Agriculture, Ecosystems and Environment 247 (2017) 265–272

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Research Paper

Organic farming provides improved management of plant parasitic nematodes in maize and bean cropping systems

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ARTICLE INFO

Keywords:
Intercropping
Sole cropping
Maize
Beans
Nematode suppression

ABSTRACT

Intensification of agriculture, combined with poor agronomic practices have increased the incidence of plant parasitic nematodes (PPN) and other soil pathogens in East Africa, which consequently affects crop productivity in small holder farms. The objective of the study was to assess the effectiveness of farming systems in management of PPN and to recommend the best practice to farmers. Therefore, two field trials were established, one in farmer fields and one on-station, using maize (*Zea mays* L.), intercropped with beans (*Phaseolus vulgaris* L.) and in rotation with beans as a sole crop. Organic farming (that received compost, *Tithonia diversifolia* and neem cake (*Azadirachta indica*)) was compared to conventional farming (that received fertilizer and nematicide), farmer practice (that received manure, *Tithonia diversifolia* and wood ash), and a farm with no input application (control). After three years of continuous cultivation, twelve genera of PPN were recovered from soil and/or root samples from the trials. Under inter- and sole-cropping at both sites, the abundance of PPN including *Pratylenchus* and *Meloidogyne* were significantly reduced in the organic system compared to the conventional, farmer practices and control. Organic farming was effective in reducing the genera of PPN below the control for a longer period (4 months) compared to conventional farming and farmer practice (2 months). The findings demonstrated the potential of organic farming in the suppression of PPN at the farmer level. Policy development and extension services can therefore consider organic farming as an alternative method in managing soil-borne nematodes in small holder farms in sub-Saharan Africa. However, further studies are required on other crops, in dry areas and the period to top-dress with organic amendments to assure effective suppression of PPN in organic farming.

1. Introduction

Maize (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.) are considered the most important food crop and legume in Kenya (Nyongesa et al., 2004; MoA, 2013). Since its introduction to East Africa in the sixteenth century (McCann, 2005), maize has become the dominant crop in Kenya, grown primarily by small-holder farmers over approximately 1.6 million ha annually (Kamidi et al., 1999). Similarly, beans are the most important legumes grown in Kenya on more than 700,000 ha (MoA, 2013) and play a major role in food security. As with all important crops, their production is limited by various biotic and abiotic constraints, including plant parasitic nematodes (PPN) (Kimenju et al., 1999; Widmer and Abawi, 2000; Karanja et al., 2002; Nyongesa et al., 2004; Agrios, 2005; McDonald and Nicol, 2005; Luc et al., 2005; Sikora et al., 2005; Wachira et al., 2009; Hockland et al., 2012).

With regard to food security, PPN are an important consideration, especially in the tropics and sub-tropics, where PPN short generation times lead to rapid population build-up all-year round, which substantially affects crop production (Agrios, 2005; Perry and Moens, 2013). In Kenya and its sub-region, intensification of agriculture, combined with poor agronomic practices such as lack of crop rotation, improper fertilizer application (soil nutrient analysis) and inconsistent irrigation have led to an increase in PPN and other soil pathogens (Wachira et al., 2009), especially root knot nematodes (*Meloidogyne* spp.) and lesion nematodes (*Pratylenchus* spp.) which are among the most damaging PPN and reported to be associated with monoculture cropping systems (Kimenju et al., 2008).

Traditionally, management of nematodes has relied on synthetic

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http://dx.doi.org/10.1016/j.agee.2017.07.002
Received 6 April 2017; Received in revised form 30 June 2017; Accepted 3 July 2017
Available online 11 July 2017
0167-8809/

chemical nematicides. These nematicides have proven unreliable for small-holder systems as they are often unaffordable and unavailable to farmers (Agyarko and Asante, 2005; Renco and Kovacik, 2012). Furthermore, due to the increasing attention to environmental safety, most nematicides have been withdrawn from markets or their use severely restricted (Chen and Ferris, 2004; Renco and Kovacik, 2012). Mineral fertilizers alone or in combination with manure can also be used in controlling PPN (Okada and Harada, 2007; Oka, 2010; Hamida et al., 2015). However, continuous use of these fertilizers can result in decreasing soil pH (Adamtey et al., 2016), consequently affecting crop growth and yields (Zhong et al., 2010); and if not well managed can pose a potential threat to the environment (Scow et al., 1994). Other management techniques, such as solarization, flooding, use of resistant cultivars and use of cover crops have been practiced but have their individual limitations. For example, solarization is expensive, can be technically challenging for farmers, and negatively impacts on the beneficial soil micro-organisms (Gaur and Perry, 1991; Kaskavalci, 2007). Flooding is not suitable for all locations and is dependent on the type of crop and nematode species (Sikora et al., 2005); resistant cultivars are often highly specific to nematode species and are not readily available to farmers in developing countries (Roberts, 1992; Bridge, 1996; Sikora et al., 2005; Hockland et al., 2012); and cover crops that are considered most effective such as rattlebox (*Crotalaria spectabilis*) and castor (*Ricinus communis*) may be toxic to livestock and are mostly species specific (McSorley, 1999).

