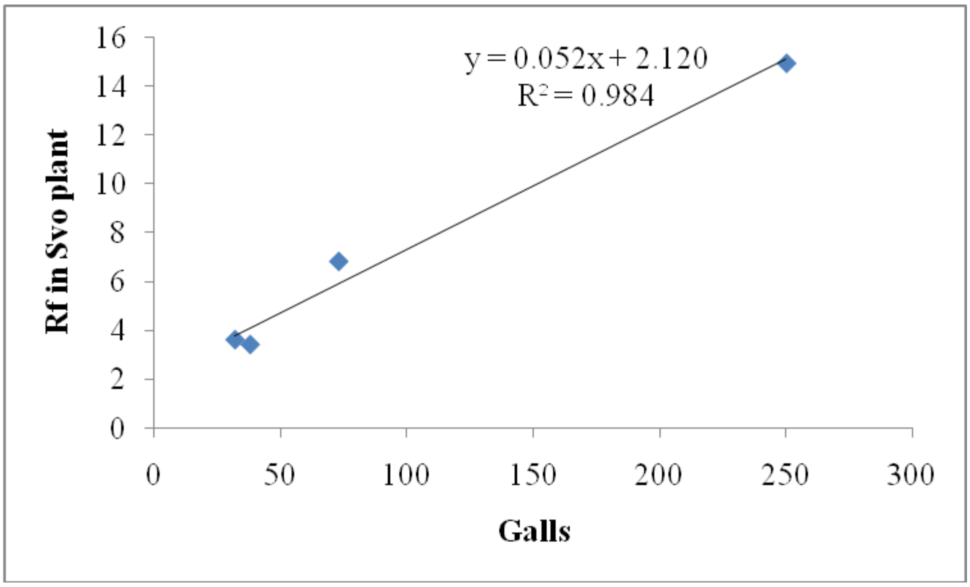

Figure 4.10: Relationship between galls and Rf in Svo in greenhouse test 1.

4.3.2 Root-knot nematode galling index (GI) on indigenous leafy vegetables in the greenhouse test 1

The GI differed significantly (P<0.05) among the ILVs. Although Sng, Sp, Svo and Ad had high GI, they did not differ significantly (P>0.05) from that of check plant (To) as depicted in Table 4.2. The GI in Ac, Cgp and Ah was significantly (P<0.05) lower than that of To (Table 4.2). The GI correlated positively with the RKN galls on the roots of the ILVs with susceptible crops recording significantly (P<0.05) more galls compared with tolerant and resistant ILVs. Further analysis revealed a significant positive correlation (r=0.883, P<0.05) between RKN galls and GI in Sng plants (Figure 4.11).

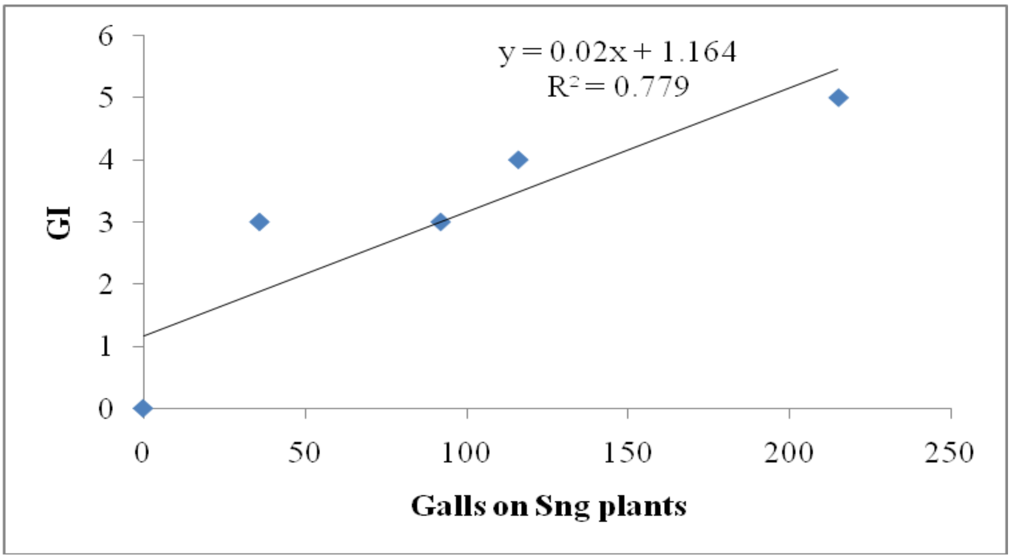

Figure 4.11: Relationship between galling index and nematode galls on *Solanum nigrum* green berried plants in greenhouse test 1.

GI = galling index, Sng = *Solanum nigrum* green berried.

4.3.3 Root-knot nematode J2s in the soil

The population of J2s did not differ significantly (P>0.05) among the ILVs (Table 4.2). Although the susceptible and tolerant ILVs had more J2s than the susceptible check, there was no significant difference (P>0.05) established. Moderately resistant ILVs had significantly (P<0.05) fewer J2s compared to susceptible ILVs and To (Table 4.2). Despite Ad being resistant, it had more J2s than To although they were not significantly (P>0.05) higher (Table 4.2). Further analysis revealed a significant positive correlation (r = 0.485, P<0.05) between the J2s and nematode galls in Ad plants (Figure 4.12).

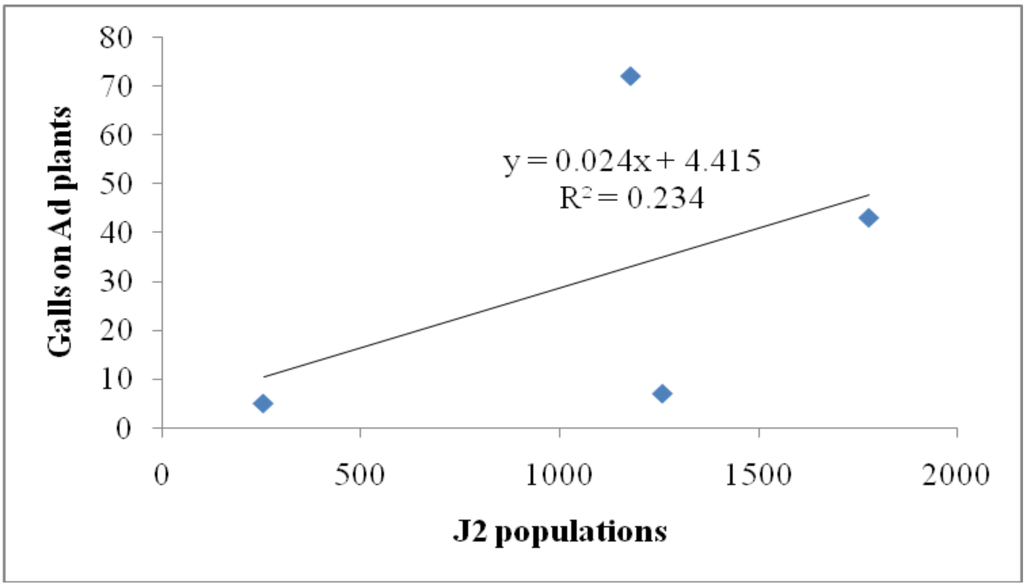

Figure 4.12: Relationship between J2 populations and nematode galls on *Amaranthus dubius* plants in greenhouse test 1.

Ad = *Amaranthus dubius*, J2 = root knot nematode second stage juvenile.

4.3.4 Influence of root-knot nematodes on growth of indigenous leafy vegetables in the greenhouse test 1

4.3.4.1 Effect on Shoot height (SH)

Shoot height reductions were recorded in ILVs inoculated with RKN compared to the control. The highest SH reduction was found in Sng (17.0 %) compared to positive control (To) though there was no significant difference (P>0.05), followed by Ac (13.4 %), Ad (8.8 %) and Svo (7.9 %) that differed significantly from that of To (P<0.05), while the least significant reductions were recorded by Ah, Sp and Cgp (5.3 %, 3.3 % and 2.5 % respectively) compared to To (16.6 %) as revealed in Figure 4.13. *Amaranthus dubius*, Ac and Sng inoculated with RKN were noted to be chlorotic and stunted compared to the controls (Plates V and VI).

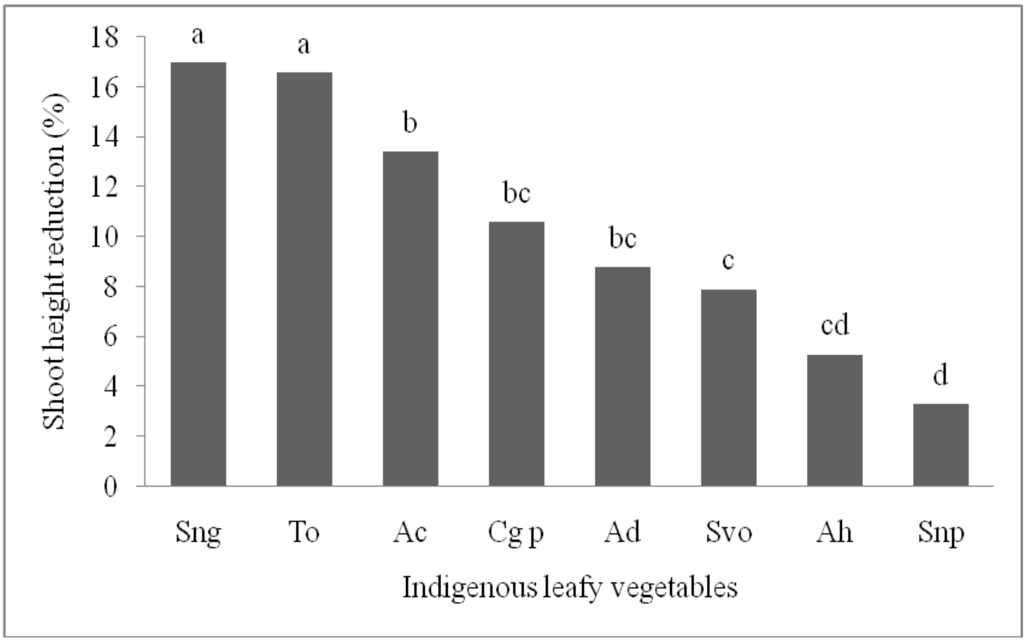

Figure 4.13: Effect of root-knot nematodes on shoot height of indigenous leafy vegetables and susceptible check plant (tomato) in the greenhouse test 1.

¶ Bars followed by the same letter (s) are not significantly different (P>0.05).
Percentage shoot height reduction based on shoot height length of inoculated ILV/shoot height length of control × 100 %.
Sng = *Solanum nigrum* green berried, To = tomato, Ac = *Amaranthus cruentus*, Cg p = *Cleome gynandra* purple stemmed, Ad = *A. dubius*, Svo = *S. villosum* orange berried, Ah = *A. hypochondriacus*, Snp = *S. nigrum* purple berried.

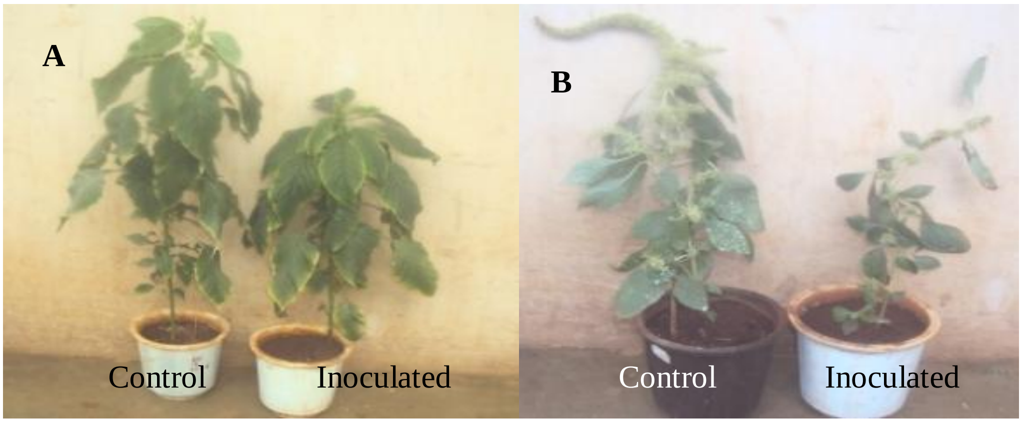

Plate V: Effect of root-knot nematodes on plant growth in *Amaranthus dubius* (**A**) and *A. cruentus* (**B**) in the greenhouse experiment.

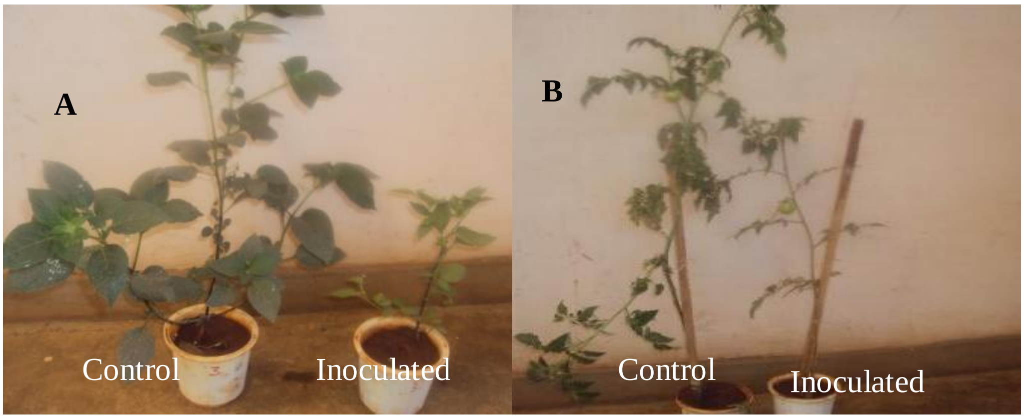

Plate VI: Effect of root-knot nematodes on plant growth in *S. nigrum* green berried (**A**) and positive control *S. lycopersicum* (**B**) in the greenhouse test.

4.3.4.2 Effect on fresh shoot weight (FSW)

There was no significant difference (P>0.05) in FSW reductions or increase in ILVs. Higher FSW reductions were found in the susceptible ILVs (Sng and Sp) and lower in the resistant ILVs (Ah) although there was no significant difference (P>0.05) established (Figure 4.14).

A higher FSW reduction was found in Sng, followed by Sp as depicted in Figure 4.14. However, these reductions were lower compared to the susceptible check although there was no significant (P>0.05) difference established. Increased FSW was recorded in Svo, followed by Cgp, Ac and Ad inoculated with RKN compared to the control (Figure 4.14).

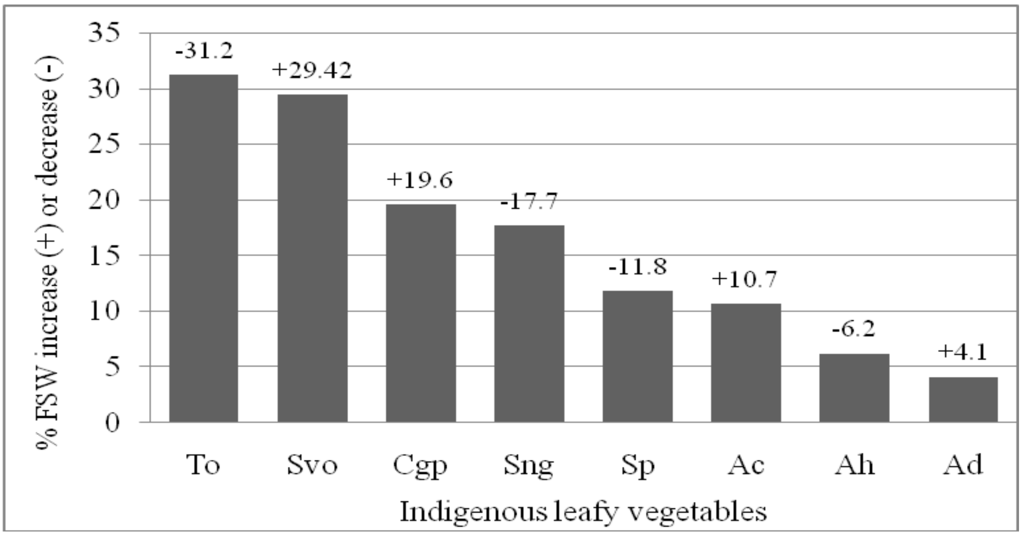

Figure 4.14: Effect of root-knot nematodes on fresh shoot weight of indigenous leafy vegetables and susceptible check (To) in the greenhouse test 1.

Percentage FSW reduction (-) or increase (+) based on shoot weight of inoculated ILV/shoot weight of control × 100 %.
To = tomato, Svo = *Solanum villosum* orange berried, Cg p = *Cleome gynandra* purple stemmed, Sng = *S. nigrum* green berried, Sp = *S. nigrum* purple berried Ac = *Amaranthus cruentus*, Ah = *A. hypochondriacus*, Ad = *A. dubius*.

4.3.4.3 Effect on fresh root weight (FRW)

There was no significant difference (P>0.05) in FRW of RKN inoculated and uninoculated ILVs. However, inoculated ILVs were found to have heavier roots relative to their controls. A higher FRW increase was recorded in Sng, Svo and To compared to Cgp that had significantly (P<0.05) lower FRW increase (Figure 4.15). *Solanum nigrum* purple berried FRW was however, noted to be reduced (Figure 4.15). The roots of susceptible ILVs (Sng and Svo) and To were heavily galled and proliferated (Plate VII A & B) compared with the tolerant or resistant ILVs (Plate VIII A & B). Moderately resistant and tolerant ILVs were found to have reduced FRW compared with the uninoculated control (Figure 4.15). A higher FRW reduction was obtained in Sp, followed by Ah and Ad while Ac had the least FRW reduction (Figure 4.15).

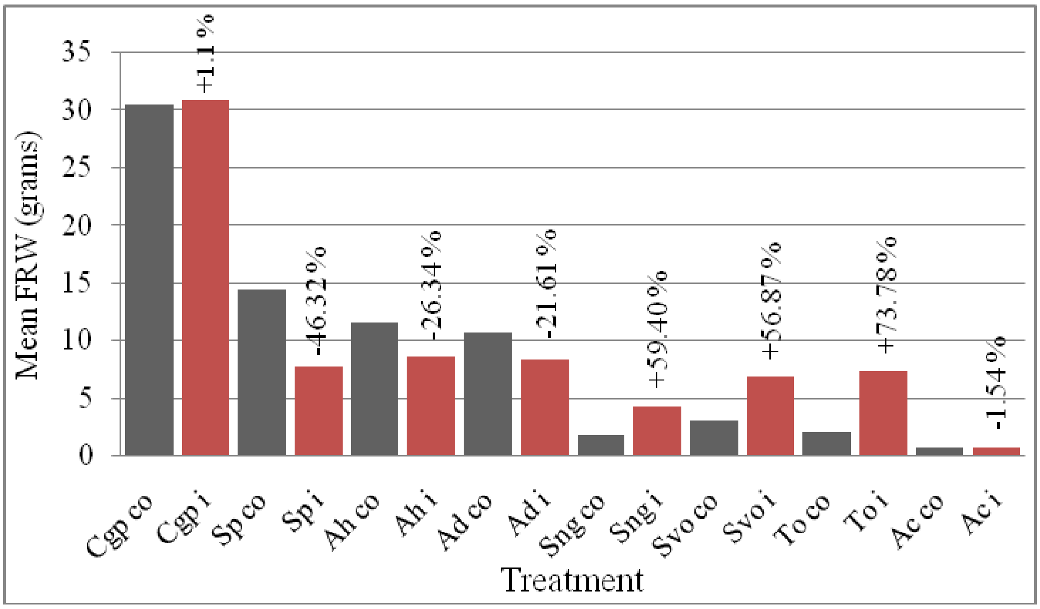

Figure 4.15: Effect of root-knot nematodes on fresh root weight of indigenous leafy vegetables and susceptible check plant (tomato) in the greenhouse test.

Cgp = *Cleome gynandra* purple stemmed, Sp = *Solanum nigrum* purple berried, Ah = *Amaranthus hypochondriacus*, Ad = *A. dubius*, Sng = *S. nigrum* green berried, Svo = *S. villosum* orange berried, To = tomato, Ac = *A. cruentus*, co = uninoculated, I = inoculated with nematode, FRW = fresh root weight.
Percentage FRW reduction (-) or increase (+) based on FRW of inoculated ILV/FRW of control × 100 %.

Plate VII: Root-knot nematode galled roots for *Solanum nigrum* green berried (susceptible) (**A)** compared to *S. lycopersicum* (susceptible check) (**B**).

Plate VIII: *Amaranthus dubius* (Tolerant) (**A**) and *A. hypochondriacus* (Moderately resistant) (**B**) roots infested with root-knot nematodes.

4.4 Effects of organic amendments on growth of indigenous leafy vegetables and disease parameters in greenhouse test 2

4.4.1 Effects of organic amendments on nematode galls and galling index

The selected OAs differed significantly (P<0.05) on their effect on GI in Svo (Table 4.3). The most effective amendments that reduced RKN galls significantly (P<0.05) were Trej, Td and Tres (92.1 %, 83.8 % and 82.5 % respectively). These amendments recorded significantly fewer galls compared to the control as depicted in Table 4.3. Consequently, these amendments reduced GI on Svo (GI=1.0, 1.0 and 2.6 for Trej, Tres and Td respectively) compared to the control (GI=4.5). More galls and higher indices (GI=3.0 and 3.5 respectively) were found in Svo plants amended with CM and GM with significantly (P<0.05) lower gall reduction (17.5 % and 23.4 % respectively) compared to the unamended control (GI=4.5) as depicted in Table 4.3.

The OAs differed significantly (P<0.05) on their effect on RKN galls in Sp plants (Table 4.3). The most superior OAs in reducing RKN galls were Tres and Trej (96.9 % and 96.1 % respectively), followed by GM and CM (69.5 % and 63.1 % respectively), while Td (49.1 %) was inferior. Tea residue and Trej had fewer galls that differed significantly (P<0.05) from GM, CM, Td and the unamended control

(Table 4.3). Consequently, the GI was effectively reduced by Tres and Trej (GI = 0.75 and GI = 0.5 respectively) followed by CM (GI = 2.75) and GM (GI = 3.0) than that of unamended control (GI = 4).

	Root-knot nematode galling index*¶					
Amendment	Svo	Sp	Sng	Ad	Ah	To
Tres	1.0^{d}	0.75^{c}	1.0^{c}	1.0^{c}	0.8^{c}	2.0^{d}
Trej	1.0^{d}	0.5^{c}	1.5^{bc}	1.5^{bc}	3.8^{c}	2.0^{d}
Td	2.6^{c}	2.0^{b}	1.0^{c}	1.75^{b}	20.8^{ab}	3.0^{c}
CM	3.0^{bc}	2.75^{ab}	2.5^{b}	1.8^{b}	5.5^{c}	4.0^{ab}
GM	3.5^{b}	3.0^{ab}	3.0^{ab}	2.3^{ab}	3.3^{c}	3.5^{b}
Unamended	4.5^{a}	4.0^{a}	3.5^{a}	3.9^{a}	11.5^{bc}	5.0^{a}
P-Value	0.000	0.004	0.004	0.000	0.601	0.000

Table 4.3 Effects of organic amendments on nematode galling index on *Solanum* and *Amaranthus* species and the check plant (*S. lycopersicum*).

¶ GI on a 0-5 galling scale where; 0= no galls; 1= 1-2; 2= 3-10; 3= 11-30; 4= 31-100 and 5= > 100 galls per root system (Quesenberry *et al*., 1989).
*Means on the same column followed by the same letter (s) are not significantly different.
Svo = *Solanum villosum* orange berried, Sp = *S. nigrum* purple berried, Sng = *S. nigrum* green berried, To = tomato, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

Tithonia diversifolia, Tres and Trej significantly (P<0.05) reduced RKN galls (86.3 %, 82.7 % and 89.9 % respectively) in Sng plants compared to the unamended control, though the effect of these OAs did not differ significantly (P>0.05) from each other (Table 4.3). These OAs also recorded lower GI that ranged from 1.0 to 1.5 compared with the unamended control (GI=3.5). Although more galls were found in Sng plants amended with CM and GM, they were significantly lower than that of unamended control (Table 4.3). These OAs also had higher GI (GI=2.5 and GI=3.0

for CM and GM respectively), compared to Tres, Trej and Td, but lower than the unamended control (GI=3.5).

The various OAs in Ad, differed significantly ($P<0.05$) on their effect on RKN galls (Table 4.3). Tea residue, Trej and CM, had significantly ($P<0.05$) higher percentage reductions (95.6 %, 90.8 % and 89.9 % respectively) with fewer RKN galls and GI compared with the control (Table 4.3). On the other hand, soils amended with Td and GM (66.2 % and 40.8 % respectively) had higher gall reduction that differed significantly ($P<0.05$) from that of unamended control. Moreover, the GI was significantly lower in Tres and Trej (GI=1.0 and 1.5 respectively) followed by CM, Td and GM (1.8, 1.75 and 2.3 respectively) compared with the unamended control.

There was no significant difference ($P>0.05$) established on the effect of the various OAs used in Ah plants (Table 4.3). Generally, fewer and smaller RKN galls were found on the roots of Ah unamended plants. Tea residue, GM, Trej and CM (93.5 %, 71.7 %, 67.4 % and 52.2 % respectively) were more effective in reducing RKN galls although they did not differ significantly ($P>0.05$) from the unamended control (Table 4.3). Similarly, Tres (GI=0.25), Trej (GI=0.75), GM (GI=1.0) and CM (GI=1.0) recorded lower GI compared with the unamended control (GI=1.25). However, Td recorded more galls (GI=1.5) that did not differ significantly ($P>0.05$) from the unamended control (Table 4.3). Suppression of RKN galls in the positive check (To) was significantly ($P<0.05$) effective in Trej, Tres and Td (95.9, 94.6, 72.5 % respectively) followed by GM and CM (42.7 and 17.7% respectively) as depicted in Table 4.3.

4.4.2 Effects of organic amendments on reproduction factor

The various OAs differed significantly (P<0.05) in suppressing RKN reproduction factor on Svo plants (Table 4.4). All the OAs except CM and GM, significantly (P<0.05) reduced Rf compared to the unamended plants (Table 4.4). Tea rejects ranked first, followed by Td and Tres that were ranked second and third respectively, in suppressing Rf on Svo plants compared to the unamended plants. Cattle manure and GM had some of the higher Rf that did not differ significantly (P>0.05) from that of unamended plants (Table 4.4).

	Root-knot nematode reproduction factor (Rf)*[¶]					
Amendment	Svo	Sp	Sng	Ad	Ah	To
Td	2.5[bc*]	3.6[bc]	2.2[bc]	2.7[ab]	1.2[ab]	2.6[bc]
Tres	2.6[bc]	2.1[c]	2.2[bc]	0.8[b]	1.2[ab]	1.2[c]
Trej	1.6[c]	3.7[bc]	1.2[c]	1.2[b]	1.2[ab]	1.2[c]
CM	4.8[ab]	4.4[bc]	4.2[a]	1.3[b]	0.8[b]	8.0[a]
GM	5.3[a]	3.6[bc]	3.4[ab]	3.7[a]	1.3[ab]	4.7[b]
Unamended	5.6[a]	8.0[a]	3.0[b]	3.0[a]	2.4[a]	7.9[a]
P-Value	0.001	0.023	0.041	0.023	0.405	0.000

Table 4.4: Effects of amendments on nematode reproduction on indigenous leafy vegetables in the greenhouse test 2.

[¶]Root-knot nematode Rf based on total RKN galls minus initial RKN gall inoculum divided by initial RKN gall inoculum.
*Means followed by same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Sp = *S. nigrum* purple berried, Sng = *S. nigrum* green berried, To = tomato, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

There was a significant difference ($P<0.05$) in Rf between Sp plants grown in amended and inoculated soils and those grown in unamended and inoculated soils (Table 4.4). However, the OAs did not differ significantly ($P>0.05$) in suppressing Rf although, those in Tres amended and inoculated soils were more suppressive, followed by Td, GM and Trej, while CM was the least suppressive to Rf (Table 4.4).

Tea reject was more suppressive to Rf in Sng plants, followed by Tres and Td, while GM and CM were the least suppressive (Table 4.4). Reproduction factor on these amended and inoculated soils was significantly ($P<0.05$) reduced compared to the unamended and inoculated soils (Table 4.4). Lower Rf was found in Trej, Tres and Td amendments although there was no significant difference ($P>0.05$) established among them (Table 4.4). On the other hand, CM and GM had higher Rf with that of CM being significantly ($P<0.05$) higher than that of unamended and inoculated soils (Table 4.4).

The various OAs significantly ($P<0.05$) suppressed Rf in Ad (Table 4.4). The most suppressive amendment was Tres, followed by Trej, CM and GM although the amendments did not differ ($P>0.05$) significantly (Table 4.4). The least suppression to Rf was found in Td, although it did not differ significantly ($P>0.05$) from the unamended and inoculated soils (Table 4.4).

There was no significant difference ($P>0.05$) on suppression of Rf in Ah established on the OAs (Table 4.4). Except for CM that had significantly ($P<0.05$) lower Rf, all the other OAs had lower Rf that did not differ significantly ($P>0.05$) from that of unamended and inoculated soil (Table 4.4).

All the OAs except CM differed significantly (P<0.05) from the unamended and inoculated soils on suppression of Rf in To (Table 4.4). Tea residue, Trej, Td and GM had some of the lowest Rf that differed significantly (P<0.05) from that of unamended and inoculated soils (Table 4.4). However, CM had some of the higher Rf that did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.4).

4.4.3 Effects of amendments on J2 populations

The various OAs did not differ significantly (P>0.05) on their effect on suppressing J2 population in Svo plants (Table 4.5). The most suppressive amendment was Tres followed by Td that differed significantly (P<0.05) from that of unamended soils (Table 4.5). All the other amendments did not differ significantly (P>0.05) from the unamended and inoculated soils although the J2 populations were lower (Table 4.5).

	J2 populations/200 cm^3 soil¶					
ILVs	**Svo**	**Sp**	**Sng**	**Ad**	**Ah**	**To**
GM	150.5 ^{ab}	133.0 ^{ab}	248.5 ^{ab}	28.0 ^{cd}	59.5 ^{bc}	56.0 ^{bc}
Tres	73.5 ^{bc}	8.75 ^{d}	278.3 ^{ab}	80.5 ^{bc}	28.0 ^{c}	36.8 ^{bc}
CM	140.0 ^{ab}	169.8 ^{ab}	288.8 ^{ab}	57.8 ^{bc}	42.0 ^{bc}	60.5 ^{b}
Trej	136.5 ^{ab}	172.8 ^{ab}	171.5 ^{b}	64.8 ^{bc}	28.0 ^{c}	15.3 ^{c}
Td	103.3 ^{b}	21.8 ^{cd}	14.25 ^{c}	37.3 ^{bc}	37.75 ^{bc}	26.3 ^{bc}
Unamended	390.3 ^{a}	226.0 ^{a}	313.3 ^{a}	303.0 ^{a}	306.3 ^{a}	753.0 ^{a}
P-Value	0.188	0.000	0.000	0.016	0.016	0.005

Table 4.5: Effects of amendments on J2 population on indigenous leafy vegetables and tomato in greenhouse test 2*.

*Means followed by same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Sp = *S. nigrum* purple berried, Sng = *S. nigrum* green berried, To = tomato, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

A significant (P<0.05) suppression on J2s was found on Sng plants grown on amended and inoculated soils (Table 4.5). *Tithonia diversifolia* and Trej significantly (P<0.05) suppressed J2 population than in unamended and inoculated soils (Table 4.5). The J2s in the other OAs were lower although they did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.5).

The J2 populations on Ad plants differed significantly (P<0.05) among the OAs in amended and inoculated soils (Table 4.5). Significantly lower J2s were found on amended and inoculated soils than that of unamended and inoculated soils. Goat manure, Td, CM and Trej amended and inoculated soils had some of the lower J2 populations that were significantly (P<0.05) lower than that of unamended but inoculated soils (Table 4.5). Although Tres had some of the higher J2s than that of the other OAs, the J2 population was significantly (P<0.05) lower than that of unamended and inoculated soils (Table 4.5).

In Ah plants, Trej, Tres and GM significantly (P<0.05) suppressed J2 population compared to the unamended and inoculated soils (Table 4.5). The most suppressive amendments on J2 populations were Tres and Trej that recorded significantly (P<0.05) lower J2s compared to the unamended soils (Table 4.5). However, these J2 populations were not significantly (P>0.05) different from those of CM, GM and Td (Table 4.5).

A higher suppression of J2 was established in Trej, followed by Td and Tres amended and inoculated soils in the check plant (Table 4.5). The J2 populations were significantly (P<0.05) lower in amended and inoculated soils compared to the unamended and inoculated soils (Table 4.5). The least effective amendments in suppressing J2 population were CM and GM that recorded more J2s compared to Tres, Trej and Td although there was no significant difference established (P>0.05) as depicted in Table 4.5.

4.4.4 Effects of amendments on growth of ILVs in greenhouse test 2

4.4.4.1 Effects of amendments on shoot height (SH)

The SH differed significantly (P<0.05) on amended and inoculated Svo plants (Table 4.6). Inoculated and amended soils with CM, GM and Td had significantly (P<0.05) taller shoots than unamended and inoculated soils (Table 4.6). Although Trej had some of the tallest shoots in inoculated and amended soils, they were not significantly (P>0.05) taller than those grown on unamended and inoculated soils (Table 4.6).

	Indigenous leafy vegetables shoot height (cm)*					
Treatment	Svo + N	Svo - N	Sp + N	Sp - N	Sng+N	Sng-N
GM	58.13a	61.33a	67.2abc	76.3a	49.25ab	60.98ab
CM	56.93a	46.5bc	77.4a	69. 3ab	44.0b	68.1a
Trej	37.13c	44.9bc	45.75c	46.63c	51.38ab	52.0ab
Tres	48.58abc	49.6abc	45.15c	56.7bc	42.75b	34.5cd
Td	57.25a	48.8abc	50.25bc	56.13bc	47.13ab	51.3bc
Unamended	44.88bc	52.13abc	66.88abc	69.13ab	42.25b	68.13a
P-value	0.001	0.102	0.000	0.001	0.093	0.000

Table 4.6: Effects of amendments on shoot height of indigenous leafy vegetables in the greenhouse test 2.

*Means followed by the same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Sp = *S. nigrum* purple berried, Sng = *S. nigrum* green berried, To = tomato, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

On the other hand, SH in amended and uninoculated soils did not differ significantly ($P>0.05$). However, GM had higher SH that differed significantly ($P<0.05$) from those grown on unamended and uninoculated soils (Table 4.6). Although amended and uninoculated soils with Tres, Td, CM and Trej had lower SH, they were not significantly ($P>0.05$) lower than those grown on unamended and uninoculated soils (Table 4.6). Except for CM, there was no significant difference ($P>0.05$) among amended inoculated and amended uninoculated Svo plants (Table 4.6).

The OAs differed significantly ($P<0.05$) on their effect on improving growth of Sp plants grown on amended and inoculated soils (Table 4.6). Plants grown on CM and GM amended and inoculated soils had some of the tallest shoots that did not differ significantly ($P>0.05$) from those on unamended and inoculated soils (Table 4.6). Inoculated and amended soils with Trej, Tres and Td had lower SH that did not in most cases differ significantly ($P>0.05$) from that of Sp plants grown on unamended and inoculated soils (Table 4.6). On the other hand, SH of Sp plants grown on amended and uninoculated soils differed significantly ($P<0.05$) among the amendments. Goat manure and CM had some of the higher SH that did not differ significantly ($P>0.05$) from those grown on unamended and uninoculated soils (Table 4.6). Tea residue, Trej and Td had lower SH that were not significantly ($P>0.05$) lower than those grown on unamended and uninoculated soil although there was no significant difference established (Table 4.6). Despite the SH of Sp plants grown on amended and uninoculated soils being generally higher, they did not differ significantly ($P>0.05$) from those grown on amended and inoculated soils (Table 4.6).

There was no significant difference ($P>0.05$) established among the amendments on SH of Sng plants grown on amended and inoculated soils (Table 4.6). Soils amended with Trej, GM, Td, CM and Tres had higher SH that did not differ significantly ($P>0.05$) from those on unamended and inoculated soils (Table 4.6). There was significant difference on SH ($P<0.05$) established among the amendments on amended and uninoculated soils (Table 4.6). Plants grown on amended and uninoculated soils with CM and GM had lower SH that did not differ significantly ($P>0.05$) from unamended and uninoculated soils (Table 4.6). Significantly ($P<0.05$) lower SH were found in plants grown on amended and uninoculated soils with Trej, Td and Tres compared to unamended and uninoculated soils (Table 4.6). Although SH of Sng plants grown on amended and uninoculated soils was higher than amended and inoculated soils, those on Tres amended and inoculated soils were significantly ($P<0.05$) higher than that on amended and uninoculated soils (Table 4.6). Similarly, amended and uninoculated soils had significantly ($P<0.05$) higher SH than amended and inoculated soils (Table 4.6). On the other hand, plants grown on unamended uninoculated soils were significantly ($P<0.05$) taller than those on unamended and inoculated soils (Table 4.6).

A significant difference was established among the amendments in Ad plants grown on amended and inoculated soils (Table 4.7). Inoculated and amended soils with Td, GM, Tres and CM had SH that were not significantly ($P>0.05$) higher than that on unamended and inoculated soils (Table 4.7). Plants grown on amended and inoculated soils had lower SH that did not differ significantly ($P>0.05$) from those on unamended and inoculated soils.

Treatment	Indigenous leafy vegetables shoot height (cm)*					
	Ad+N	Ad-N	Ah+N	Ah-N	To+N	To-N
GM	22.63ab	23.03b	23.65bc	26.63bcd	61.5ab	82.0a
CM	20.5ab	14.8d	24.63bc	25.9bcd	71.5a	72.25ab
Trej	15.08bc	15.63cd	17.75c	15.13e	52.88ab	47.13c
Tres	20.88ab	20.2bcd	23.0bc	24.0cd	50.25ab	52.63bc
Td	26.88a	23.88ab	33.38a	28.13abc	59.5ab	62. 3bc
Unamended	17.58b	20.13bcd	24.13bc	25.88bc	54.38ab	68.5bc
P-value	0.026	0.071	0.002	0.052	0.708	0.248

Table 4.7: Effects of amendments on shoot height in indigenous leafy vegetables and the check plant in the greenhouse test 2.

*Means followed by the same letter (s) are not significantly different (P>0.05).
Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

Similarly, SH of Ad grown on amended and uninoculated soils did not differ significantly (P>0.05) among the amendments (Table 4.7). Plants grown on amended and uninoculated soils with Trej and CM had shoots that were not significantly (P>0.05) shorter than those on unamended and uninoculated soils (Table 4.7). Although GM, Td and Tres had higher SH, they were not significantly (P>0.05) higher than those grown on unamended and uninoculated soils (Table 4.7). Generally, amended and uninoculated soils had higher SH that did not differ significantly from those grown on amended and inoculated soils (Table 4.7). Soils amended with Td, CM and Tres but without nematodes had higher SH that did not differ significantly (P>0.05) from those grown on unamended and uninoculated soils (Table 4.7).

The SH of *A. hypochondriacus* differed significantly (P<0.05) between the OAs on amended and inoculated soils (Table 4.7). Significantly (P<0.05) taller shoots were found in Ah grown on amended and inoculated soils with Td compared to plants grown on unamended and inoculated soils (Table 4.7). The SH of amended and inoculated soils with CM and GM were higher although they did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.7). Although SH in amended and inoculated soils with Tres and Trej were lower, they were not significantly (P>0.05) lower than those on unamended and inoculated soils (Table 4.7).

There was no significant difference (P>0.05) among the SH on amended and uninoculated soils (Table 4.7). Although Td, GM and CM had higher SH, they were not significantly higher than those on unamended and uninoculated soils (Table 4.7. Tea residue and Trej had lower SH than that on unamended and uninoculated soils, although Trej had significantly (P<0.05) lower SH (Table 4.7). Amended and uninoculated soils had generally higher SH that did not differ significantly (P>0.05) from those on amended and inoculated soils (Table 4.7). Although SH in Trej and Td amended and uninoculated soils were lower than that on amended and inoculated soils, they did not differ significantly (P>0.05).