The use of organic amendments as a potential alternative to nematode management presents a promising option (Sharma, 2001; Devi and Hassan, 2002; Stephan et al., 2002; Summers, 2011; Stirling et al., 2011; Renco and Kovacik, 2012; Olabiyi and Oladeji, 2014). Briar et al. (2016) confirmed that amending soil with green or organic manure and crop residues in a field, would significantly suppress PPN populations. Several studies indicate a reduction of PPN abundance and damage following addition of organic amendments (Sasanelli et al., 2006; D'Addabbo et al., 2011; Renčo et al., 2011). Possible mechanism for this reduction could be attributed to toxic compounds released during decomposition or increase in PPN antagonists (McSorley, 2011; Briar et al., 2016). In contrast, Sharma et al. (2000) reported that organic amendments were not effective in that they resulted in build-up of the nematodes. Another study by Kimpinski et al. (2003) showed that populations of *Pratylenchus* spp. and *Meloidogyne* spp. did not respond to organic soil amendments over long-term studies.

There is limited information in sub-Saharan Africa on organic management techniques and situations that effectively lead to the suppression of PPN, which are economical and can easily be adopted by most farmers. To address this, the Research Institute of Organic Agriculture (FiBL) and partners in Kenya are using different farming systems within the framework of the "Farming systems comparison trials in the tropics" (SysCom; www.systems-comparison.fibl.org) to address the obstacles (including soil-borne nematodes) that confront organic crop production in small-holder farms. The hypothesis for the study was that organic farming is more effective than conventional farming in suppressing PPN. Therefore, the specific objectives of this study were to assess the effects of organic and conventional farming, and farmer practice on the relative abundance and variations of PPN genera, population of PPN and the dynamics of PPN genera over time.

2. Materials and methods

2.1. Site description

The study was conducted at Chuka in Tharaka Nithi County, Kenya (Longitude 037° 38.792′ and Latitude 00° 20.864′). The area is situated in the agro-ecological zone 2 (AEZ 2) of the upper midland 2 (UM 2) located in the mid-altitude (1458 m above sea level). It receives a mean annual rainfall of 2000 mm in two seasons a year (long rains from March to June and short rains from October to December) with temperatures at site ranging between 19.2–20.6 °C (Fig. 1). The soils at the study site are classified as humic nitisols (IUSS Working Group WRB, 2006; Wagate et al., 2010). The percentage proportion of sand, silt and clay in the study area is 9.4, 16.6 and 74.0% respectively (Adamtey et al., 2016). Table 1 shows the initial chemical characteristics of the soils at the study site to a depth of 20 cm.

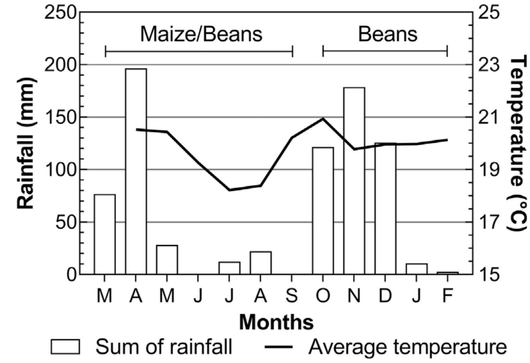

Fig. 1. Mean temperature and rainfall data for the study site during the growing period of the trial, from March 2015 to February 2016, at Chuka in the Central Highlands of Kenya.

Table 1
Initial soil chemical characteristics of the study area at Chuka in the Central Highlands of Kenya.

Parameter	On-farm	On-station
pH	5.82 ± 0.19	5.18 ± 0.05
EC(S) (μS/cm)	80.00 ± 8.03	99.00 ± 0.58
C.E.C (meq/100 g)	16.74 ± 0.86	16.10 ± 0.03
SOC (%)	23.6 ± 0.80	23.2 ± 0.90
N total (%)	2.3 ± 0.10	2.4 ± 0.70
P (Olsen) (mg/kg)	29.48 ± 5.16	29.48 ± 5.16
K (Cmolc kg^{-1})	0.90 ± 0.16	0.31 ± 0.02
Ca (Cmolc kg^{-1})	8.59 ± 1.09	5.85 ± 0.26
Mg (Cmolc kg^{-1})	2.58 ± 0.25	2.25 ± 0.16
Na (Cmolc kg^{-1})	0.25 ± 0.03	0.19 ± 0.01

Key to Parameters: EC – Electrical conductivity, C.E.C – cation exchange capacity, SOC – Soil Organic Carbon, N – Nitrogen, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Na – Sodium; μS – micro siemens, meq - milliequivalent, ppm – parts per million.