The SH of Tomato plants grown on amended and inoculated did not differ significantly (P>0.05) among the amendments (Table 4.7). Moreover, To grown on amended and inoculated soils with CM, GM and Td were taller than those on unamended and inoculated soils although, they did not differ significantly (P>0.05). Although the SH on amended and inoculated soils with Trej and Tres were lower than those on unamended and inoculated soils, they did not differ significantly (P>0.05) as depicted in Table 4.7. The SH of To grown on amended and uninoculated soils did not differ significantly (P>0.05) among the amendments (Table 4.7).

Goat manure and CM had significantly (P<0.05) taller shoots that did not differ significantly from unamended and uninoculated soils (Table 4.7). The SH of plants on soils amended with Td, Trej and Tres were lower though not significantly (P>0.05) lower than that of unamended and uninoculated soils. Plants grown on amended and uninoculated soils had generally higher SH that did not differ significantly (P>0.05) from those on amended and inoculated soils except for Trej (Table 4.7).

4.4.4.2 Effect of amendments on fresh shoot weight (FSW)

The various OAs differed significantly (P<0.05) on their effect on FSW on Svo plants grown on amended and inoculated soils (Figure 4.16). Except for Trej, FSW were higher in all the other amendments with those of Tres being significantly (P<0.05) higher than those on unamended and inoculated soils (Figure 4.16). The FSW of Svo plants grown on amended and uninoculated soils differed significantly (P<0.05) among the amendments. Goat manure, Td and Tres had higher FSW than unamended and uninoculated soils. Moreover, the SH of plants grown on GM and Td differed significantly (P<0.05) from those on unamended and uninoculated soils (Figure 4.16).

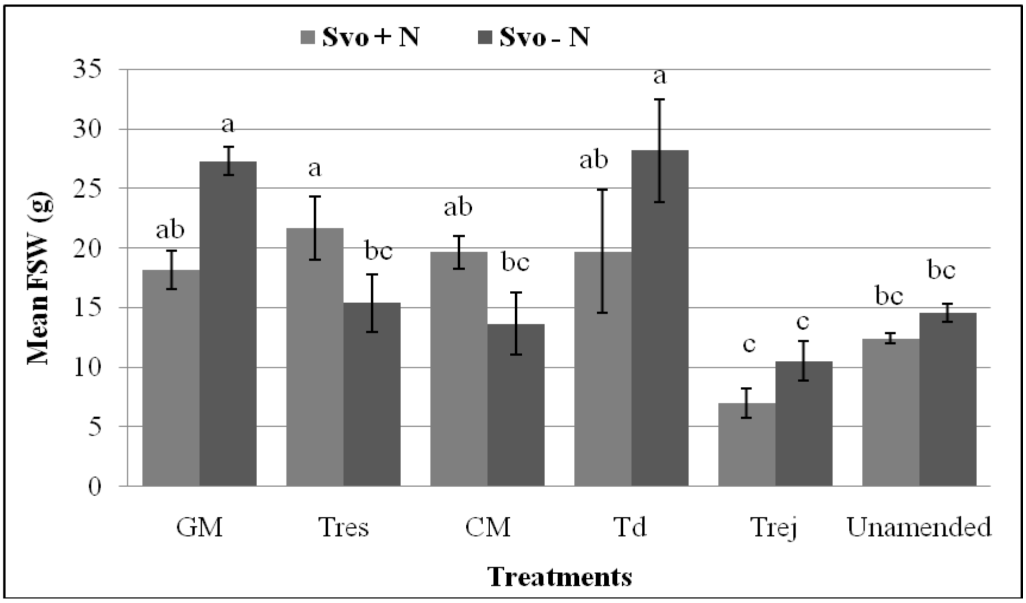

Figure 4.16: Effects of OAs on FSW of *Solanum villosum* orange berried in the greenhouse test 2*.

*Means followed by the same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

Although CM and Trej had lower FSW, they were not significantly lower than that of plants on unamended and uninoculated soils (Figure 4.16). Except for Tres and CM, FSW in amended and uninoculated soils were higher than that of amended and inoculated soils though they did not differ significantly (P>0.05).

There was no significant difference (P>0.05) in FSW established among the amendments in Sp plants grown on amended and inoculated soils (Table 4.8). The FSW of Sp plants on amended and inoculated soils did not in most cases differ significantly (P>0.05) from those grown on amended and uninoculated soils (Table 4.8). Goat manure, Td and CM had some of the highest FSW that did not differ significantly from that of Sp on unamended and uninoculated soils (Table 4.8).

Amendment	Mean FSW (grams) of ILVs *¶			
	Sp+N	**Sp-N**	**Sng + N**	**Sng - N**
GM	22.08a	21.1ab	18.75a	19.18ab
CM	20.4a	24.42a	13.08ab	22.64a
Trej	10.55ab	25.63a	15.48ab	10.07b
Tres	7.9b	19.2ab	18.65ab	14.9ab
Td	22.08a	28.15a	22.03a	18.23ab
Unamended	15.27ab	21.98a	8.58b	15.8ab
P-Value	0.070	0.275	0.074	0.076

Table 4.8: Effect of amendments on fresh shoot weight of *Solanum nigrum* purple and green berried varieties in the greenhouse test 2.

¶ Data is the mean of four fresh shoots of ILVs in the greenhouse test 2.
*Means followed by the same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Sp = *S. nigrum* purple berried, Sng = *S. nigrum* green berried, To = tomato, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

Although Tres and Trej had lower FSW than unamended and uninoculated plants, they did not differ significantly (P>0.05). On the other hand, FSW of Sp grown on amended and uninoculated soils did not differ significantly (P>0.05) among the amendments (Table 4.8). *Tithonia diversifolia*, CM and Trej had higher FSW although they were not significantly (P>0.05) higher than that of unamended and uninoculated plants (Table 4.8).

Tea residue and GM had FSW that were lower than those of unamended and uninoculated plants although they did not differ significantly (P>0.05). Plants grown on amended and uninoculated soils had in most cases higher FSW than those on amended and inoculated soils though they were not significantly different (P>0.05). Further analysis revealed a negative correlation (r=-0.168, P>0.05) between the FSW and J2 populations although there was no significant difference established (Figure 4.17).

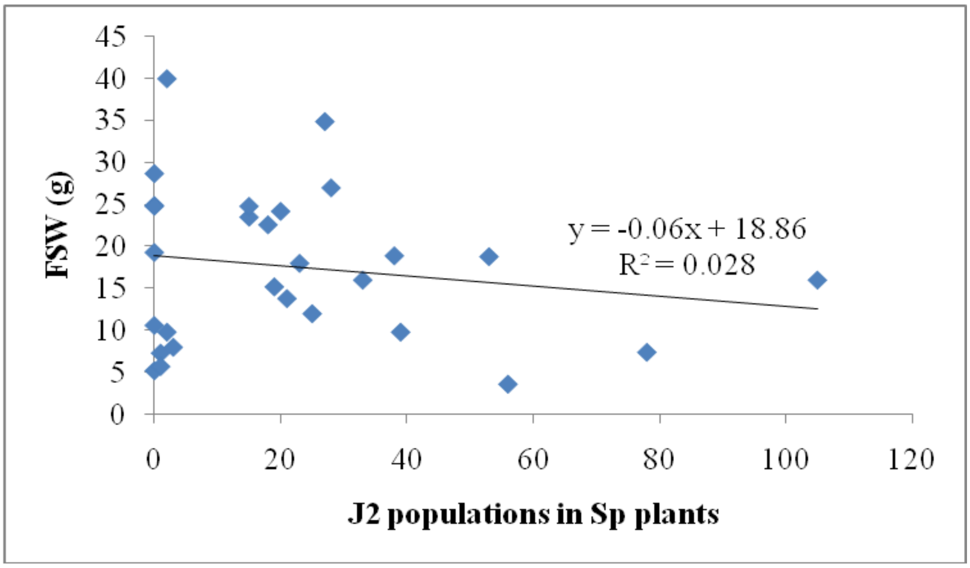

Figure 4.17: Relationship between fresh shoot weight and J2 populations in *Solanum nigrum* purple berried plants in the greenhouse test 2.

In Sng plants, FSW did not differ significantly (P>0.05) among the amendments in amended and inoculated soils (Table 4.8). Plants grown on Td and GM amended and inoculated soils had significantly (P<0.05) higher FSW than that of unamended inoculated soils (Table 4.8). Although FSW of Sng on Tres, Trej and CM amended and inoculated soils were generally heavier, they were not significantly (P>0.05) heavier than those grown on unamended and inoculated soils (Table 4.8).

Fresh shoot weights of Sng grown on amended and uninoculated soils did not differ significantly (P>0.05) from those grown on unamended and uninoculated soils (Table 4.8). Cattle manure had some of the highest FSW that differed significantly (P<0.05) from unamended and uninoculated soils, while FSW of Sng on GM and Td amended and uninoculated soils were not significantly higher than that of unamended and uninoculated soils (Table 4.8). Although FSW of Tres and Trej amended and uninoculated soils were lower than that of unamended and uninoculated soils, they did not differ significantly (Table 4.8). Fresh shoot weight of Sng grown on amended and inoculated soils did not in most cases differ significantly (P>0.05) from those grown on amended and uninoculated soils (Table 4.8). Although FSW of Sng grown on amended and uninoculated soils were higher, those grown on Tres and Trej amended and uninoculated soils were lower though not significantly lower (P>0.05).

The FSW of Ad plants grown on amended and inoculated soils differed significantly (P<0.05) among the amendments (Table 4.9). *Tithonia diversifolia* had significantly (P<0.05) higher FSW compared to those on unamended and inoculated soils (Table 4.9). Although CM, GM and Tres amended and inoculated soils had higher FSW, they were not significantly higher than that of unamended and inoculated soils (Table 4.9). The FSW of Ad grown on Trej amended and inoculated soils was lower although it did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.9).

The FSW of Ad grown on amended and uninoculated soils did not differ significantly (P>0.05) among the amendments, with those of Td and GM being higher than those of unamended and uninoculated soils although they did not differ significantly (P>0.05) as shown on Table 4.9. Although FSW of CM, Tres and Trej in amended and uninoculated soils were lower than that of unamended and uninoculated, they did not differ significantly (P>0.05). There was no significant difference established between amended and inoculated soils with amended and uninoculated, although those that were amended and inoculated had in most cases higher FSW that did not differ significantly (P>0.05) from that of unamended and uninoculated soils (Table 4.9).

Amendment	Mean FSW in Ad, Ah and Tomato in greenhouse test 2*[¶]					
	Ad+N	**Ad-N**	**Ah+N**	**Ah-N**	**To+N**	**To-N**
GM	8.52abc	8.21ab	7.1b	6.0ab	24.13a	26.4a
CM	10.21abc	4.4b	7.33b	7.35ab	28.03a	15.95ab
Trej	4.35bc	4.43b	4.03bc	2.13b	18.05ab	13.43b
Tres	6.93bc	6.17ab	5.21bc	7.43ab	14.4ab	16.92ab
Td	16.25a	13.03a	16.0a	12.11a	17.58ab	24.25ab
Unamended	5.75bc	8.1ab	11.23ab	8.65ab	12.13ab	20.45ab
P-Value	0.035	0.070	0.022	0.131	0.323	0.097

Table 4.9: Comparative efficacy of amendments on fresh shoot weight and root-knot nematodes on amaranth and tomato in the greenhouse test 2.

[¶] Data is the mean of four fresh shoots of ILVs and To in the greenhouse.
*Means followed by the same letter (s) are not significantly different (P>0.05).
Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

The various treatments on Ah plants grown on amended and inoculated soils differed significantly (P<0.05) on their effect on FSW (Table 4.9). The most effective amendment was Td recording higher FSW that did not differ significantly (P>0.05) from plants grown on unamended and inoculated soils (Table 4.9). All the other amendments on Ah plants in amended and inoculated soils had lower FSW that did not differ significantly from that of plants on unamended and inoculated soils (P>0.05). On the other hand, FSW of Ah grown on amended and uninoculated soils did not differ significantly (P>0.05) (Table 4.9). Although Td had higher FSW, they were not significantly higher than those of unamended and uninoculated soils (Table 4.9). The FSW of plants grown on GM, CM, Tres and Trej amended and uninoculated soils had some of the lower FSW that did not differ significantly (P>0.05) from unamended and uninoculated soils (Table 4.9). Although there was no significant difference (P>0.05) established in FSW between amended and inoculated with amended and uninoculated soils, those of unamended and inoculated were higher though they did not differ significantly (P>0.05) from those of unamended and uninoculated soils (Table 4.9).

There was no significant difference (P>0.05) established on the effect of OAs on FSW in To grown in amended and inoculated soils (Table 4.9). The FSW of To grown on amended and inoculated soils were higher in all the amendments with CM and GM having some of the higher FSW, followed by Trej, Td and Tres though they did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.9). On the other hand, FSW of To grown on amended and uninoculated soils did not differ significantly (P>0.05) among the amendedments (Table 4.9). Although GM and Td had higher FSW, they were not higher than that of unamended and uninoculated soils (Table 4.9). Tea residue, CM and Trej had some of the low FSW that were not significantly (P>0.05) lower than those of unamended and uninoculated soils (Table 4.9). Except for CM and Trej that had lower FSW, all the other amendments on amended and uninoculated soils had higher FSW that did not differ significantly (P>0.05) from those of amended and inoculated soils (Table 4.9).

4.4.4.3 Effect of amendments on fresh root weight

The FRW of Svo plants grown on amended and inoculated soils differed significantly (P<0.05) as depicted on Figure 4.18. Heavier roots were found in CM, followed by GM, Td and Tres although they did not differ significantly (P>0.05) from those on unamended and inoculated soils (Figure 4.18). Tea rejects had significantly lower FRW than unamended and inoculated soils (Figure 4.18).

On the other hand, Svo plants grown on amended and uninoculated soils with GM, CM, Td and Trej had higher FRW, with that of GM being significantly higher than that of unamended and uninoculated soils. All the other amendments did not differ significantly (P>0.05) from unamended and uninoculated soils (Figure 4.18). Except GM and Trej that had higher FRW in amended and uninoculated soils, all the other amendments had lower FRW that did not differ significantly (P>0.05) from that of amended and inoculated soils (Figure 4.18). Similarly, unamended and inoculated soils had significantly higher FRW than that of unamended and uninoculated soils (Figure 4.18).

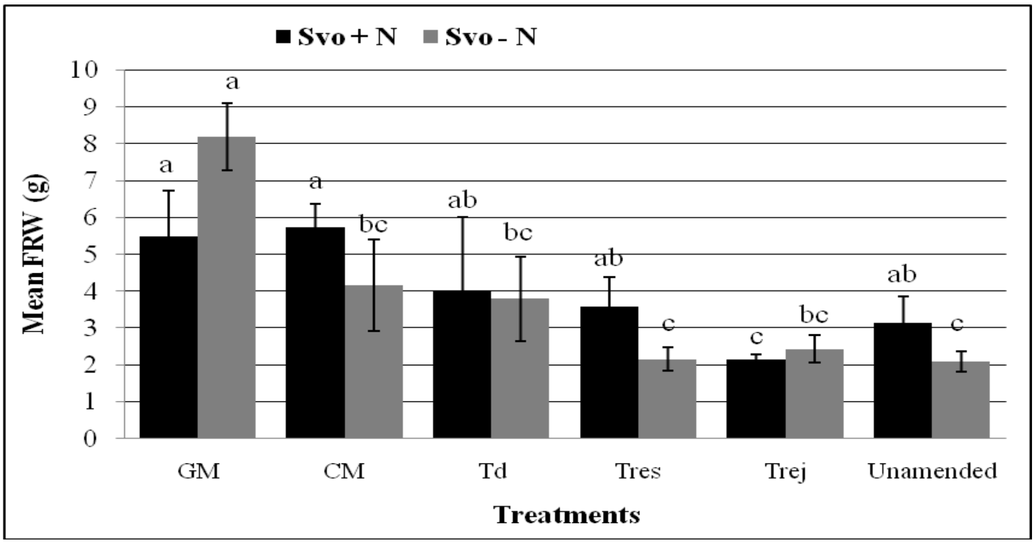

Figure 4.18: Effects of amendments on fresh root weight of indigenous leafy vegetables in the greenhouse test 2*.

*Means followed by the same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

The FRW of Sp plants did not differ significantly (P>0.05) among the amendments on amended and inoculated soils (Table 4.10). Heavier roots were found in Td, CM and GM while those grown in Trej and Tres had lower FRW that did not differ significantly (P>0.05) from unamended and inoculated soils (Table 4.10). The FRW of plants on amended and uninoculated soils did not differ significantly among the amendments (Table 4.10).

Amendment	**Mean FRW (grams) in Sp and Sng plants***			
	Sp + N	**Sp - N**	**Sng + N**	**Sng – N**
GM	3.38a	2.78ab	1.9a	1.45ab
CM	3.67a	3.77a	1.75a	1.18ab
Trej	1.36ab	3.66a	0.99ab	1.2b
Tres	1.78ab	2.08ab	1.6a	0.89bc
Td	3.99a	3.79a	1.95a	2.7a
Unamended	2.74ab	2.06ab	1.1ab	0.89bc
P-Value	0.103	0.741	0.585	0.021

Table 4.10: Effects of amendments on fresh shoot weight of *Solanum nigrum* purple and green berried plants in greenhouse test 2.

*Means followed by the same letter (s) are not significantly different (P>0.05).
Sp = *Solanum nigrum* purple berried, Sng = *S. nigrum* green berried, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

The roots of Sp grown on amended and uninoculated soils were generally heavy with those on Td, CM and Trej being heavier, followed by GM and Tres. However, they did not differ significantly (P>0.05) from those grown on unamended and uninoculated soils (Table 4.10). Moreover, plants grown on Tres and Trej had roots that were stunted (Plate IX).

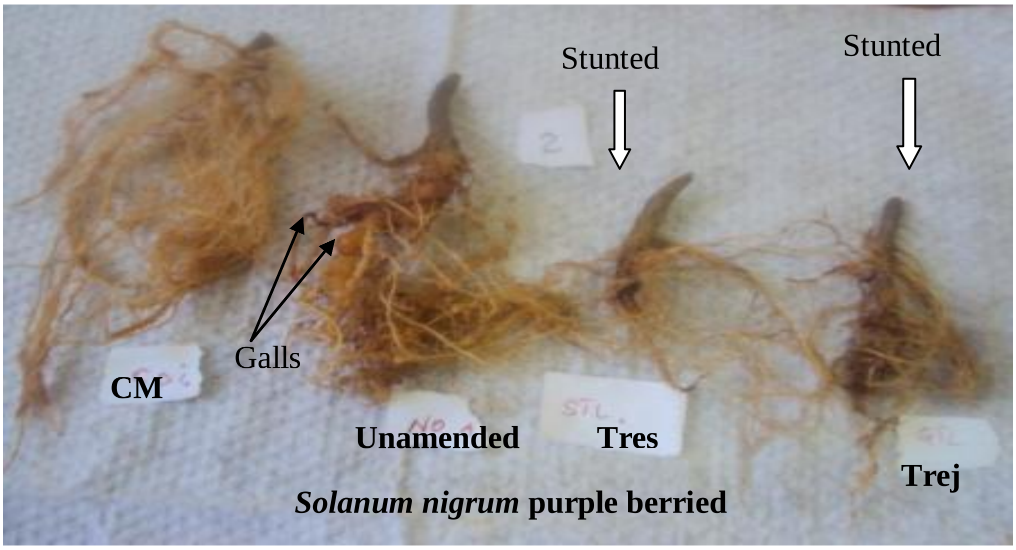

Plate IX: Comparative effect of cattle manure (CM), unamended, Tres and Trej (L-R) amendments on *S. nigrum* purple berried FRW and RKN in greenhouse test 2.

Although plants grown on amended and uninoculated soils had FRW that were in most cases higher than those on amended and inoculated soils, those grown on GM and Td amended and inoculated soils were high. However, they were not significantly (P>0.05) high than that of amended and uninoculated soils (Table 4.10). Similarly, plants grown on unamended and inoculated soils had heavier roots that were not significantly different (P>0.05) from those of unamended and uninoculated soils (Table 4.10). Further analysis revealed a significant positive correlation relationship (r=0.397, P<0.05) between FRW and nematode galls (Figure 4.19).

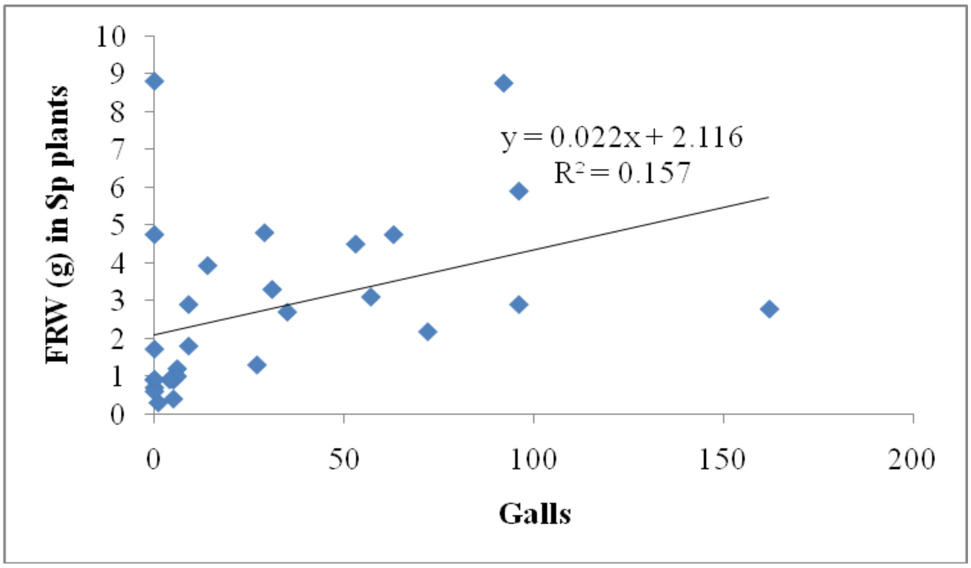

Figure 4.19: Relationship between fresh root weight and nematode galls on *Solanum nigrum* purple berried plants in greenhouse test 2.

There was no significant difference (P>0.05) on FRW of Sng plants on amended and inoculated soils (Table 4.10). Except for Trej, all the other OAs on inoculated soils had higher FRW that did not differ significantly (P>0.05) from that on unamended and inoculated soils (Table 4.10). The highest FRW were found on Td, followed by GM, CM and Tres, while Trej had low FRW compared to unamended and inoculated soils though they did not differ significantly (Table 4.10). Tea reject had low FRW that did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.10). On the other hand, a significant difference (P<0.05) was established among the amendments on Sng plants grown on amended and uninoculated soils (Table 4.10). *Tithonia diversifolia* had some of the high FRW than that of unamended and uninoculated plants (Table 4.10). Although GM, CM, Tres and Trej had high FRW, they did not differ significantly from those grown on unamended and uninoculated soils (Table 4.10). Generally, high FRW were found on amended and inoculated soils than amended and uninoculated soils except in Trej and Td that were lower than those of amended and uninoculated plants (Table 4.10). Plants grown on unamended and inoculated soils had high FRW that did not differ significantly (P>0.05) from unamended and uninoculated soils (Table 4.10).

The FRW of Ad plants grown on amended and inoculated soils did not differ significantly (P>0.05) among the amendments (Table 4.11). *Tithonia diversifolia* was the most effective amendment, followed by CM and Tres on increasing FRW of plants in amended and inoculated soils though they were not significantly higher than that of unamended and inoculated soils (Table 4.11). Goat manure and Trej had low FRW that did not differ significantly (P>0.05) from that of unamended and inoculated soils. The FRW of plants grown on amended and uninoculated soils did not differ significantly (P>0.05) among the amendments (Table 4.11). However, Ad plants grown on soils amended with Td and GM had high FRW though not significantly higher than that on unamended and uninoculated soil (Table 4.11). Although plants grown on CM, Tres and Trej amended and uninoculated soils had low FRW, they were not significantly lower than that of unamended and uninoculated soils (Table 4.11). Except for GM and unamended and uninoculated soils, all the other amendments on inoculated soil had high FRW that did not differ significantly (P>0.05) from those that were amended and uninoculated (Table 4.11).

A significant difference on the effect of OAs on FRW of Ah plants grown on inoculated soils was established (Table 4.11). The most effective amendment was Td that recorded heavier roots that did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.11). All the other amendments had lower FRW that differed significantly (P<0.05) from that of unamended and inoculated soils (Table 4.11). On the other hand, FRW of Ah plants grown on amended and uninoculated soil differed significantly (P<0.05) among the amendments (Table 4.11). Although all the amendments had low FRW, they did not differ significantly (P>0.05) from that of unamended and uninoculated soils (Table 4.11). Except for Tres and Trej amended and uninoculated soils, high FRW were found in amended and inoculated soils than that of amended and uninoculated soils (Table 4.11).

Amendment	Mean FRW (g) in Ad, Ah and To plants*					
	Ad+N	**Ad-N**	**Ah+N**	**Ah-N**	**To+N**	**To-N**
GM	0.74ab	1.13ab	1.55b	1.18b	1.66ab	2.08a
CM	2.31a	0.65ab	1.43b	1.3ab	4.07a	0.67ab
Trej	0.54ab	0.51b	0.633bc	0.68b	1.02ab	0.94ab
Tres	0.98ab	0.87ab	0.55bc	1.2ab	0.51ab	1.53ab
Td	2.82ab	1.45a	3.08a	2.2ab	3.8a	2.02a
Unamended	0.87ab	0.96ab	2.92a	2.3ab	0.88ab	2.0a
P-Value	0.391	0.160	0.000	0.025	0.194	0.131

Table 4.11: Effect of amendments on fresh root weight of indigenous leafy vegetables in the greenhouse test 2.

*Means followed by the same letter (s) are not significantly different (P>0.05).
Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, +N = inoculated with nematodes, -N = uninoculated, GM = goat manure, CM = cattle manure, Td = *Tithonia diversifolia*, Tres = tea residue, Trej = tea rejects, FRW = fresh root weight.

Although higher FRW were recorded in all the amendments in To plants, those grown on Tres amended and inoculated soils were lower though they did not differ significantly (P>0.05) from that of unamended and inoculated soils (Table 4.11). Heavier roots were found in plants grown on GM and Td amended and uninoculated soils compared to the unamended and uninoculated soils though there was no significant difference established (Table 4.11). The FRW of To plants grown on amended and uninoculated soils with CM, Trej and Tres were lower than that of unamended and uninoculated soils though they did not differ significantly (Table 4.11). Although To grown on amended and inoculated soil with CM, Trej and Td had higher FRW, they did not differ significantly from that of amended and uninoculated soils. Similarly, plants grown on amended and inoculated soils with GM, Tres and unamended inoculated soils had low FRW that did not differ significantly (P>0.05) from that of amended and uninoculated soils (Table 4.11).

4.5 Effect of organic amendments on plant growth and disease parameters in field test

4.5.1 Effect on galling index (GI) on indigenous leafy vegetables

The GI of Sng plants grown on amended soils without mocap, did not differ significantly (P>0.05) among the amendments. All the amendments had low GI that did not differ significantly (P>0.05) from that of unamended soils without mocap (Table 4.12). Although lower GI were recorded on Sng grown on amended soils with mocap, those grown on GM amended soils with mocap did not differ significantly from unamended soil with mocap (Table 4.12).

	Root-knot nematode GI in field test*									
Amendment	Sng-M	Sng+M	Svo-M	Svo+M	Ad - M	Ad + M	Ah - M	Ah + M	To - M	To + M
Td	2.0ab	1.3ab	0.8b	0.8b	1.8ab	1.0ab	0.8ab	1.0ab	2.5ab	1.7ab
Tres	1.5ab	1.0b	1.5ab	0.5b	1.8ab	0.8b	0.3b	0.3b	2.7ab	1.0b
CM	2.0ab	0.8b	2.0ab	1.5ab	1.5b	1.0ab	2.0a	0.8ab	2.0ab	1.8ab
Trej	2.3a	1.3ab	3.0a	2.8a	2.3ab	1.3ab	2.0a	1.3ab	1.5b	1.1b
GM	2.5a	1.5ab	3.0a	2.3ab	2.0ab	1.5ab	1.8ab	0.8ab	2.8ab	2.3ab
Unamended	3.3a	1.3ab	3.8a	0.5b	2.8a	2.4a	2.5a	2.0a	3.8a	3.3a
P-value	0.077	0.018	0.018	0.019	0.667	0.440	0.037	0.043	0.082	0.067

Table 4.12: Comparative efficacy of organic amendments and mocap on galling indices on indigenous leafy vegetables and tomato in the field test

*Means on the same column followed by the same letter (s) are not significantly different (P>0.05).
Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, +N = inoculated with nematodes, -N = uninoculated,
Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, GI = galling index.

The GI of Sng plants grown on Td, Tres and Trej was lower though not significantly ($P>0.05$) low than that of unamended soils with mocap. Although the GI of plants grown on GM amended soils with mocap was high, there was no significant difference established with that of unamended soils with mocap (Table 4.12). Generally, GI in Sng grown on amended soils without mocap was higher than that of plants grown on amended soils with mocap although there was no significant difference ($P>0.05$) established (Table 4.12).

The GI differed significantly ($P<0.05$) among the amendments in Svo plants grown on amended soils without mocap (Table 4.12). Significantly low GI was found in Td amended soils without mocap, followed by Tres, CM, Trej and GM that did not differ significantly ($P>0.05$) from unamended soils without mocap (Table 4.12). Similarly, GI of Svo plants grown on amended soils with mocap differed significantly among the amendments. Higher GI that did not differ significantly ($P>0.05$) from unamended soils with mocap were found in Td, Tres and CM. However, Tres and GM amended soils with mocap had significantly high GI than unamended soils with mocap (Table 4.12). Although Svo plants grown on amended soils without mocap had higher GI, they did not differ significantly ($P>0.05$) from that of amended soils with mocap. Plants on unamended soils without mocap had significantly high GI than that of unamended soils with mocap (Table 4.12).

The various treatments did not differ significantly ($P>0.05$) on their effect on GI on Ad (Table 4.12). Significantly ($P<0.05$) lower GI was found in Ad plants grown on GM amended soils without mocap compared with those grown on unamended soils without mocap (Table 4.12). All the other amendments though they had low GI did not differ significantly (P>0.05) from unamended soils without mocap (Table 4.12).

The GI on Ad plants grown on amended soils with mocap did not differ significantly (P>0.05) among the amendments. Soils amended with Tres had some of the low GI than those grown on unamended soils with mocap (Table 4.12). Although low GI was found in amended soils with mocap, they were not significantly low than those of unamended soils with mocap (Table 4.12). Plants grown on amended soils with mocap had lower GI than those amended without mocap though they did not differ significantly (P>0.05) although the interaction effect between mocap treated and those without mocap was not significant (P>0.05) as indicated on Appendix III.

A significant difference (P<0.05) on the effect of OA on GI was established on Ah grown on amended soils without mocap. Although lower GI was found in Ah plants grown on amended soils without mocap, only those grown on Tres were significantly lower than unamended soils without mocap. On the other hand, GI on plants grown on amended soils with mocap differed significantly (P<0.05) among the amendments (Table 4.12). Tea residue had low GI that differed significantly from that of plants grown on unamended soils with mocap. The other amendments had low GI that did not differ significantly (P>0.05) from plants grown on unamended soils with mocap (Table 4.12). On the other hand, GI on plants grown on amended soils without mocap was generally high than that of plants grown on amended soils with mocap although the interaction effect between mocap treated and those without mocap was not significant (P>0.05) as indicated on Appendix IV.

Galling indices of To plants grown on amended soils without mocap did not differ significantly (P>0.05) among the amendments (Table 4.12). Tomato grown on Tres amended soils without mocap had some of the low GI that differed significantly (P<0.05) from that of unamended soils without mocap (Table 4.12). Although lower GI was found in plants grown on amended soils with CM, GM, Tres and Td, they were not significantly low than that of unamended soils without mocap (Table 4.12). The GI of plants grown on amended soils with mocap did not differ significantly (P>0.05) among the amendments (Table 4.12). Tea residue and Trej had some of the low GI that were significantly (P<0.05) low than that of unamended soils with mocap (Table 4.12). Although Td, CM and GM had low GI, they were not significantly (P>0.05) low than that of unamended soils with mocap (Table 4.12). Generally, plants on amended soils without mocap had some of the high GI than those with mocap although they did not differ significantly (P>0.05).

4.5.2 Effect on reproduction factor (Rf) on indigenous leafy vegetables

There was a significant difference (P<0.05) established on nematode Rf among the OAs in Svo grown on amended soils without mocap (Figure 4.20). Significantly (P<0.05) lower Rf was found on Svo grown on amended soils without mocap compared with those grown in unamended soils without mocap.

Tea residue, Td and Trej had significantly low Rf, followed by GM and CM that were significantly lower than those in unamended soils without mocap (Figure 4.20). Similarly, Rf on Svo plants grown in amended soils with mocap varied significantly (P<0.05) with all amendments having significantly (P<0.05) low Rf than that of unamended soils with mocap (Figure 4.20). When comparing the effect of amendments, it was found that those grown in amended soils without mocap had generally high Rf than those in amended soils with mocap although they did not differ significantly (Figure 4.20).

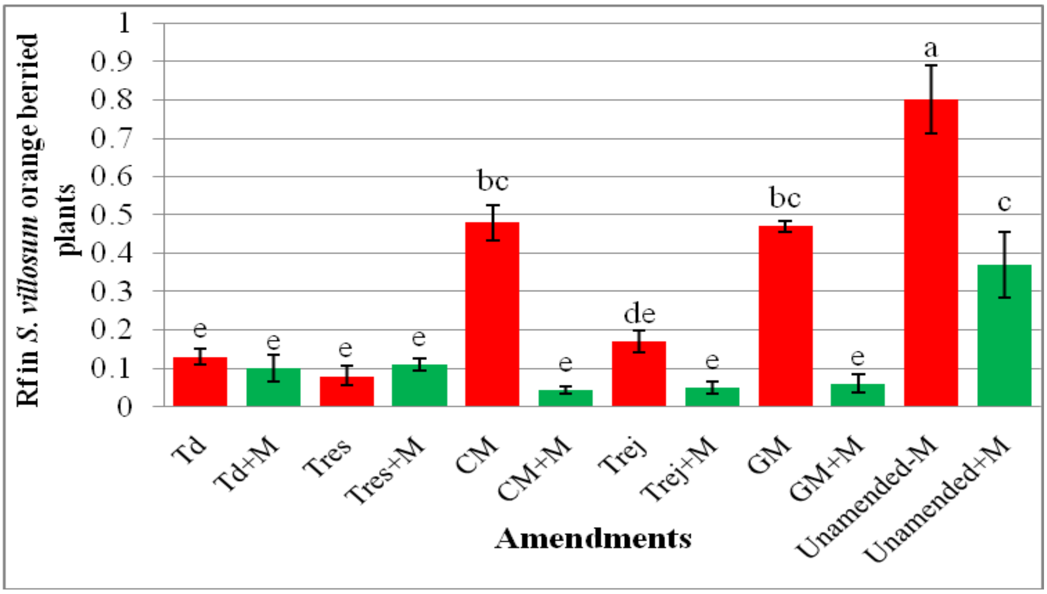

Figure 4.20: Comparative effect of amendments and mocap on nematode reproduction on *Solanum villosum* orange berried plants in field test.

Means followed by the same letter (s) are not significantly different (P>0.05). Svo = *Solanum villosum* orange berried, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, Rf = reproduction factor, -M = without mocap, +M = with mocap.

Generally, amended soils without mocap had high Rf than amended soils with mocap except for Tres. Reproductive factor on CM, GM and unamended soils with mocap differed significantly (P<0.05) from that of amended soils with mocap, while the other amendments did not differ significantly (P>0.05). On further analysis, a significant positive correlation (r=0.998, P<0.05) was established between Rf and J2 populations in Svo plants (Figure 4.21).

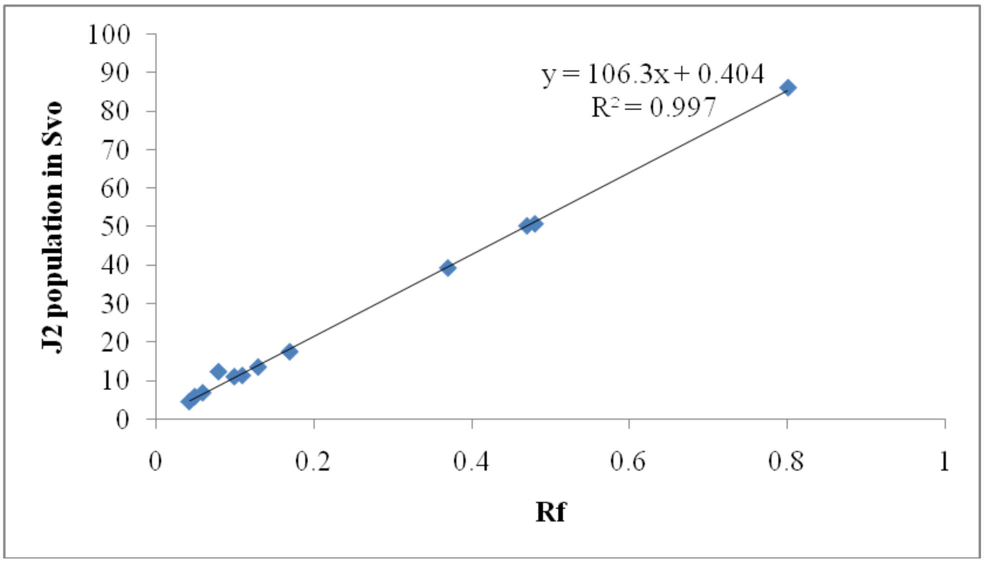

Figure 4.21: Relationship between reproduction factor and J2 population on *Solanum villosum* orange berried plants in field test.

Reproduction factor differed significantly (P<0.05) among the amendments in Sng plants grown in amended soils without mocap. *Tithonia diversifolia* and Trej had some of the Rf that were significantly (P<0.05) lower than that of unamended soils without mocap (Figure 4.22). Although Tres, CM and GM had low Rf than that of unamended soils without mocap, they did not differ significantly (P>0.05) from unamended soils without mocap (Figure 4.22).

On the other hand, Sng grown in amended soils with mocap had Rf that differed significantly (P<0.05) among the amendments. Significantly (P<0.05) low Rf than that of unamended soils with mocap were found in soils amended with Tres, CM and Trej, while Sng plants grown in Td and GM amended soils with mocap had Rf that were low though not significantly low than that of unamended plants with mocap (Figure 4.22).

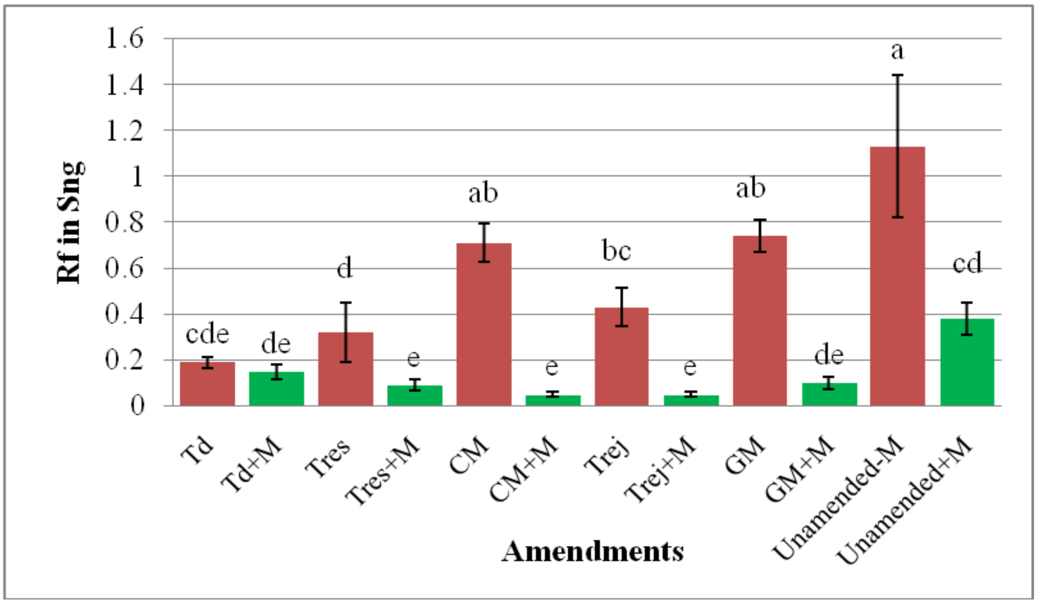

Figure 4.22: Comparative efficacy of amendments and mocap on reproduction factor on *Solanum nigrum* green berried plants in field test.