Annual crops such as maize (*Zea mays*), beans (*Phaseolus vulgaris* L.), potatoes (*Solanum tuberosum* L.), sweet potatoes (*Ipomoea batatas* L.), sorghum (*Sorghum bicolor* L.) and vegetables are predominantly grown by small holder farmers on 0.5–1 ha at Chuka (Adamtey et al., 2016). Perennial crops like bananas (*Musa* spp. L.), avocado (*Persea americana* M.), passion fruits (*Passiflora* spp.), pineapples (*Ananas comosus*), sugarcane (*Saccharum officinarum* L.); and cash crops like tea (*Camellia sinensis* L.) and coffee (*Coffea* spp.) are also normally grown alongside dairy farming as a source of income for smallholder farmers (Adamtey et al., 2016).

2.2. Field experimental design and treatments (farming systems)

The study was conducted over two cropping seasons in 2015 and 2016 in two ongoing trials (on-farm and on-station) established in March 2013. The on-farm trial (Type 2 experimental design; designed by the researcher, managed by the farmer) consisted of four farmers, each serving as a replicate or a block and located in close proximity to each other. Farmers were selected based on severity of soil-borne diseases in the study area, following a group discussion and interactions with researchers and Ministry of Agriculture extension agents. Four farming systems were being compared: farmer practice, organic, conventional and non-amended control, represented the treatments based upon the amendments that each practice received (Table 2).

The on-station trial (Type 1 experimental design; designed and

Table 2
Soil amendments applied in the farming systems.

Farming system	Fertilizer	Pesticides
Farmer practice	2640 kg ha^{-1} FYM[a], 256 kg ha^{-1} DAP[b]	8000 kg ha^{-1} Wood ash
Organic	4640 kg ha^{-1} Compost, 4312 kg ha^{-1} Tithonia diversifolia mulch	448 kg ha^{-1} Neem cake applied at planting
Conventional	512 kg ha^{-1} CAN[c], 294.4 kg ha^{-1} DAP[2]	4000 kg ha^{-1} Marshal EC used in coating seeds at planting
Control	No fertilizer application	No pesticide application

[a] FYM = Farmyard manure.
[b] DAP = Di-ammonium phosphate.
[c] CAN = calcium ammonium nitrate. All amendments were incorporated into the soil at the time of planting.

managed by the researcher) was in a single location, comprising the same treatments (farming systems) as in the farmer field trials (Table 2), replicated four times and arranged in a randomized complete block design. Maize (*Zea mays*, var. H513) was intercropped with beans (*Phaseolus vulgaris*, var. KATB9) in the long rainy season (March–September 2015) wheareas beans as sole crop in the short rainy season (October–February 2016). Plots for both on-farm and on-station measured 5 × 5 m with a buffer zone of 1 m between plots.

The trials were strictly rain fed. Hand tillage was done using a hoe up to a depth of 20 cm. Weed densities and species were similar at both sites and hand weeding was done twice in each season. During the intercrop season, maize and beans were row intercropped at a spacing of 75 × 60 cm between maize and 30 × 37.5 cm between beans. Two seeds per hole were used for both crops. In the bean sole crop, spacing was 45 × 30 cm and two seeds per hole were sown.

2.3. Soil and root sampling

For maize and bean intercrop, soil samples were taken at different plant growth stages (pre-planting, vegetative, flowering and at bean harvest and maize harvest). Similarly, for the beans as sole crop, soil samples were taken at pre-planting, flowering and harvest. Roots were sampled only at harvest of each crop. Five sub-samples per plot were taken, using a cross diagonal sampling pattern (Coyne et al., 2014), and bulked into composite samples of approximately 1 kg soil and 75 g roots for each sample occasion.

2.4. Nematode extraction and assessment

Nematodes were extracted from a 100 ml soil and 5 g roots obtained from each composite sample using a modified Baermann technique (Coyne et al., 2014). Nematodes were counted from sub-aliquots of the extraction under a Leica MZ12 stereo-microscope and densities calculated according to the method of Coyne et al. (2014). Afterwards the nematodes were identified to genus level, based on morphological features, using at least 100 nematodes per sample (KSU, 2015).

2.5. Data analysis

The relative abundance was calculated as a percentage contribution of each PPN genus to the total population. To show the effect of farming systems on genera composition compared to the control at a corresponding time, principal response curves were used. This was achieved by modeling the abundance of each particular genus as a sum of three terms: mean abundance in the control, a month-specific treatment (farming system) effect, and an error (Van den Brink and Ter Braak, 1998):

$$Y_{d(t)tk} = y_{0tk} + b_{kCdt} + \Sigma_{d(j)tk}$$

where $Y_{d(j)tk}$ = abundance of genus k (=12) in replicate j (=4) of treatment d (=4) at time t (0–5 months); y_{0tk} = mean abundance of genus k in month t in the control; b_k = genus weight; c_{dt} = least-squares estimate of the coefficients; and $\Sigma_{d(j)tk}$ = a random error term.