Means followed by the same letter (s) are not significantly different (P>0.05).
Sng = *Solanum nigrum* green berried, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, Rf = reproduction factor, -M = without mocap, +M = with mocap.

Significantly high Rf in Sng was found in amended soils without mocap than that of amended soils with mocap, except for soils amended with Td. On further analysis, a significant positive correlation (r=0.999, P<0.05) was estblished between the Rf and J2 population in Sng plants (Figure 4.23).

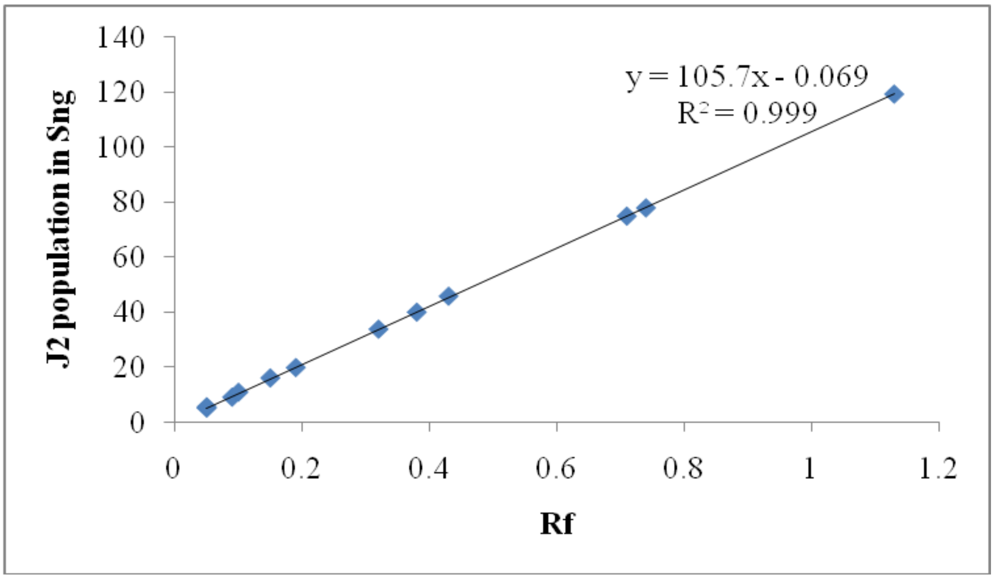

Figure 4.23: Relationship between reproduction factor and J2 population on *Solanum nigrum* green berried plants in field test.

Amaranthus dubius grown on amended soils without mocap had Rf that differed significantly among the amendments with all the OAs having significantly (P<0.05) low Rf than that of unamended soils without mocap (Table 4.13). Similarly, Rf differed significantly (P<0.05) among the OAs in Ad plants grown on amended soils with mocap. Cattle manure, Tres, Trej and Td had some of the low Rf that differed significantly (P<0.05) from that of unamended soils with mocap, while GM had low Rf that did not differ significantly (P>0.05) from that of unamended soils with mocap (Table 4.13). Although amended soils without mocap had high Rf, they did not differ significantly (P>0.05) from that of plants grown on amended soils with mocap. However, unamended soils without mocap had significantly (P<0.05) high Rf than that of unamended soils without mocap (Table 4.13).

Amendment	Root-knot nematode reproduction factor (Rf) *					
	Ad-M	Ad+M	Ah-M	Ah+M	To-M	To+M
Td	0.16 cd	0.12d	0.09c	0.07c	0.22bcd	0.2bcd
Tres	0.11d	0.09d	0.13c	0.06c	0.16cd	0.07d
CM	0.21bcd	0.07d	0.19bc	0.05c	0.34b	0.10c
Trej	0.14cd	0.016d	0.10c	0.03c	0.30bc	0.13cd
GM	0.29b	0.08cd	0.16bc	0.05c	0.40b	0.06d
Unamended-M	0.53a	0.24bc	0.91a	0.22bc	1.06a	0.14cd
P-value	0.001	0.001	0.001	0.146	0.000	0.171

Table 4.13: Comparative efficacy of amendments and mocap on nematode reproduction on indigenous leafy vegetables and tomato in field test.

*Means on the same column followed by the same letter (s) are not significantly different (P>0.05).
Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, -M = without mocap, +M = with mocap, Td = *Tithonia diversifolia,* Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, Rf = reproduction factor.

The OAs differed significantly (P<0.05) on their effect on Rf in Ah plants grown on amended soils without mocap (Table 4.13). All the amendments had significantly (P<0.05) low Rf with Td, Trej and Tres having the lowest, followed by GM and CM than that of unamended soils without mocap (Table 4.13). On the other hand, Rf in Ah plants grown on amended soils with mocap did not differ significantly (P>0.05). Although there was low Rf in amended soils with mocap, they were not significantly (P>0.05) low than that of unamended soils with mocap (Table 4.13). Amended soils without mocap were having high Rf than those with mocap although only that of unamended soils without mocap differed significantly (P<0.05) from the unamended soils with mocap (Table 4.13).

There was a significant difference ($P<0.05$) in Rf among the OAs in To plants grown on amended soils without mocap, with all the amendments having low Rf than unamended soils without mocap (Table 4.13). Amended soils without mocap had Rf that did not differ significantly ($P>0.05$) among the amendments. Soils amended with GM, Tres, CM and Trej were having some of the lowest Rf that did not differ significantly ($P>0.05$) from that of unamended soils with mocap (Table 4.13). However, Td had some of the high Rf that did not differ significantly ($P>0.05$) from that of unamended soils with mocap (Table 4.13). Although amended soils without mocap had high Rf, they were not significantly high than that of amended soils with mocap. However, To plants grown on CM and unamended soils without mocap were having significantly high ($P<0.05$) Rf than those grown on CM and unamended soils with mocap (Table 4.13).

4.5.3 Effect on J2 population

The J2 population was significantly reduced ($P<0.05$) by the various OAs as indicated in Figure 4.24. In Svo, significantly ($P<0.05$) low J2 population was found in all the amended soils without mocap with Td, Tres and Trej having the lowest J2 population, followed by CM and GM with significantly ($P<0.05$) low J2 population than that of unamended soils without mocap (Figure 4.24). On the other hand, the J2 population differed significantly ($P<0.05$) among the amendments in amended soils with mocap (Figure 4.24). All the amendments suppressed J2 population significantly ($P<0.05$) in amended soils with mocap with Trej, CM and GM having the lowest J2 population, followed by Tres and Td than that of unamended soils with mocap (Figure 4.24). Although amended soils without mocap had high J2 population than that of amended soils with mocap, they did not differ significantly except in CM, GM and unamended soils without mocap (Figure 4.24).

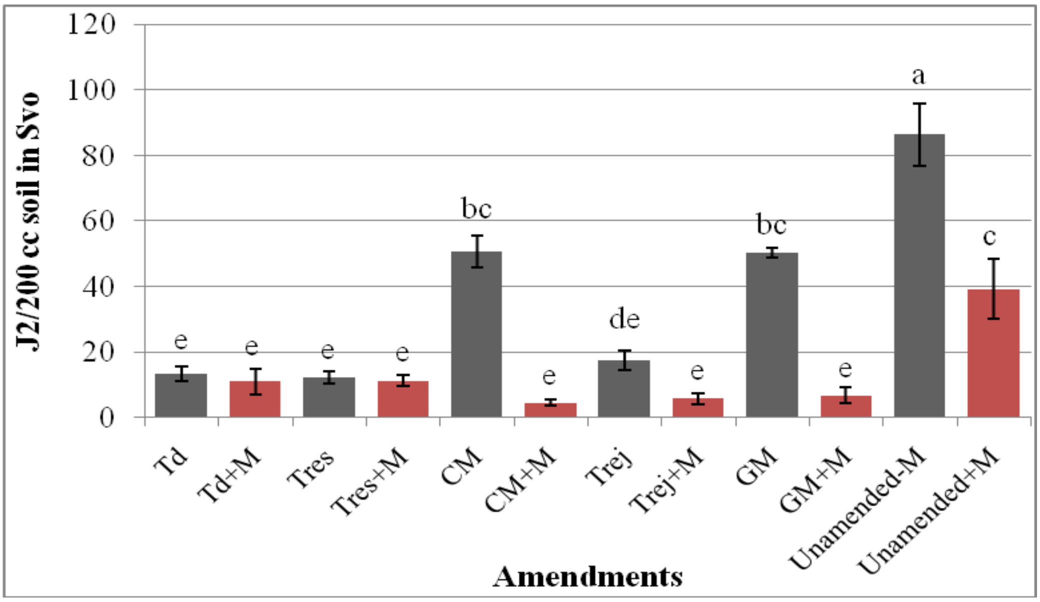

Figure 4.24: Efficacy of amendments and mocap on J2 populations of *Solanum villosum* orange berried plants in the field test.

Means followed by the same letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, -M = without mocap, +M = with mocap.

The various OAs differed significantly (P<0.05) in suppressing J2 population in Sng grown on amended soils without mocap (Figure 4.25). The J2 population was significantly (P<0.05) lower in the soils amended with Td, Tres, Trej, CM and GM but without mocap, than that of unamended soils without mocap (Figure 4.25). On the other hand, all the amended soils with mocap had significantly lower J2 population than that of unamended soil with mocap in Sng plants (Figure 4.25). Tea rejects, CM and Tres were more suppressive to J2 population than unamended soils with mocap.

Amended soils with mocap had significantly lower J2 populations than that of amended soils without mocap.

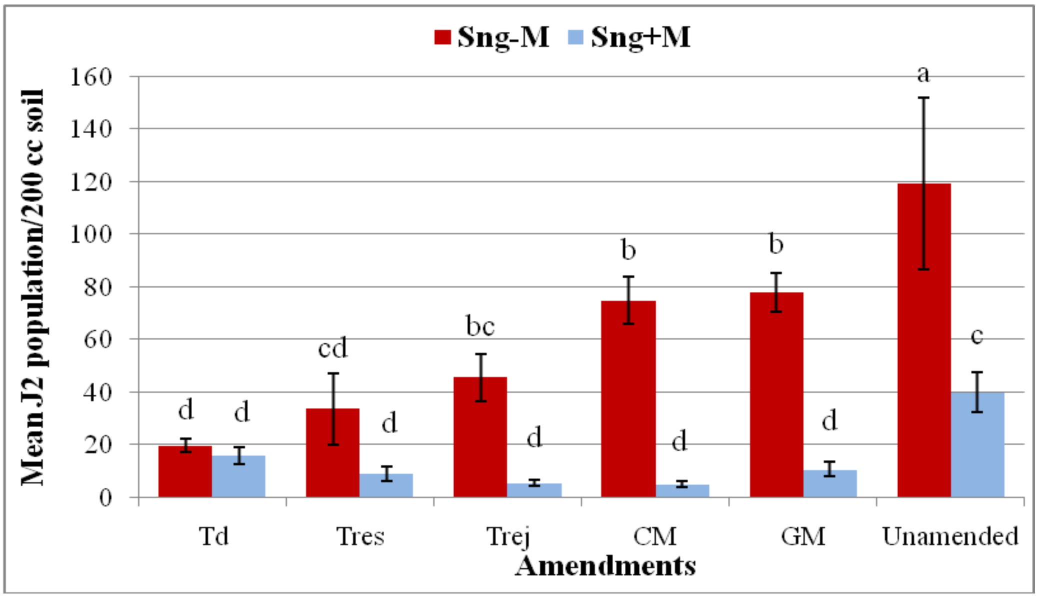

Figure 4.25: Efficacy of amendments on J2 populations on *Solanum nigrum* green berried plants in the field test.

Data are Means ± SE in Sng from field test.
Means followed by the same letter (s) are not significantly different (P>0.05).
Sng = *Solanum nigrum* green berried, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, -M = without mocap, +M = with mocap.

Similarly, unamended soils without mocap recorded significantly high J2 population than that of unamended soils with mocap (Figure 4.25). Further analysis revealed a positive correlation (r=0.312, P>0.05) between the GI and J2 population although there was no significant difference established (Figure 4.26).

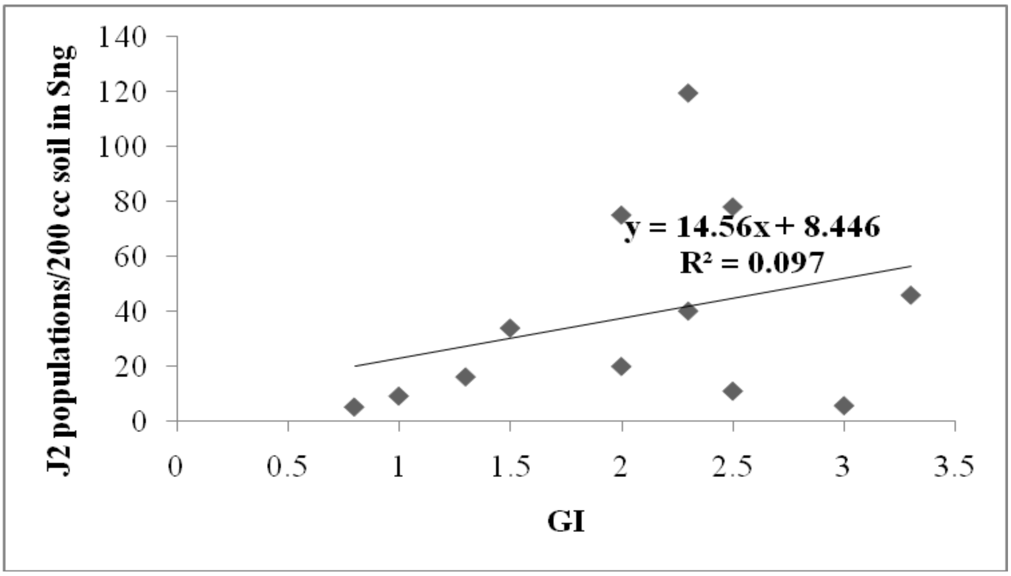

Figure 4.26: Relationship between galling index and J2 population in *Solanum nigrum* green berried plants in the field test.

The J2 population differed significantly (P<0.05) among the amendments in amended soils without mocap in Ad plants (Table 4.14). All the amended soils without mocap had lower J2 population with Tres and Trej having the lowest J2s, followed by Td, CM and GM compared to unamended soils without mocap (Table 4.14).

Amended soils with mocap differed significantly (P<0.05) on their effect on J2 populations in Ad plants (Table 4.14). All the amendments with mocap, had lower J2 populations that differed significantly (P<0.05) from that of unamended soils with mocap (Table 4.14). Soils amended with CM, Trej, GM and Tres were more suppressive to J2 population followed by Td amended soils with mocap. Although the J2 of amended soils without mocap did not differ significantly from that of amended soils with mocap, those amended with GM as well as those that were unamended without mocap had significantly (P<0.05) high J2 populations (Table 4.14).

	Mean J2 population/200 cc soil*					
Amendment	Ad-M	Ad+M	Ah-M	Ah+M	To-M	To+M
Td	16.8bc	13.0c	10.0c	7.8c	23.3cd	20.8cd
Tres	11.3c	9.5c	13.5bc	6.3c	17.0cd	7.8d
CM	22.5bc	7.3c	20.3bc	4.8c	35.5c	10.8cd
Trej	14.8bc	6.5c	10.3bc	2.8c	31.5bc	14.3cd
GM	30.3b	8.8c	17.3bc	5.3c	42.8b	6.5d
Unamended	55.8a	25.3b	64.8a	22.8bc	112.5a	15.3cd
P-value	0.002	0.030	0.036	0.236	0.000	0.222

Table 4.14: Efficacy of amendmets and mocap on J2 population on amaranth and tomato in field test.

*Means on the same row followed by the same letter (s) are not significantly different (P>0.05).
Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, -M = without mocap, +M = with mocap, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure.

There was a significant difference (P<0.05) established among the J2 population in Ah grown on amended soils without mocap (Table 4.14). All the amendments had significantly low J2 populations than that of unamended soils without mocap (Table 4.14). On the other hand, there was no significant difference (P>0.05) established among the amendments on J2 population of Ah plants grown on amended soils with mocap. However, amended plants had lower J2 populations that did not differ significantly (P>0.05) from that of unamended soils with mocap (Table 4.14). Plants grown on amended soils without mocap had high J2 populations that did not differ significantly from those on amended soils with mocap. Unamended soils without mocap had significantly higher J2 population than that of unamended soils with mocap (Table 4.14).

The J2 populations in To plants grown on amended soils without mocap differed significantly ($P<0.05$) among the amendments (Table 4.14). All the amended soils without mocap had lower J2 populations that differed significantly ($P<0.05$) from that of unamended soils without mocap (Table 4.14). On the other hand, J2 populations in amended soils with mocap did not differ significantly among the amendments (Table 4.14). Except for soils amended with Td, all the other amendments had lower J2 populations than that of unamended soils with mocap in To plants. Soils amended with Tres, GM and CM had some of the low J2 populations that did not differ significantly from unamended soils with mocap (Table 4.14).

Generally, To grown on amended soils without mocap had higher J2 populations that did not differ significantly from that of amended soils with mocap, except for GM amended soils without mocap that differed significantly. Similarly, unamended soils without mocap had some of the high J2 populations that differed significantly ($P<0.05$) from that of unamended soils with mocap (Table 4.14).

4.5.4 Effect on indigenous leafy vegetable growth parameters

4.5.4.1 Effect on shoot height

The treatments differed significantly ($P<0.05$) on their effect on Sng shoot height (Figure 4.27). Significantly ($P<0.05$) taller shoots were found in Td, Tres, CM and Trej compared to unamended soils without mocap (Figure 4.27). Although GM had higher SH than unamended plants without mocap, they were not significantly ($P>0.05$) higher (Figure 4.27).

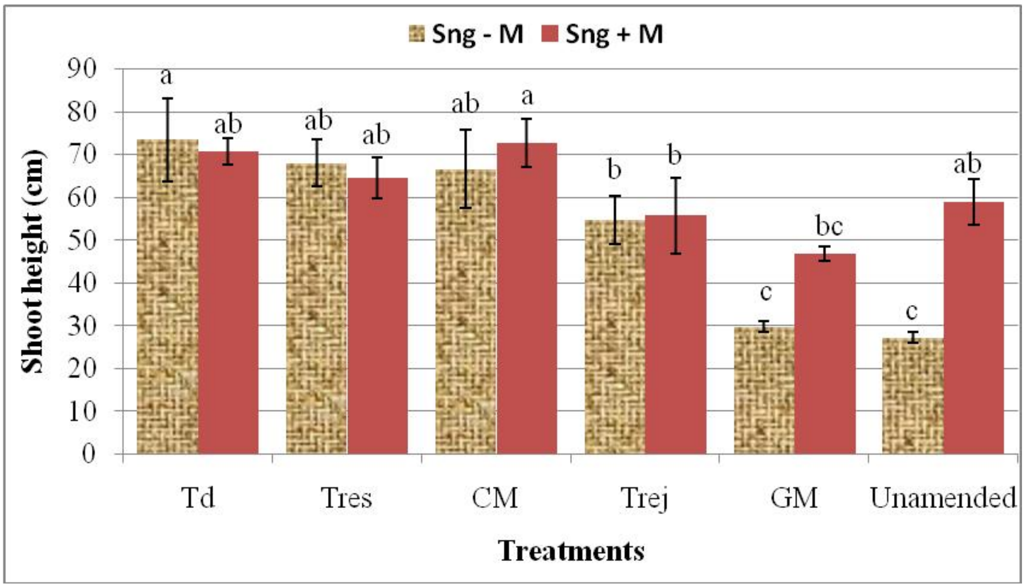

Figure 4.27: Efficacy of amendmets and Mocap on shoot height of *Solanum nigrum* green berried plants in the field test.

Data are Means ± SE in Sng from field test.
Bars followed by similar letter (s) are not significantly different (P>0.05).
Sng = *Solanum nigrum* green berried, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, -M = without mocap, +M = with mocap.

Although CM, Td and Tres had the highest SH than unamended plants with mocap, they did not differ significantly (Figure 4.27). However, the treatments differed (P<0.05) significantly on soils with mocap (Figure 4.27). The SH were lower in Trej and GM amended soils than unamended soils with mocap although they were not significantly lower (Figure 4.27). High SH were found in unamended soils with mocap than unamended soils without mocap (Figure 4.27). Taller shoots were found in amended plants with mocap compared to amended plants without mocap except for Td and Tres amended plants without mocap that had higher SH that did not differ significantly (Figure 4.27).