Nematode abundance data were transformed using natural logarithm [ln(x + 1)] prior to analysis to stabilize the variance and normalize the data. The transformed data were subjected to a two-way analysis of variance to evaluate the effect of fixed factors; farming system and site. Means were separated using Fisher's least significant difference (LSD) test at $p \leq 0.05$ using the package "agricolae" (De Mendiburu, 2015), whereas the significance of the PRC model was assessed using ANOVA in the package "vegan" (Oksanen et al., 2016). All analyses were implemented using R version 3.2.3 (R Core Team, 2015).

3. Results

3.1. Effect of farming systems on relative abundance and variations in genera of plant parasitic nematodes

Twelve genera of PPN, belonging to five families were identified: Tylenchidae (*Tylenchus, Pratylenchus, Meloidogyne* and *Filenchus*); Hoplolaimidae *(Hoplolaimus, Helicotylenchus, Scutellonema* and *Rotylenchus*); Longidoridae (*Xiphinema* and *Longidorus*); Trichodoridae (*Trichodorus*) and Tylenchorynchidae (*Tylenchorynchus*).

Under intercropping, all 12 genera were recovered at farmer fields and on-station (Fig. 2), with *Helicotylenchus*, *Pratylenchus* and *Tylenchus* as the most dominant genera in conventional, farmer practice and

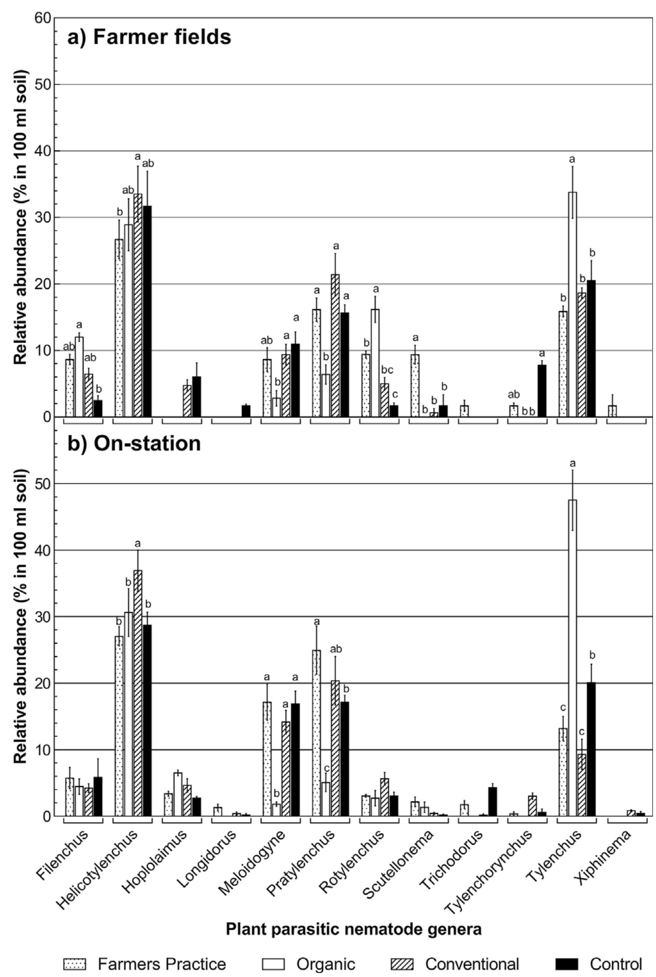

Fig. 2. Farming system influence on the relative abundance of plant parasitic nematode assemblage in 100 ml of soil under maize and beans intercrop at a) on-farm and b) on-station in Chuka.

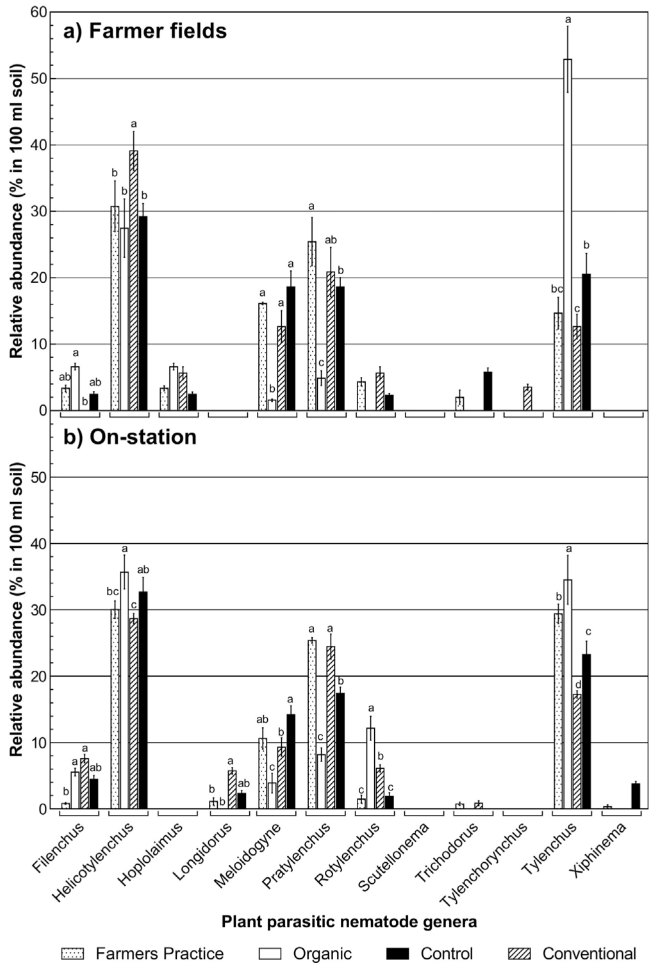

Fig. 3. Farming system influence on the relative abundance of plant parasitic nematode assemblage in 100 ml of soil under beans sole crop at a) on-farm and b) on-station in Chuka.

control plots in farmer fields. Whereas organic plots showed a similar abundance for *Helicotylenchus*, the plots had higher ($p < 0.05$) numbers of *Tylenchus* and *Rotylenchus* when compared to conventional, farmer practices and the control plots. At the on-station trials, a similar trend was observed as in the farmer fields (Fig. 2). Besides *Helicotylenchus*, *Tylenchus* and *Pratylenchus, Meloidogyne* was also dominant in the conventional, farmer practice and the control plots. The genera *Longidorus*, *Xiphinema* and *Trichodorus* were generally low in all farming systems and absent in the organic systems at both sites.

Under sole cropping in the farmer and on-station trials, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus* and *Tylenchus* were again dominant in the conventional, farmer practice and control plots (Fig. 3). On the other hand, *Helicotylenchus* and *Tylenchus* were dominant in the organic plots at both sites. In addition, the organic plots were higher ($p < 0.005$) in *Rotylenchus* on-station compared to conventional, farmer practice and control plots. The genera *Longidorus*, *Scutellonema* and *Xiphinema* were not recovered from the farmer fields during inter- and sole cropping (Figs. 2 and 3), while *Hoplolaimus*, *Scutellonema* and *Tylenchorynchus* were not recovered during sole cropping on-station (Fig. 3).

3.2. Effect of farming systems on plant parasitic nematode population densities

The mean abundance of PPN varied ($p \leq 0.05$) among the four farming systems in both the farmer fields and on-station site. The highest abundance was recorded in the non-amended control followed by farmer practice and conventional treated plots for soil (Table 3) and root samples (Table 4). Soils from organic plots had half as many PPN ($p < 0.01$) as those from conventional plots under inter- and sole

Table 3
Mean density of plant parasitic nematodes in soil samples under various farming systems and cropping systems.

Cropping system	Farming system	Site: Farmer fields Mean[2]	s.e.m.	On-station Mean[2]	s.e.m.	Source of variation (p-value[1])
Intercrop (Maize and beans)	Farmers practice	660 b	41.58	720 b	17.44	0.236
	Organic	308 c	64.91	266 d	32.49	0.740
	Conventional	776 ab	118.56	588 c	47.90	0.230
	Control	961 a	129.82	845 a	63.59	0.432
Source of variation (p-value[1])		0.003		< 0.001		
Sole crop (Beans)	Farmers practice	476 a	99.32	549 a	104.83	0.591
	Organic	188 b	26.35	109 b	27.63	0.137
	Conventional	586 a	74.83	532 a	104.92	0.638
	Control	735 a	76.23	638 a	65.33	0.507
Source of variation (p-value)		0.008		0.010		

[1] P-values are shown for mean differences between farming systems and between sites. Significant differences ($p < 0.05$) between farming systems are indicated by letters (a–d) next to the mean values.
[2] Intercrop[2] mean represents the value of five sampling times done during the growing season of the crop (i.e. pre-plant, vegetative, maturity, bean harvest and maize harvest) while sole crop[2] mean represents three sampling times (i.e. pre-plant, flowering and harvest).

Table 4
Mean density of plant parasitic nematodes in root samples under various farming systems and cropping systems.

Cropping system	Farming system	Site: Farmer fields Mean[2]	s.e.m.	On-station Mean[2]	s.e.m.	Source of variation (p-value[1])
Intercrop (Beans)	Farmers practice	725 b	60.53	259 b	38.24	0.090
	Organic	389 d	26.96	306 b	51.06	0.169
	Conventional	520 c	47.30	381 b	55.03	0.221
	Control	987 a	57.03	1187 a	122.99	0.121
Source of variation (p-value[1])		< 0.001		< 0.001		
Intercrop (Maize)	Farmers practice	458 b	64.65	185 b	27.55	0.051
	Organic	85 c	22.98	95 b	16.81	0.802
	Conventional	25 c	9.89	201 b	70.01	0.105
	Control	850 a	84.91	1058 a	85.67	0.281
Source of variation (p-value[1])		< 0.001		< 0.001		
Sole crop (Beans)	Farmers practice	527 c	56.65	440 b	12.87	0.240
	Organic	373 c	21.64	217 c	20.95	0.062
	Conventional	821 b	105.42	589 ab	92.84	0.162
	Control	1085 a	57.49	734 a	81.91	0.078
Source of variation (p-value[1])		< 0.001		< 0.001		

[1] P-values are shown for mean differences between farming systems and between sites. Significant differences ($p < 0.05$) between farming systems are indicated by letters (a–d) next to the mean values.
[2] Mean values represent root samples collected at crop harvest.