The various OAs differed significantly ($P>0.05$) on their effect on SH in Svo plants (Table 4.15). All the amendments without mocap had higher SH than unamended plants without mocap (Table 4.15). *Tithonia diversifolia* and Tres were having the tallest shoots that differed significantly ($P<0.05$) from unamended plants without mocap (Table 4.15). Although CM, Trej and GM were having higher SH, they were not significantly ($P>0.05$) higher than those of unamended plants without mocap (Table 4.15).

The treatments did not differ significantly ($P>0.05$) in amended plants with mocap (Table 4.15). Although Td, Tres, Trej and GM were having higher SH, they were not significantly ($P>0.05$) higher than those of unamended plants with mocap (Table 4.15). Cattle manure had lower SH that did not differ significantly ($P>0.05$) from unamended plants with mocap (Table 4.15). Except for CM, all amendments with mocap had higher SH that were not significantly ($P>0.05$) higher than those of amended plants without mocap (Table 4.15).

In Ad plants, the various OAs on soils without mocap differed significantly ($P<0.05$) with Td having significantly ($P<0.05$) higher SH, followed by Tres, GM, CM and Trej compared to unamended soils without mocap (Table 4.15). The OAs did not differ significantly ($P>0.05$) on their effect on SH in amended soils with mocap. Although CM amended soils with mocap had taller shoots that did not differ significantly from those on unamended soils with mocap, all the other amendments had lower SH that were not significantly ($P>0.05$) lower than unamended soils with mocap (Table 4.15). All amendments, except CM and GM on soils without mocap had taller shoots that did not differ significantly ($P>0.05$) from those on amended soils with mocap. Plants on unamended soils with mocap were significantly ($P<0.05$) taller than those amended without mocap (Table 4.15).

The SH differed significantly ($P<0.05$) among the amendments in Ah plants grown on amended soils without mocap (Table 4.15). Cattle manure, Trej, Tres and Td had some of the tallest shoots that were not significantly ($P>0.05$) taller than that of unamended soils without mocap (Table 4.15). Goat manure had lower SH that did not differ significantly ($P>0.05$) from Ah on unamended soils without mocap (Table 4.15). On the other hand, SH differed significantly ($P<0.05$) in Ah on amended soils with mocap, with GM, CM and Td having the tallest shoots, followed by Tres and Trej that were significantly taller than that of Ah on unamended soils with mocap (Table 4.15).

Although Ah grown on amended soils with mocap had higher SH, they did not differ significantly ($P>0.05$) from that of plants on amended soils without mocap except for GM (Table 4.15). Plants grown on unamended soils without mocap had high SH that did not differ significantly ($P>0.05$) from those in unamended soils with mocap (Table 4.15).

The SH of To plants grown in amended soils without mocap differed significantly ($P<0.05$) among the amendments (Table 4.15). Generally, all the amendments had significantly taller shoots, with CM having the tallest shoots, followed by Td, Tres, Trej and GM compared with unamended plants without mocap (Table 4.15). The SH of To grown on amended soils with mocap differed significantly ($P<0.05$) among the amendments. Goat manure and CM had some of the tallest shoots that differed significantly ($P<0.05$) from those grown on unamended soils with mocap (Table 4.15). Although Td, Tres and Trej had high SH, they were not significantly ($P>0.05$) high than that on unamended soils with mocap (Table 4.15). Tomato grown on unamended soils without mocap had significantly ($P<0.05$) lower SH than that grown on unamended soils with mocap.

	Mean shoot height (cm) of ILVs and tomato in the field test							
	Svo		Ad		Ah		To	
Amendment	-M	+M	-M	+M	-M	+M	-M	+M
Td	69.6a	76.0a	205.8a	196.4a	156.6bc	181.8ab	181.8b	182.0ab
Tres	65.0a	69.8a	192.2a	190.0a	162.2b	164.6b	167.6b	172.4b
CM	60.6ab	50.8ab	188.4a	203.0a	182.6ab	202.8a	203.0a	202.0a
Trej	55.3ab	67.8a	186.6a	177.6ab	166.4b	166.7b	166.4ab	166.7ab
GM	36.1b	54.5ab	191.9a	195.2a	122.7c	206.1a	160.4b	204.8a
Unamended	34.2b	53.2ab	144.2b	200.8a	133.4bc	120.2c	116.6c	158.6b
P-value	0.042	0.120	0.001	0.496	0.018	0.000	0.000	0.017

Table 4.15: Comparative efficacy of organic amendments and Mocap (M) on shoot height on indigenous leafy vegetables and tomato in field test*.

*Means on the same column followed by similar letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, -M = without mocap, +M = with mocap.

4.5.4.2 Effect on Fresh shoot weight

The FSW of Sng grown on amended soils without mocap differed significantly among the amendments with Tres and Trej having some of the highest FSW that were significantly ($P<0.05$) higher than that of unamended soil without mocap. Although Td, CM and GM had higher FSW, they were not significantly ($P>0.05$) higher than that on unamended soil without mocap (Table 4.16).

The FSW of Sng grown on amended soils with mocap did not differ significantly ($P>0.05$) among the amendments (Table 4.16). Generally, Tres and Trej had heavier shoots that did not differ significantly ($P>0.05$) from that of unamended soil with mocap. The FSW in Td, CM and GM were lower than those on unamended soils with mocap although they were not significantly different ($P>0.05$). The FSW on Tres amended soils without mocap were significantly higher than those on Tres with mocap.

On the other hand, Sng plants amended with Trej without mocap had higher FSW that did not differ significantly from that with mocap (Table 4.16). However, all the other amendments with mocap had higher FSW that did not differ significantly from those on amended soils without mocap (Table 4.16). Plants grown on unamended soil with mocap had higher FSW that did not differ significantlt ($P>0.05$) from those on unamended soil without mocap as depicted in Table 4.16. Correlation analysis revealed a significant negative relationship ($r=-0.343$, $P<0.05$) between the FSW of Sng with J2 population (Figure 4.28).

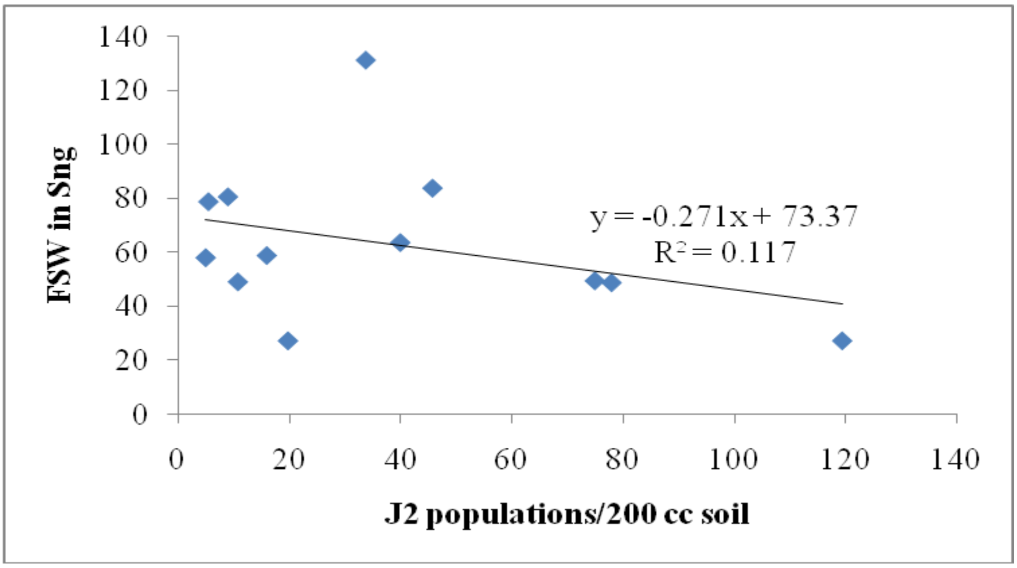

Figure 4.28: Relationship between J2 and fresh shoot weight on *Solanum nigrum* green berried plants in the field test.

Fresh shoot weight of amended Svo without mocap differed significantly ($P<0.05$) among the amendments (Table 4.16). All the amendments without mocap had generally heavier shoots with GM and CM having the highest, followed by Tres, Trej and Td that differed significantly from unamended plants without mocap (Table 4.16).

Although the FSW of Svo plants in amended soils with mocap differed significantly ($P<0.05$) among the amendments, the FSW did not in most cases differ significantly ($P>0.05$) from unamended plants with mocap (Table 4.16). The FSW of plants in amended soil without mocap did not differ significantly from those on amended soil with mocap. Moreover, FSW in amended soil with mocap were generally higher than those of amended soil without mocap except for Trej (Table 4.16). Unamended soil with mocap had significantly ($P<0.05$) heavier FSW than that of unamended soil without mocap (Table 4.16).

Amendment	Sng		Svo		Ad		Ah		To	
	-M	+M	-M	+M	-M	+M	-M	+M	-M	+M
Td	57.1c	58.8bc	72.9b	77.5ab	893.0b	993.0abc	635.4ab	679.8b	365.3a	414.5a
Tres	131.4a	80.6b	81.3ab	83.1ab	777.5bc	709.7c	634.0ab	660.2b	314.5ab	314.5ab
CM	49.4bc	58.0bc	97.2ab	106.3a	1173.8a	1200.0a	443.4bc	908.3a	336.1ab	426.8a
Trej	83.8b	78.8b	79.5ab	59.0b	1098.3ab	1109.5ab	524.3bc	484.9bc	315.9ab	303.4b
GM	48.7bc	49.0bc	106.0a	107.7a	1036.0ab	1053.9ab	693.3a	710.9ab	386.5a	392.0ab
Unamended	27.1c	63.6bc	11.4c	85.1ab	757.2bc	801.3bc	213.5cd	494.2bc	246.8bc	302.4b
P-value	0.000	0.063	0.000	0.015	0.029	0.000	0.000	0.000	0.020	0.023

Table 4.16: Comparative efficacy of organic amendments and Mocap (M) on fresh shoot weight of indigenous leafy vegetables and tomato in field test.

*Means on the same column followed by similar letter (s) are not significantly different (P>0.05).
Svo = *Solanum villosum* orange berried, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, -M = without mocap, +M = with mocap.

A significant difference (P<0.05) was established among the FSW in Ad plants on amended soil without mocap (Table 4.16). Of the amendments, CM had significantly higher FSW than Ad plants on unamended soil without mocap. All the other amendments though they had higher FSW, did not differ significantly from that of plants on unamended soil without mocap (Table 4.16).

The FSW differed significantly (P<0.05) among the amendments in Ad grown on amended soils with mocap (Table 4.16). Cattle manure had some of the highest FSW that differed significantly (P<0.05) from that of plants on unamended soils with mocap (Table 4.16). Although Trej, GM, Td and Tres had some of the heavier shoots, they were not significantly (P>0.05) heavier than that of plants on unamended soils with mocap (Table 4.16). Plants grown on soils with mocap and those without mocap did not in most cases differ significantly (P>0.05) although those on amended soils with mocap except in Tres were generally heavier (Table 4.16).

The FSW of Ah grown on amended soils without mocap differed significantly (P<0.05) among the amendments (Table 4.16). Goat manure, Td and Tres had some of the highest FSW that were significantly (P<0.05) heavier than that grown on unamended soils with mocap (Table 4.16). Although FSW in Trej and CM were higher they did not differ significantly (P>0.05) from unamended soils with mocap (Table 4.16).

A significant difference (P<0.05) was established among amendments in Ah grown on amended soils with mocap (Table 4.16). Cattle manure had the heaviest shoots that differed significantly (P<0.05) from that of plants grown on unamended soils with mocap (Table 4.16). The FSW of the other amendments were higher though they did not differ significantly (P>0.05) from that of Ah grown on unamended soils with mocap (Table 4.16). Except for soils amended with CM, FSW in other amendments in soils with mocap did not differ significantly (P>0.05) from that of Ah grown on amended soils without mocap (Table 4.16). Although FSW of Ah grown on unamended soils without mocap were negatively correlated to J2 population (r= -0.160, P>0.05), there was no significant difference established (Figure 4.29).

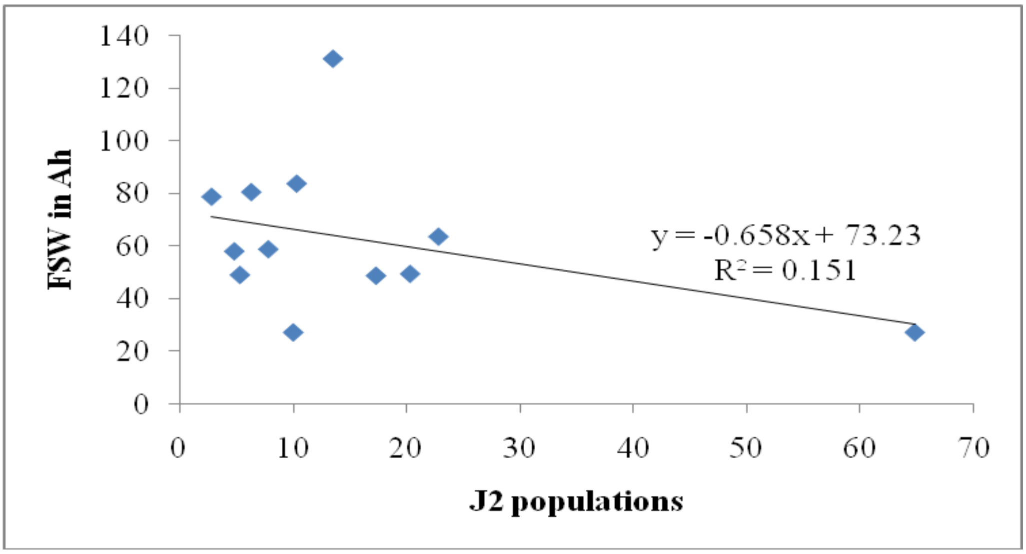

Figure 4.29: Relationship between J2 population and fresh shoot weight on *Amaranthus hypochondriacus*.

Although a significant difference (P<0.05) was established among FSW of To grown on amended soils without mocap, those grown on unamended soils without mocap did not differ significantly (Table 4.16). On the other hand, FSW on amended soils with mocap differed significantly (P<0.05) among the amendments with CM and Td having significantly (P<0.05) higher FSW than unamended To with mocap (Table 4.16). Although, the FSW of GM, Tres and Trej was high, it did not differ significantly from that of unamended soils with mocap (Table 4.16). Except for To grown in Trej, those grown on amended soils with mocap had heavier shoots, that did not differ significantly ($P>0.05$) from those of amended soils without mocap (Table 4.16).

4.5.4.3 Effect on fresh root weight

Fresh root weight of Sng grown on amended soils without mocap did not differ significantly ($P>0.05$) among the various OAs (Table 4.17). Although Tres, Trej, GM, CM and Td had some of the heaviest roots, they did not differ significantly ($P>0.05$) from unamended soils without mocap (Table 4.17). On the other hand, FRW of Sng grown on amended soils with mocap did not differ significantly ($P>0.05$) among the treatments. Tea residue had some of the high FRW that did not differ significantly ($P>0.05$) from that of unamended soils with mocap (Table 4.17). The Sng grown on Trej, GM, CM and Td had lower FRW that did not differ significantly ($P>0.05$) from that of unamended soils with mocap (Table 4.17).

There was no significant difference ($P>0.05$) established between Sng grown in amended soils without mocap with those in amended soils with mocap. However, those grown on amended soils with mocap were heavier than those without mocap though not significantly different ($P>0.05$). Further analysis revealed a significant negative correlation ($r= -0.619$, $P<0.05$) between FRW and J2 population as depicted in Figure 4.30.

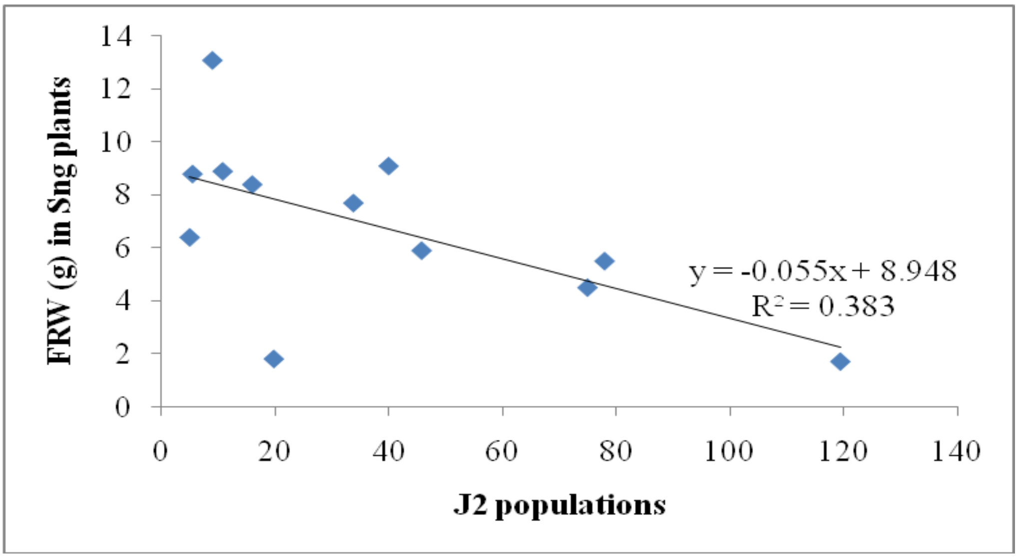

Figure 4.30: Relationship between fresh root weight of *Solanum nigrum* green berried plants and J2 population in the field test.

The FRW did not differ significantly (P>0.05) among the amendements in Svo plants grown on amended soils without mocap (Table 4.17). Cattle manure had some of the high FRW that were significantly heavier (P<0.05) than unamended soils without mocap (Table 4.17). Although Trej, GM, Td and Tres had some of the high FRW, they were not significantly (P>0.05) higher than that of unamended soils without mocap (Table 4.17).

Significantly (P<0.05) high FRW was established among the amendments on amended soils with mocap in Svo plants (Table 4.17). Tea rejects and Td had some of the high FRW that were significantly (P<0.05) heavier than unamended soils with mocap (Table 4.17). Although GM, Tres and CM had high FRW, they did not differ significantly from unamended soils with mocap (Table 4.17).

Amendment	Sng		Svo		Ad		Ah		To	
	-M	+M	-M	+M	-M	+M	-M	+M	-M	+M
Td	1.8b	8.4ab	7.0ab	5.7abc	172.2ab	165.7ab	119.3ab	172.0a	15.2bc	16.8ab
Tres	7.7ab	13.1a	6.2abc	9.4ab	164.4ab	204.5a	79.1b	79.6b	10.0c	10.5c
CM	4.5b	6.4ab	5.5abc	7.4ab	155.0ab	164.1ab	121.5ab	165.8a	18.9ab	21.8a
Trej	5.9ab	8.8ab	6.9abc	9.2a	135.7b	130.3b	73.4b	81.2b	12.7bc	13.5bc
GM	5.5ab	8.9ab	6.8abc	8.4ab	213.1a	124.2b	160.1ab	79.6b	18.6ab	15.0bc
Unamended	1.7b	9.1ab	2.3c	4.0bc	148.1ab	125.0b	175.1a	122.3ab	14.1bc	14.6bc
P-value	0.054	0.0718	0.124	0.048	0.02	0.176	0.043	0.095	0.002	0.06

Table 4.17: Comparative efficacy of organic amendments and Mocap (M) on fresh root weight on indigenous leafy vegetables and tomato in field test.

Means on the same column followed by similar letter (s) are not significantly different (P>0.05).
Sng = *Solanum nigrum* green berried, Svo = *Solanum villosum* orange berried, Ad = *Amaranthus dubius*, Ah = *A. hypochondriacus*, To = tomato, Td = *Tithonia diversifolia*, Tres = tea residue, CM = cattle manure, Trej = tea rejects, GM = goat manure, FRW = fresh root weight, -M = without mocap, +M = with mocap.

The FSW of Svo on amended soils with mocap were higher, though not significantly (P>0.05) higher than those on amended soils without mocap (Table 4.17). Further analysis revealed a significant negative relationship between FRW and J2 population (r= -0.625, P<0.05) as shown in Figure 4.31.