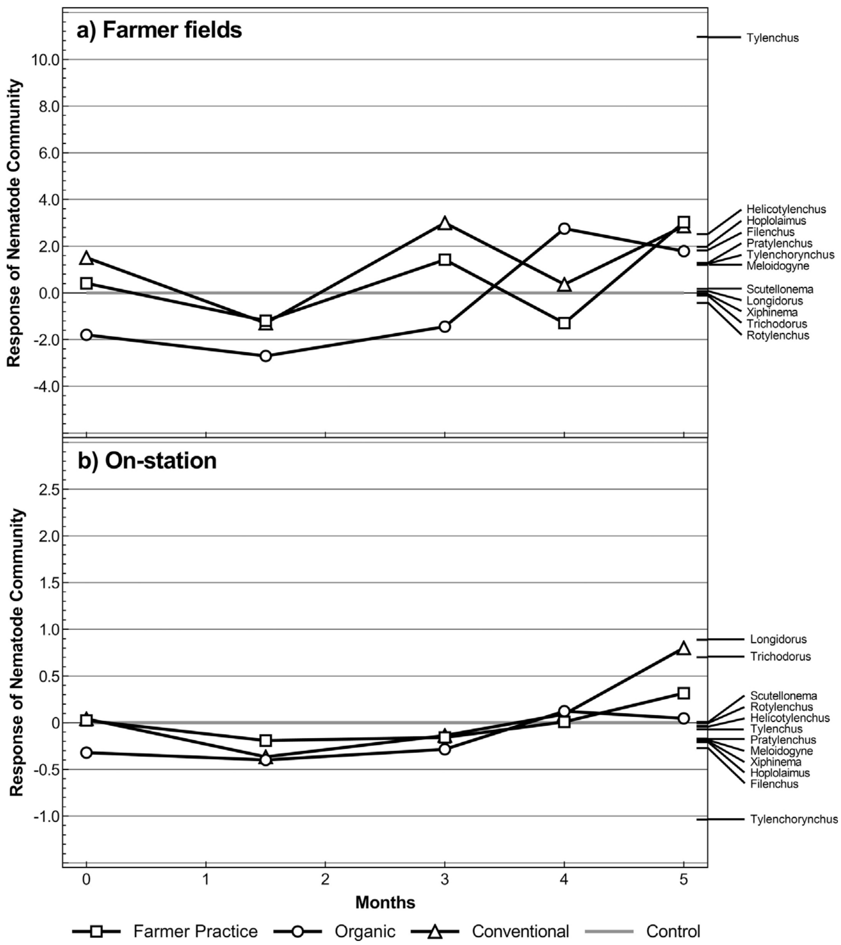

Fig. 4. Principal response curves of the plant parasitic nematode genera showing the effects of farmer practice, conventional and organic farming compared to the control from the study site in Chuka. The ordinate axis represents the first principal component of the variance due to treatment effect whereas the abscissa axis represents the sampling time (in months). The horizontal line at 0 shows the response of the plant parasitic nematodes in the control. The genera scores that were associated with the reference system (control) are shown on the right axis.

cropping in the farmer fields. Plant roots from organic farms also showed low ($p < 0.001$) densities of PPN during intercropping of maize and beans and during sole cropping of beans. The results of the on-station trials for both soils and plant root samples followed a similar trend as in the farmer fields. There were no significant differences in the densities of PPN found in the farmer fields and on station trials.

3.3. Effect of farming systems on the dynamics of plant parasitic nematode genera over time

In farmer fields, multivariate analysis showed that *Tylenchus, Helicotylenchus,* and *Hoplolaimus* genera contributed mostly to the pattern of the curve. The nematodes with the least contribution in the control system (below the 0) were *Rotylenchus*, *Trichodorus* and *Xiphinema*. The conventional and farmer practice systems were effective in suppressing PPN below the control for a period of one-and-half months (Fig. 4a). However, the organic system was effective in suppressing PPN over a period of almost three-and-half months. There was a rise in PPN above the control from the fourth month in conventional and organic systems.

In the on-station trial, *Longidorus, Trichodorus* and *Scutellonema* were the main drivers of the PRC, with *Tylenchorynchus*, *Filenchus* and *Hoplolaimus* contributing the least (Fig. 4b). All the systems were effective in suppressing PPN below the control over a period of three-and-half to four months. Afterwards the PPN populations rose above the control.