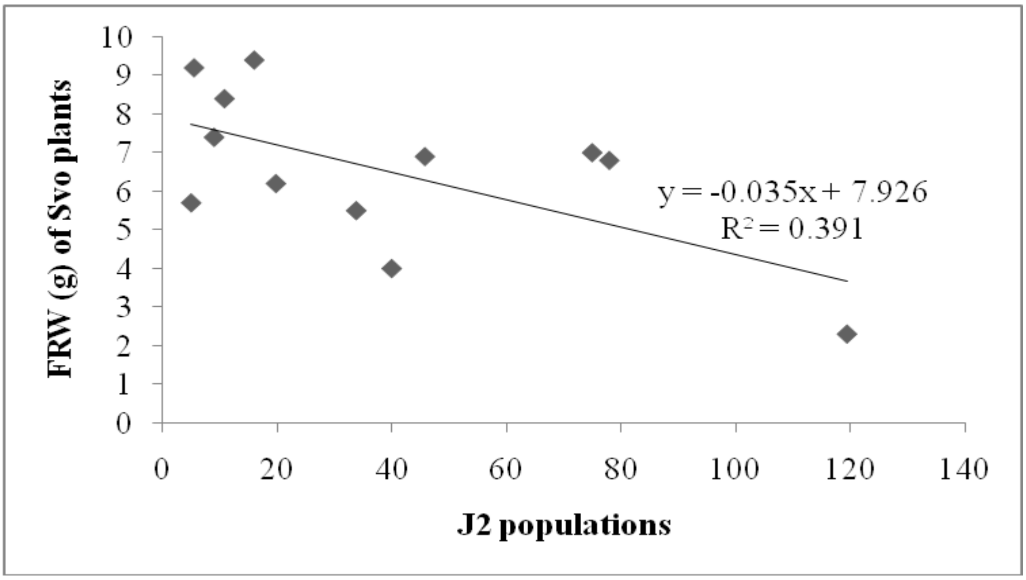

Figure 4.31: Relationship between fresh root weight and J2 population on *Solanum villosum* orange plants in the field test.

A significant difference (P<0.05) on FRW of Ad plants was established among the various OAs in amended soils without mocap (Table 4.17). The FRW of all OAs was generally higher though not significantly different from that of unamended soils without mocap (Table 4.17). In Ad grown on amended soils with mocap, FRW did not differ significantly (P>0.05) among the amendments. However, Tres had some of the highest FRW that differed significantly (P<0.05) from that in unamended soils with mocap (Table 4.17). All the other OAs except GM had higher FRW that did not differ significantly (P>0.05) from unamended soils with mocap (Table 4.17).

Amaranthus hypochondriacus grown on GM amended soils with mocap had lower FRW that were not significantly lower (P>0.05) than that of unamended soils with mocap (Table 4.17). The FRW in Ah plants on amended soils with mocap did not differ significantly (P>0.05) from that of amended soils without mocap except for GM. Although FRW on unamended soils without mocap were higher, they did not differ significantly (P>0.05) from plants on unamended soils with mocap (Table 4.17). A significant difference (P<0.05) on the effect of OAs on FRW of Ah grown on amended soils without mocap was established with all the amendments having lower FRW that did not differ significantly from that of unamended soils without mocap (Table 4.17).

The FRW on Tres and Trej amendments were significantly (P<0.05) lower than those on unamended soils without mocap (Table 4.17). Fresh root weight of Ah on amended soils with mocap did not differ significantly (P>0.05) among the amendments (Table 4.17). However, Td and CM had some of the highest FRW that were not significantly (P>0.05) higher than those of plants on unamended soils with mocap (Table 4.17). Although Tres, Trej and GM had lower FRW, they were not significantly (P>0.05) lower than that of unamended soils with mocap (Table 4.17). Although Ah plants on amended soils with mocap had high FRW than that on amended soils without mocap, those of GM and unamended soils with mocap were lower though they did not differ significantly (P>0.05).

The various OAs differed significantly (P<0.05) on their effect on FRW on To plants grown on amended soils without mocap (Table 4.17). Cattle manure, GM and Td had higher FRW that were not significantly (P>0.05) higher than that grown on unamended soils without mocap (Table 4.17). Those of Trej and Tres though lower than that grown on unamended soils without mocap, did not differ significantly (P>0.05). Similarly, FRW of To grown on amended soils with mocap did not differ significantly (P>0.05) among the OAs (Table 4.17). However, CM had significantly heavier roots than To on unamended soils with mocap, while those of Td and GM though they were high did not differ significantly (P>0.05) from that of unamended soils with mocap (Table 4.17). Although FRW on Tres and Trej were lower, they were not significantly (P>0.05) lower than that on unamended soils with mocap (Table 4.17). Except for GM, FRW of To on amended soils with mocap were generally high than that of amended soils without mocap, although they did not differ significantly (P>0.05). Further analysis revealed a positive correlation (r=0.094, P>0.05) between FRW of unamended To and J2 population though there was no significant difference established (Figure 4.32).

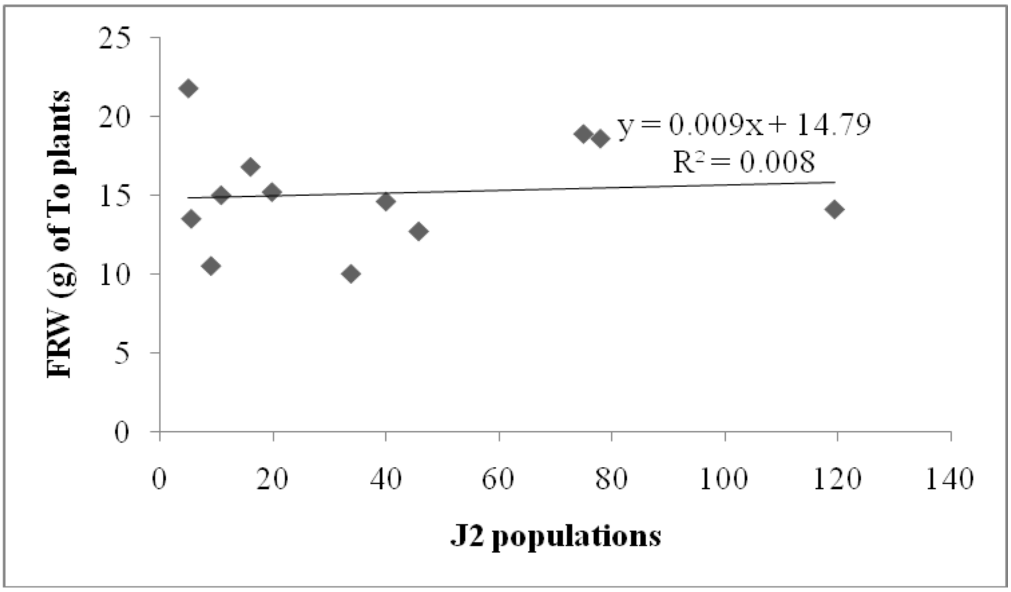

Figure 4.32: Relationship between fresh root weight and J2 population on check plant (To) in the field test.

CHAPTER FIVE

DISCUSSION

5.1 Cultivation of indigenous leafy vegetables in Kisii and Trans-Mara Counties

This study reports cultivation of different species of ILVs in the study area. Five species of black nightshades, four amaranth and two spider plants were cultivated. These ILVs were cultivated for subsistence in Kisii County while in Trans-Mara they were mainly for commercial purposes. Of the nightshades, the green berried species was the most preferred for subsistence and commercial cultivation as depicted by majority of the farmers cultivating it, followed by the purple berried. On the other hand, *C. gynandra* purple stemmed was the most preferred for cultivation probably due to its nutritional and agronomic advantages over *C. gynandra* green stemmed.

Amaranthus dubius was the most preferred species as depicted by high proportion of farmers cultivating it. Studies conducted in Western Kenya by Abukutsa-Onyango, (2002); Schippers, (2002) and Maundu *et al*., (1999a) also reported the cultivation of *C. gynandra*, *S. nigrum*, *S. villosum*, *A. cruentus*, *A. dubius*, *A. hypochondriacus*, *A. hybridus* and *A. blitum* in home gardens. This also concurs with earlier studies by Jaetzold and Schmidt, (1983) revealing the production of black nightshades and other leafy vegetables in the study areas.

Increased cultivation of the ILVs may also be attributed to increased demand of these vegetables in urban areas as well as increased awareness among the farmers of their nutritional and economic benefits (Ministry of Agriculture, 2007). Farmers apply DAP fertilizers and urea for production of the crops where ILVs were intercropped to optimize the economic gains. Atleast each of the farmers owned a cow, goat and chiken making animal manure available to most small scale farmers in the study areas. In Trans-Mara, ILVs were grown on cattle shed or farmers obtained manure from cattle shed and applied it on their farms. This may explain the large proportion of farmers applying cattle manure for cultivation of ILVs as monocrops. Availability of animal manure (cattle, goat or chicken manure) has been reported to contribute to increased vegetable production by farmers as nutrient sources. This concurs with the findings by Nchore *et al*., (2011; 2012) in a study on black nightshade cultivation in Kenya, reporting the use of locally available organic materials and agro-industrial wastes as nutrient sources for crop production and RKN disease control.

Decreasing farm acreage in Kisii county may have contributed to intercropping or continuous cultivation of black nightshade with the aim of optimizing the available piece of land. This may have led to a decline in ILV cultivation reported in Kisii.

5.2 Disease incidence and prevalence of root-knot nematodes on indigenous leafy vegetables in Kisii and Trans-Mara Counties

Root-knot nematode was found in all the ILVs sampled in both Kisii and Trans-Mara Counties. Highest RKN incidence occurred on Sng in Kisii relative to Trans-Mara, while *Amaranthus* and *Cleome* species, recorded lower RKN incidence. The black nightshades may be susceptible and good hosts of RKN. It has been reported to host RKN by Rogers and Ogg, (1981); Khurma *et al*., (2008); Kirby, (1977) and Orton-Williams (1980) in a study carried in Fiji. Naples, (2005) and Ateeq-ur-Rehman, (2009), reported occurrence of RKN in *Cleome* spp. and *Amaranthus* spp. However, these plants were found to have few and small galls. This reveals that black nightshades are susceptible to RKN infection, while *C. gynandra* are moderately resistant.

The tropical climatic and edaphic conditions in Kenya favour the build-up of RKN populations. The study areas falls within potential agricultural zones characterized with moderate rainfall and warm climate throughout the year (Jaetzold and Schmidt, 1983). The influence of climate on nematode infectivity has been reckoned by Anwar and McKenry, (2010) in Pakistan on a study on vegetables. These conditions are suitable for nematode multiplication in host plants throughout the year. Temperatures above the invasion threshold of 16 °C prevail throughout the year in the study areas (Jaetzold and Schmidt, 1983). The soil type in these areas is sand-loam and loams (Tables 3.1 and 3.2) a factor that may have increased nematode movement, rate of growth, reproduction and host suitability (Starr *et al.,* 1993; Ogbuji, 2004) hence high disease incidence.

During the survey, it was noted that farmers in Kisii and Trans-Mara do not follow distinct growing seasons in the cultivation of black nightshades and amaranths. The prevailing favourable climatic conditions support cultivation of these crops throughout the year (Jaetzold and Schmidt, 1983). It was also noted that a great number of farmers in Kisii were unaware of the use of nematicides as opposed to Trans-Mara. Moreover, lack of awareness among growers (Figure 4.4), inappropriate nematode control strategies and unintentional spread of RKN through sharing of seedlings and farm implements may have favoured the higher disease incidences observed in black nightshade. Similarly, a higher proportion of farmers could not identify RKN symptoms and its control. This findings concurs with those of Anwar and McKenry, (2010) in a study conducted in Pakistan on different vegetable varieties to determine incidence and reproduction of RKN revealing higher incidences due to lack of awareness, sharing of farm implements and seedlings. Khurma *et al*., (2008) made similar observation in Fiji that lack of awareness among farmers increased nematode infestation. Wallace, (1963) and Kimenju, *et al*., (2009) reported that crop varieties and cropping system greatly influenced the occurrence of PPN with poor farm management practices attributed to stimulate higher nematode infection.

Inadequate application of organic manure during ILV production may have led to poor and infertile soils that may have resulted to the high disease incidences reported herein. This may be attributed to low nitrogen, relatively high potassium and medium acidic soils in the study area (Tables 3.1 and 3.2). The most common organic manure applied by the farmers in study area was animal manure such as CM that has a low C: N ratio with slightly alkaline pH. Although CM is cheap, abundant and readily available in the study areas, only a small proportion of farmers in Kisii compared to Trans-Mara applied them for the cultivation of ILVs. The most effective amendment materials are those with low C: N ratio (Rodriguez-Kabana *et al*., 1984). It has been indicated that these materials effectively suppress PPN populations due to the production of Nematicidal ammonia, stimulation of antagonistic bacteria and actinomycetes that reduces the population of RKN in the soil (Gaur and Prasad, 1970; Vasalo, 1967).

A large proportion of farmers use DAP (60 %) and Urea (45 %) synthetic fertilizers in vegetable production irrespective of the availability of livestock manure. This practice may have led to slightly acidic soil pH condition observed in Kisii (Table 3.1). The acidic soil is attributed to ionizing free ammonia in water to ammonium ion which is not nematicidal (Oka *et al*., 2000). Synthetic fertilizers are also associated with increased pathogenic micro-organisms, decreasing beneficial micro-organism

(Bulluck *et al.*, 2002), as well as reduced plant resistance to insect pest attack (Yardım and Edwards 2003). Farms in Kisii where synthetic fertilizers were applied recorded high incidence of RKN relative to those from Trans-Mara where farmers used animal manure. This is supported by a study by Wang *et al.*, (2002), reporting build-up of nematode trapping fungi in soils amended with animal manure compared to inorganic fertilizer.

Mono-cropping and continuous cultivation of ILVs as well as intercropping them with susceptible crops like beans and tomatoes was commonly observed in Kisii compared to Trans-Mara. This may be attributed to decreasing farm acreage in Kisii than Trans-Mara resulting to build-up of RKN populations over time. As a result, it might have resulted to higher disease incidence in vegetable from Kisii than those from Trans-Mara. The findings by Sanchez *et al*., (1997) reckoned that agricultural practices may have positive or negative impacts on micro-organisms in the soil. The effect of mono-cropping with susceptible crops has been associated with an increase in *Meloidogyne* spp. infection (Ateeq-ur-Rehman, 2009). Gowen and Channer, (1988) reported that PPN can be a constraint in vegetable production in areas where there is mono-cultivation and succession with nematode susceptible crops and where nematode control strategies are currently inappropriate, uneconomical, ineffective and for low input farmers. This may pose a major hindrance to commercial and subsistence vegetable production of up to 80 % yield losses.

Farmers grow susceptible crop hosts prior to growing ILVs or intercropping ILVs with susceptible hosts (tomatoes, potatoes and beans) as well as mono-cropping and continuous cultivation. This may have led to high populations in the soils and hence high disease incidences. Where non-host crops were grown or virgin fields used (Trans-Mara), the incidence was low probably due to low populations of nematodes in the soil. Similar findings were reported by Jaiteh, (2010) that crop rotation with non-host plants led to reduced PPN populations by interrupting the spread, reproduction and survival in the soil.

The study revealed that 62.8 % of the farms surveyed were infected with RKN. It was noted that farms with black nightshades had higher disease prevalence (100.0 %) compared to those with spider plant (50.0 %) and *Amaranthus* (20.0 %) in both Counties. This may be attributed to high disease incidences recorded in black nightshades than the other ILVs. The higher disease prevalence in farms with black nightshades may have been due to differences in farm practices that may have led to different amount of nutrients that may have influenced RKN damage on the ILVs. Studies in Montenegro by Esfahani, (2009) and Pajovic *et al.*, (2007) reported the prevalence of RKN (*M. arenaria*) in *S. nigrum* similar to the findings of our study.

The prevalence of RKN was lower in vegetable gardens where animal manure was applied compared to those where it was not applied. A number of explanations could account for low prevalence of RKN in farms that are subject to regular use of organic and inorganic soil enhancement materials. Ateeq-ur-Rehman, (2009) reported that deficient quantities of organic matter in the soils was also important in increasing nematode attack. These OAs had varied effects on the soil ecosystems resulting to increased populations of beneficial micro-organism. It has been demonstrated that composted cattle manure reduced PPN population in tomato plants hence reducing the effects of these pests in tomatoes compared to the synthetic fertilizers thus making the soil healthy (Yardım and Edwards, 2003).

Those farms where organic manure was not added and continuous cropping practised had high galling indices than those where the farmers were reported to be using CM, grew ILVs on former cow sheds and or practised rotational cropping system in Kisii and Trans-Mara. This was as evidenced by severe root-galls associated with Sng grown on farms where farm yard or CM were not applied and continuous cultivation of Sng on the piece of land previously having the same crop. Conversely, low RKN damage was recorded on farms with high organic manure (cow sheds).

Organic amendments have beneficial effects on soil nutrients, soil physical conditions, soil biological activity and crop viability (Ibrahim *et al.*, 2007). The availability of relatively high levels of phosphorus, organic carbon, magnesium, nitrogen and low levels of potassium in the soil may have resulted to reduced infectivity of nematode pests in the soil (Tables 3.1 and 3.2). Akhtar and Malik, (2000) reported that organic manure in soil improves crop protection against PPN attack due to improved water holding capacity as well as increasing population of PPN antagonistic micro-organisms in soil. Otiefa, (1959) stated that RKN damage on vegetable increased with amounts of potassium available to the host plant because potassium increased the rate of reproduction of the nematode. Huber, (1980) reported a reduction in RKN damage on Lima bean with increased ammonium supplied to the plant. Nematode infection decreases with increased levels of nitrogen in the soil (Talwana *et al.*, 2008). Rodrỉguez-kåbana *et al.*, (1987) reported a significant reduction in RKN population with increased levels of nitrogen added to the soil through organic soil amendment.

Different developmental stages of the RKN were observed as a disease sign associated with root galling. Similarly, various stages of *Meloidogyne* were excised from roots indicating nematode infection and damage to the root system of these ILVs. The galls in black nightshade were abundant, irregularly shaped and often distorting the root system compared to spider plant and amaranth where they were small in size and often few in number. Moderate root-galls and galling indices occurred in Cgp while *Amaranthus* spp. had minimal values, although there was a relatively higher egg-mass/root system established than in Cgp. This may be attributed to variation in disease severity that may have negatively affected growth and development of the ILVs studied (Anwar and McKenry, 2010).

5.3 Response of indigenous leafy vegetables to root-knot nematodes in greenhouse test 1

There was considerable variation in response/levels of susceptibility of ILVs to *Meloidogyne* spp. infection among the selected ILVs that were screened. All ILVs varied greatly in their response to RKN from resistant to susceptible. All black nightshade were susceptible and good hosts to RKN infection although the level of susceptibility varied among them. Black nightshade green, purple and orange berried ILVs were generally susceptible to RKN attack compared to *Amaranthus* and *Cleome* varieties that were tolerant and moderately resistant.

Although this study reports that Ad was moderately resistant, it was found to support relatively high number of J2, galls and egg-masses. Comparatively, Ah and Cgp were found to be resistant (GI ranging from 0.5 − 1.0) against RKN while the rest were moderately resistant and susceptible. Although Ah and Cgp hosted RKN, there was no appreciable damage caused as depicted by the small and discrete galls on the root system. This is contrary to Sng, Svo and check plant that had numerous and conspicuous galls that were merged together forming a multiple galls. These may indicate that amaranths are poor hosts to RKN (Naples, 2005).

A study by Jaiteh, (2010) and Sajid *et al*., (2011) working with tomato genotypes in Ghana and Pakistan respectively reported variability in response to RKN that ranged from resistant to susceptible similar to the findings of our study. The variation in response may be attributed to differences in their susceptibility to nematodes (Castagnone-Sereno, 2006; Anwar and McKenry, 2010). Moreover, plants with resistance genes may have few and small galls, egg-masses and reduced reproduction as may have been the case of amaranths (Ateeq-ur-Rehman, 2009; Naples, 2005; Khurma *et al*., 2008; Castagnone-Sereno, 2006; Zarina and Shahid, 2002; Kelly O’Brien and Price, 1998; Heffes *et al*., 1991 and Hutton *et al*., 1983). In this study, there was more galls/root system on susceptible ILVs compared to the resistant ones. This observation is in line with that of Khan (1994), Mai and Abawi (1987) where susceptible varieties recorded higher RKN galling that destroyed root functioning.

The larger final populations on Sng, Svo, Snp than Ah, Ad, Cgp or Cgg crops can be partially explained by the host response to the nematode (Verma and Pandey, 1987). Solanaceae crops are susceptible to nematode damage than Amaranthaceae or Cleomaceae crops; therefore, they support higher nematode densities by allowing penetration, maturation and reproduction than resistant ILVs (Karssen and Moens, 2006). It was observed that amaranth and spider plants had lower egg-masses mainly on the fine root hairs and none on the main root system unlike Sng and Svo. Few galls on spider plant may be attributed the presence of insecticidal, anti-feedant and repellent characteristics in this ILV (Verma and Pandey, 1987).

Heavily infested plants showed stunted growth and reduced shoot height similar to observations made by Sidiqque and Alam (1987). Chlorosis and stunting that was also observed on Sng and Ad may be attributed to the damage caused by the nematodes to the roots causing heavy galling that may have interfered with the uptake of essential minerals for normal plant growth (Anwar and McKenry, 2010; Jaiteh, 2010; Wallace, 1978). Similar findings were obtained by Khan, (1969), Mai and Abawi (1987) and Eisenback *et al.* (1991), reporting that deficiency of some macro-nutrients results to stunting and chlorosis in plants. Stunting may be attributed to the fact that manufactured food in RKN infested plants is redirected specialized feeding cells interfering with normal plant growth (Hunt *et al.*, 2005). This is as opposed to tolerant *Cleome* spp. and Ah that had well developed roots facilitating uptake of essential nutrients (Izuogu *et al.*, 2010). Khan, (2009) reported that formation of galls on plant roots negatively affected growth and development of those plants. This may also be attributed to disruptured vascular bundles interfering with uptake of water and mineral salts and translocation of photosynthates (Anwar and McKenry, 2010).

Galling and egg-mass indices revealed differences in the degree of disease severity in the test ILVs due to RKN infection. High GI was observed in Sng and To that were moderately infected by RKN, while Ah and Cgp recorded very mild infections. These may be attributed to the variation in response of these ILVs to RKN. Highly susceptible hosts allow the juveniles to enter the roots, reach maturity and produce many eggs while the resistant plants suppress their development and thus, do not allow reproduction (Karssen and Moens, 2006). Related observations were made by Khan (1994) who reported that juvenile development is poor on the resistant variants relative to susceptible ILVs. This may explain the low population densities recorded on resistant ILVs relative to high densities recorded in susceptible ones. Higher populations were recorded in Ad, while those of Cgp recorded low populations relative to the check plant. This may be attributed to the ability of the host genes to resist nematode reproduction (resistance) or to withstand and recover from the damaging effects of RKN attack (tolerance) (Trudgill, 1986; Cook and Evans, 1987).

The Sng and To had proliferated roots and heavy galling and this may have been as a result of secretion of chemical growth hormones stimulated by the nematodes. Similarly, heavy roots were observed in susceptible ILVs resulting to higher fresh root weights. This may be attributed to stimulation of nursing cells that acts as sinks for photosynthates resulting to increased root biomass (Jaiteh, 2010).

The damage caused by RKN, represents one of the major obstacles for the production of an adequate food supply (Carter and Sasser, 1982). Use of resistant variants for the management of nematode population is being considered as an important management tool in nematode control programs (Anwar and McKenry, 2010). Therefore they can be recommended for rotational systems to reduce nematode populations for subsequent crops.

5.4 Effect of organic amendments on disease and plant growth parameters

The various OAs effectively suppressed RKN galling, reproduction and population in both greenhouse and field test. The GI was effectively suppressed by Tres, Trej, Td, CM and GM with percentage reductions in galls of up to 96.9 % compared to unamended control recorded in the greenhouse test 2. Greatest percentage reduction in RKN galls ranging from 17.5-96.9 % observed on all the amendments. Moreover, higher reduction on GI on a range 0f 0.5-3.0 was recorded on Svo plants, followed by Sp, Sng, Ad, Ah and To plants respectively.

Reduced RKN galls in ILVs on amended soils may be caused by the availability in the soil of organic matter and nematicidal gases (ammonia). This may be due to high nitrogen content in these materials, narrow C: N ratio in Tres, Trej and Td, relatively low potassium levels which are associated with reducing the infectivity of nematode pests in the soil. These results concur with those of Wachira *et al*., (2009) and Otiefa (1959). Huber (1980) reported a reduction in RKN damage on beans with increased ammonium supplied to the plant. Studies by Kimenju *et al*. (2004), Otiefa and Elgindi, (1962) showed that application of organic matter into the soil reduced RKN galls on vegetables.

On the other hand, reproduction of RKN was significantly suppressed by the OAs. The most suppressive amendments in Svo were Td, Tres and Trej with Rf ranging from 1.6-2.6, while in Sp, Sng and Ah, these amendments recorded suppression to Rf ranging from 1.2-3.6 compared to that of unamended and inoculated control. However in *A. dubius*, CM, Trej and Tres suppressed Rf ranging from 0.8-1.3. The populations in the soil were suppressed in amended soils with Tres, Trej and Td being the most effective amendments in Svo, Sp and Sng. These amendments had lower populations compared to unamended soils. On the other hand, all the amendments suppressed RKN populations in Ad, Ah and the check plant. The suppression of reproduction may be attributed to the presence of phenolic, tannins and terpenoids present in Tres, Trej and Td (Rivera and Aballay, 2008; Ragasa *et al*., 2007).

Addition of OAs may have increased organic matter in the soil that is attributed to have increased the number of free-living nematodes that increased decomposition of organic materials in soil (Abuzar and Haseeb, 2009). Moreover, they increase number of predatory nematodes that antagonize PPN (Abuzar and Haseeb, 2009). These materials have high nitrogen content, narrow C: N ratio and slightly alkaline pH that may lead to the release of nematoxic ammonia. Production of ammonia by organic amendments has been associated with reduced nematode population in the soil (D'Addabbo and Sasanelli, 1996; Korayen, 2003; Stirling, 1991). The materials also stimulate antagonistic micro-organisms to nematodes (Mankau and Das, 1969; Miller *et al*., 1973). These organisms compete for space, food and water hence causing a decrease in RKN population (Ferris and Matute, 2003; Agbenin, 2004; Wachira *et al.*, 2009; Oka *et al*., 2010). This could have led to a reduction in Rf and populations on ILVs as observed in amended soils. Rodriguez-Kabana *et al*., (1984) found significant reduction in PPN population by application of organic manures. Similarly, when these materials undergo mesophilic decomposition, they are known to increase temperature of the rhizosphere soil which may alter nematode development (Chen and Katan, 1980; Hasin, 2002; Stapleton, 1991).

In this study, the pH of CM and GM was considered slightly alkaline (Table 3.3). This factor facilitates the liberation and stability of ammonia in the soil atmosphere (Oka and Pivonia, 2002) although high K content, low N levels and wide C: N ratio might have led to relatively higher RKN galling, Rf and population observed than that of Trej, Tres and Td. High K and low N (ammonium) levels available to the host plant have been associated with increased nematode reproduction (Otiefa, 1959; Huber, 1980; Rivera and Aballay, 2008).

In the field, the population of RKN was relatively lower in plants amended with various OAs than the controls. Similarly, variations in nematode population existed between individual host plants and organic manure that was used. Generally, Trej, Tres and Td recorded lower populations as opposed to the animal manures and chemical nematicides (Mocap). Use of animal manure as soil amendment has been reported to effectively manage PPN and RKN (Agbenin, 2004). When these materials are used as dry manure, they have been associated to have saprophytic nematodes that are antagonistic to PPN (D'Addabo and Sasanelli, 1998; Oka and Yermiyahu, 2002). In this study however, OA of plant origin were effective in reducing RKN infection than animal manure. The chemical nematicide was also effective in reducing RKN galling, population and Rf compared to the CM in the field condition. Similar findings by Gonzalez (1991) revealed inadequate level of control of PPN using animal manure. Rivera and Aballay, (2008) found similar results while working on grapevines that chemical nematicides effectively suppressed RKN Rf, population and galling relative to poultry manure but less effective compared to tea residue.

The findings of this study reveal that Tres and Trej, potentially reduces reproduction of RKN in ILVs. The fine structure of these materials may have increased soil aggregation that might have reduced nematode movement and root penetration. This may have contributed to the lower Rf, population and galling in soils amended with Tres and Trej. Jatala, (1986) found that nematode activity and movement in the soil was affected by soil porosity, particle size, thickness and thickness of water film that resulted to reduced nematode survival and reproduction.

Tea residues and Trej contain high levels of polyphenols and tannins that may alter the attractiveness of roots to nematodes (Stirling, 1991), reduce their mobility and capacity for laying eggs (Rivera and Aballay, 2008). The presence of these chemicals in the soils amended with Tres and Trej could have been the reason for reduced RKN Rf, galling and population in amended soils. Nutrient content analysis (Table 3.3) revealed variation in nutrient amount of K, P, N, Mg, C, Ca, Mn, Cu, Zn that may have influenced nematode infectivity on ILVs. Tea residue and Trej had slightly acidic pH with relatively high amount of nitrogen, low K content and narrow C: N ratio. These factors are attributed to low nematode galling and population and Rf in ILVs grown on soils amended with these materials (Otiefa, 1959; Huber, 1980; Oka *et al*., 2000; Rivera and Aballay, 2008).

The various OAs used influenced plant growth differently. The most effective OAs that improved plant height and weight in the greenhouse experiment were those of Td, CM and GM. Goat manure and CM have high organic carbon and alkaline pH attributed to release of nitrates in the soil for plant growth. They also have relatively high potassium level that is attributed to proper growth of roots hence more nutrients taken for plant development. *Tithonia diversifolia* has high organic carbon, nitrogen, potassium and phosphorous that promotes plant growth. Significantly higher shoot heights and biomass were observed on plants grown on soils amended with Td, CM and GM. This may be attributed to the consecutive increase in root biomass through improved soil fertility and reduced nematode populations that may have enhanced plant tolerance to nematodes as well as increased absorption of minerals from the soil that support growth (Stirling, 1991; Oka *et al*., 2000). Similarly, plants grown on soils amended with Mocap nematicide and unamended soils with Mocap had improved shoot height and weight. This may be attributed to reduced RKN reproduction and damage to roots facilitating proper plant growth. Similar findings were reported by Zarina, (1996) that plants treated with Mocap nematicide developed improved growth parameters relative to the control.

Plants grown on soils amended with Tres and Trej on the greenhouse were found to be stunted and had low shoot weight. However, the current levels of amendment with Tres and Trej led to stunted plant growth, low shoot weight, and reduced and poorly developed root systems in greenhouse. Despite this, improved plant growth was observed on plants grown on Tres and Trej amended soils in the field. Stunted growth and low biomass obtained in greenhouse on plants grown on Tres and Trej may be attributed to the presence of polyphenols and tannins that are phytotoxic. These compounds may have accumulated in the pots resulting to root damage hence interfering with uptake of essential nutrients for plant growth. On the other hand, these materials were found to aggregate and compact the soil particles that might have hindered proper development of roots. However, in the field, tannins and polyphenolic compounds may have been converted into utilizable and soluble forms for plant uptake. Micro-organisms in the soil interact with other factors stimulating the release of nutrients and organic matter necessary for crop growth. Dilution of the effect of polyphenols and tannins through decomposition to less toxic compounds that could be utilized by plants hence promoting higher growth and biomass may also have occurred in the field.

Moreover, the high nitrogen content in Tres and Trej may have been converted to nitrates that promote higher shoots and biomass. Studies have shown that when organic amendments are incorporated into the soil as alternative sources for the management of PPN, they add nutrients and improving crop production (Hasabo and Noweer, 2005; Wachira *et al.*, 2009).

Similarly, the root system of plants amended with Trej and Tres were necrotic in the greenhouse. This may have been caused by the presence of tannins and polyphenols that are associated with phytotoxicity in plants causing root necrosis as observed on the test ILVs (Rivera and Aballay, 2008). However, field experiment revealed contrasting results with ILVs developing health root systems and that were not necrotic. This observation may be attributed to a myriad of factors including high moisture content and warm conditions present in field that may have converted the phytotoxic compounds to utilizable form than confined pot conditions. This findings support earlier observation by Rivera and Aballay (2008) reporting improvement in root system of grapevines amended with composted tea residue in Philippines.

Improved and increased root system on most ILVs was found in soils amended with Td, CM and GM manure in the greenhouse conditions and Tres in the field. This could be partially due to the ability of these materials to add nutrients and organic matter to the soil as well as improving soil structure, drainage, aeration and water retention hence resulting to improved root biomass and system that leads to increased plant tolerance to PPN attack (Stirling, 1991; Kimenju *et al*., 2004). A myriad of mechanisms are involved in the reduction of nematode infection on roots of plants (Stirling, 1991). Among these mechanisms, physical barrier, chemical and biological have been found effective (Pakeerathan *et al*., 2008, Ragasa *et al*., 2007). The organic amendments of CM, GM, Td, Tres and Trej may have produced ammonia that is toxic to nematodes as well as anti-fedant chemicals that reduces root attractiveness to RKN hence reducing their infection on roots. Similarly, they may have stimulated antagonistic organisms that predates on RKN reducing its population. On the other hand, Tres and Trej amended soils were found to be compacted hence this may have hindered movement of RKN towards roots.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSIONS

From the survey results, it can be concluded that lack of awareness on nematode control, declining acreage and increasing demand for ILV consumption may have prompted farmers to resort to poor agronomic practices like continuous cultivation. This may have contributed to higher disease prevalence and incidence in the study areas. Farmers from both Kisii and Trans-Mara are less aware of the problem and use different cultural and chemical treatments to control the pest, without much success as reported herein. The survey results indicate that RKN is widespread in farms in Kisii than those from Trans-Mara where it is reported in all the farms surveyed for *Solanum* species in both Counties. This study provides crucial information required by scientists as well as creating awareness to growers about the incidence, prevalence of RKN infecting ILVs. Crops grown in rotation with ILVs are also susceptible to the RKN disease. Widespread prevalence and incidence of RKN can be used as an indicator of great potential that can be exploited for the management of PPN.

Greenhouse experiment on ILVs revealed considerable variation in response to RKN. Black nightshade recorded higher galling, reproduction and final J2s compared to amaranths and spider plants. Black nightshade green berried was more susceptible to RKN compared to the purple and orange types. *Amaranthus dubius* was tolerant while *A. Cruentus*, *A. hypochondriacus* and *C. gynandra* purple stemmed were moderately resistant.

The various OAs effectively suppressed RKN infection comparable to that of Mocap nematicide on ILVs hence their potential for adoption into RKN management programs as non-chemical measure for controlling RKN. Tea reject and residue, caused phytotoxicity and growth retardation of ILVs in the greenhouse than in the field conditions.

6.2 RECCOMMENDATIONS

- There is need for proper nematode management strategies in ILVs production among the farmers in Kisii and Trans-Mara Counties.
- This study recommends that farmers should be sensitized on the effective management strategies for nematode control.
- Further studies are needed to correctly identify all the prevailing races of *Meloidogyne* spp. across the various soil types in the study areas.
- Evaluation of nematodes on exotic vegetables grown by farmers particularly for export is imperative for effective management decisions.
- The study recommends the use of tolerant and resistant ILVs including *A. hypochondriacus* and *C. gynandra* purple ILVs in rotation programmes. Further screening of other of ILVs should be done in other vegetable producing zones in search of solutions to the RKN disease problems.
- There is need to determine the least but effective level of application of tea residue and rejects that is not phytotoxic for the management of RKN and other PPN in ILVs production. There is need also to ascertain the mechanism of nematode control in *T. diversifolia*, tea residue and reject that are used in soil amendment and vegetable production systems.

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APPENDICES

Appendix I: Questionnaire

A structured questionnaire was used to collect information or data from the farmers. The questions were translated into the local language by the members of the research team and in other cases a translator was used. In-depth information or interview was carried out on the farmers that were practising commercial production and those that were well versed with knowledge on pest management strategies.

Questionnaire used in the study

Date …………….. Questionnaire No. …………… GPS ……………….…………

Particulars of the area of study

Division……………………Location………………….Sub-Location……….………

Village………………………   Agro ecological zone……...........…………………

Social demographic data

Name of farmer………………………………Contact………………………………..

Sex: Male………………………. Female……………………………..……………....

Age (estimate/ask): 20-30 □ 30-40 □ 40-50 □ Above 50 □

Level of education received: None □ Primary □ Secondary □ College □ University □

Others (specify) ……………………………………………………………..…………

Occupation: Main □ Agro-based business □ Others ………….………………………

Questions

1. Which crops do you grow in your farm? …………………..….……………………

   Please indicate crops in order of their economic significance to you.

Maize □ Beans □ Bananas □ Tomatoes □ Potatoes □ Cash crops □

2. For how long have you been growing these crops? 1 yr □ 3yrs □ 5 yrs □ more than 5 yrs □
3. Do you grow indigenous leafy vegetables (ILV)? Yes□ No □

   If yes which ones? Black nightshades □ Amaranths □ Spider plant □ Others ………………………………………………………………………………………
4. Do you grow ILVs for commercial or subsistence? Commercial □ Subsistence □ Both □
5. What size of land is dedicated to these ILVs? Less than ¼ acre □ ¼ acre □ ½ acre □ >1/2 acre □
6. Is cultivation of ILVs on the increase or decrease? Increase □ Decrease □ Not aware □
7. Which ILVs are most profitable? Amaranths □ Black nightshades □

   Spider plant □ Others ……………………..………………………………………
8. Which varieties of ILVs are most common? Improved □ Traditional □ Both □
9. Which ILVs are most productive? Improved □ Traditional □ Both □
10. Where do you get planting materials /seeds from? Own farms □ Neighbours □ Certified seeds from breeders □ Others ……………………………………………
11. Are planting materials cheap or expensive to buy? Expensive □ Cheap □ Not sure □
12. About how much do you earn per punch of ten leaves/shoots of ILVs? Ksh 2-5 □ Ksh 5-10 □ >Ksh 10 □
13. Do you use fertilizers for planting? Yes □ No □

    If yes which ones? D.A.P □ T.S.P □ S.S.P □ D.S.P □ Others……………………

14. Do you use fertilizer for top dressing? If yes, which type? C.A.N □ S.A.N □ Urea □ Others…………………………………………………………………………
15. Do you use organic manure in the production of ILVs? Compost □ Green manure □ Livestock manure □ Others……………………………………………………………
16. Are there diseases that attack ILVs? Yes □ No □
17. How do you control these diseases? By chemicals □ Sprinkling wood ash □ Others ………………………………………………………………………………
18. Are there major pests that attack the ILVs in the field? Aphids □ Nematodes □ Insects □ Thrips □
19. Have you ever heard of pests called nematodes? Yes □ No □
20. Do you know how to look for their symptoms of attack? Yes □ No □
21. Do they cause yield losses in ILVs? Yes □ No □
22. How are they controlled? Chemicals □ Manure □ Not aware □
23. To whom do you sell your ILVs? Middle men □ Traders □ Consumers □ Others ……………………………..…………………………………………….
24. Who determines the selling prices of ILVs? Farmers □ Traders □ Consumers □ Others……………………………………………………………….…………………
25. Where do you sell your ILVs? Farm gate □ Open market □ Towns & City □ Others ……………………………...…………………………………………….
26. Do you face any problems selling your vegetables? Yes □ No □
27. What problems do you face in the production of these vegetables? Lack of land □ Lack of inputs □ Lack of market □ Drought □ Others …………………………...
28. Do you irrigate your vegetables? Yes □ No □
29. How do you harvest your vegetables? Whole meal □ Piece meal □

Appendix II: The berries of *Solanum nigrum* green berried variety (A) and *Solanum villosum* orange berried variety (B).

Appendix III: Interaction effect between mocap and amendment treatments in *Amaranthus dubius* in field test.

Source of Variation	SS	df	MS	F	P-value	F crit
Amendments	8.1875	5	1.6375	1.196954	0.330225	2.477169
-M and +M	4.6875	1	4.6875	3.426396	0.07238	4.113165
Interaction	2.1875	5	0.4375	0.319797	0.89779	2.477169
Within	49.25	36	1.368056			
Total	64.3125	47				

Appendix IV: Interaction effect between mocap and amendment treatments in *Amaranthus hypochondriacus* in field test.

Source of Variation	SS	df	MS	F	P-value	F crit
Amendments	19.35417	5	3.870833	5.746392	0.000536	2.477169
-M and +M	3.520833	1	3.520833	5.226804	0.02823	4.113165
Interaction	3.854167	5	0.770833	1.14433	0.355198	2.477169
Within	24.25	36	0.673611			
Total	50.97917	47				