4. Discussion

The genera *Tylenchus* and *Helicotylenchus* were the most dominant genera in all farming systems under intercrop and sole crop in both farmer and on-station trials. They did not seem to respond to either organic or conventional farming systems, as evidenced by their consistently high relative abundance. This lack of response could be due to the nature of their reproductive patterns in that *Tylenchus* has the shortest generation times among the PPN (Yeates et al., 1993; Ferris et al., 2001). They are also not viewed as being particularly damaging in general, and as Cadet et al. (2002) observed in sugarcane, *Helicotylenchus* can be beneficial and when present in high numbers is associated with good sugarcane growth. Nonetheless, the efficacy of the organic amendments against individual PPN genera was demonstrated in both the intercrop and sole crop systems, with densities of the key pathogenic nematodes *Meloidogyne* and *Pratylenchus* significantly reduced. Similar results were observed by Abbasi et al. (2005) who reported a 67–70% reduction in the number of *Pratylenchus* and *Meloidogyne* in tomatoes treated with 1% neem cake. Neem cake (*Azadirachta indica*) has been shown to possess nematotoxic activity due to the content of limonoids, azadirachtin nimbine, nimbidine, kemferol and tagitinin C (Yasmin et al., 2003; Wani and Bhat, 2012; Odeyemi et al., 2014).

The low abundance of *Trichodorus*, *Xiphinema* and *Longidorus* in the study could be explained by the fact that nematodes in c-p 4 and 5 are classified *k-strategists,* with relatively long generation times (Bongers and Bongers, 1998). A reduction of these nematodes in the organic systems was observed. Some studies indicate that the application of organic amendments and natural products may control longidorid and trichodorid nematodes in fields that are already infested (MacFarlane and Robinson, 2004; Bilevai et al., 2009), while the doubling of soil organic matter content was the likely cause of *Trichodorus* and *Paratrichodorus* reductions under corn and sorghum (McSorley and Gallaher, 1996).

The lowest population densities of PPN in soil and root samples were found in the organic system, under both cropping systems and sites. These results were consistent with those of Neher (1999), who observed a reduction in PPN density while comparing organic and conventional amendments. The nematicidal effects of some organic amendments have been recognized; *Tithonia diversifolia* as a botanical has been shown to be effective in the management of *Meloidogyne* spp., as it contains active ingredients, which exhibit nematicidal properties (Odeyemi and Adewale, 2011; Akpheokhai et al., 2012; Odeyemi et al., 2014). Moreover, the presence of terpenoids in *T. diversifolia* has been suspected to have nematotoxic effect against most PPN (Ragasa et al., 2007; Osei et al., 2011). There has also been considerable progress in the use of compost as a soil amendment for the control of PPN in infested fields (McSorley and Gallaher, 1996; Akhtar and Malik, 2000; Zhang and Zhang, 2009; D′Addabbo et al., 2011).

Conventional farming was less effective than organic farming in suppressing PPN and these results complement those of Neher (1999), who found significantly higher densities of PPN in soils under conventional farming practices. However, compared to the non-amended control, the conventional system had lower densities of PPN. The obtained results indicate that the conventional amendments may have a suppressive effect on PPN due to the use of inorganic fertilizers. Bednarek and Gaugler (1997) reported that the addition of inorganic amendments, particularly NPK fertilizer, suppressed nematode densities. They confirmed that prolonged exposure to high inorganic fertilizer concentrations inhibited their reproduction. For suppressing PPN in the soil, inorganic fertilizers containing N in the form of ammoniacal nitrogen have been recommended (Rodriguez-Kabana, 1986).

The principle response curves (PRC) were applied as they allow for the evaluation of the nematode genera with the most pronounced treatment-related decrease in abundance. The pattern of the PRC revealed that in both farmer and on-station trials, the conventional farming and farmer practice were effective in PPN reduction for a relatively short time after which the densities increased to levels above the control. This may be attributed to the effect of the amended inputs and pest management practices that were undertaken; Marshal EC (nematicide) was amended in the conventional system, while wood ash was amended in the farmer practice system, likely explaining the initial reduction of PPN in these systems. The application of nematicides provides an immediate impact on population densities of PPN, although the nemastatic nature of many nematicides results in the resumption of nematode activity once the chemical concentration declines (Stanton and Stirling, 1997). Wood ash has been shown to a have some level of suppressive effect against PPN (Olaniyi, 2015), such as in legumes where wood ash effectively reduced the number of root-knot galls and nematode population in soil and roots (Ononuju and Nzenwa, 2011).

The organic system was the most effective system for suppressing PPN at different time points and for a longer duration, when compared to conventional and farmer practice. Organic amendments have been shown to increase antagonists of PPN, such as predatory nematodes (*Mononchus* and *Discolaimus*) (Kimenju et al., 2004; Oka, 2010) and nematode-trapping fungi (*Arthrobotrys oligospora*) (Wachira et al., 2009; Zhang et al., 2013). Similarly, Summers (2011) suggested that organic amendments, such as manure, result in multiplication of micro-organisms, including fungi and bacteria that might be parasitic to PPN. However, in both farmer and on-station trials, PPN densities had increased by the time of harvest of the crops in the organic system. This is common, as an increase in root mass enables nematode multiplication, in tandem with the declining residual effects of organic amendments, such as oil-seed cakes, which may only be effective for up to six months (Siddiqui and Alam, 1997).

In general, all the systems showed an inability to reduce the PPN in both farmer fields and on-station after the fourth month. Apart from the natural nematode multiplication mentioned above, a possible explanation could be due to weather conditions at the time, as it was hot and dry. Higher temperatures in general increase multiplication rates of PPN (Agrios, 2005; Coyne et al., 2014). These results also reflect a study by Wu et al. (2014), who found the greatest densities of PPN when mean soil temperatures were high.

The results of the current study indicate that time and farming systems had limited impact on PPN densities in either farmer or on-station fields. Although farmer fields were in different locations, they were all within close proximity and had the same soil classification, with efforts made initially to ensure similarity between the farmer fields. Furthermore, data collected over a short period (5 months), compared with long term experimental observations over several seasons or years may have some shortcomings (Duncan, 1986; Thornton and Matlack, 2002; Rizvi et al., 2012; Korthals et al., 2014).

5. Conclusion

Organic farming offers a promising nematode management alternative and was in no way inferior to conventional management, if not superior in terms of PPN management. In this study, we have demonstrated that organic farming at the practical on-farm level suppresses key PPN genera. The combination of three amendments known to suppress PPN may have contributed to this effect. Thus, organic farming can help to avoid over reliance and dependency on harmful toxic chemicals that can lead to environmental degradation. Policy development and extension services can therefore consider organic farming as an alternative method in managing soil-borne nematodes in small holder farms in sub-Saharan Africa. However, further studies with other crops, under arid conditions over longer periods of time and assessing top-dressing with organic amendments remain necessary to properly determine organic farming suppression of PPN.

Acknowledgements

This work was supported by the Swiss Agency for Development and Cooperation(SDC); Liechtenstein Development Service (LED); Coop Sustainability Fund (CSF) and Biovision Foundation. The views expressed herein do not necessarily reflect the official opinion of the donors. The lead author was supported by the Research Institute of Organic Farming (FiBL) under the “Farming Systems Comparison Trial in the Tropics” (SysCom) program in Kenya.

References

Abbasi, P.A., Riga, E., Conn, K.L., Lazarovits, G., 2005. Effect of neem cake soil amendment on reduction of damping-off severity and population densities of plant-parasitic nematodes and soil-borne plant pathogens. Can. J. Plant. Pathol. 27, 38–45.
Adamtey, N., Musyoka, M.W., Zundel, C., Cobo, J.G., Karanja, E., Fiaboe, K.K.M., Muriuki, A., Mucheru-Muna, M., Vanlauwe, B., Berset, E., Messmer, M.M., Gattinger, A., Bhullar, G.S., Cadisch, G., Fliessbach, A., Mäder, P., Niggli, P., Foster, D., 2016. Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya. Agric. Ecosyst. Environ. 235, 61–79.
Agrios, G.N., 2005. Plant Pathology, 5th edition. Elsevier Academic Press Publications, USA (pp 948).
Agyarko, K., Asante, J.S., 2005. Nematode dynamics in soil amended with neem leaves and poultry manure. Asian Journal of Plant Science 4, 426–428.
Akhtar, M., Malik, A., 2000. Roles of organic soil amendments and soil organisms in the biological control of plant-parasitic nematodes: a review. Bioresour. Technol. 74, 35–47.
Akpheokhai, I.L., Claudius-Cole, A.O., Fawole, B., 2012. Evaluation of some plant extracts for the management of *Meloidogyne incognita* on soybean (*Glycine max*). World J. Agric. Sci. 8, 429–435.
Bednarek, A., Gaugler, R., 1997. Compatibility of soil amendments with entomopathogenic nematodes. J. Nematol. 29, 220–227.
Bilevai, T., Choleva, B., Hockland, S., Ciancio, A., 2009. Management of Virus Transmitting Nematodes with Special Emphasis on South-East Europe in Integrated Management of Plant Pests and Diseases 4. Springer, Netherlands, pp. 215–242.
Bongers, T., Bongers, M., 1998. Functional diversity of nematodes. Applied Soil Ecology 10 (3).
Briar, S.S., Wichman, D., Reddy, G.V., 2016. Plant-parasitic nematode problems in organic agriculture. In: Nandawani, D. (Ed.), Organic Farming for Sustainable Agriculture. Springer International Publishing, pp. 107–122.
Bridge, J., 1996. Nematode management in sustainable and subsistence agriculture.

Annu. Rev. Phytopathol. 34, 201–225.
Cadet, P., Spaull, V.W., McArthur, D.G., 2002. Relationships between plant parasitic nematodes: abiotic soil factors and heterogeneity in growth of sugarcane in sandy soil in South Africa. Plant Soil 246, 259–271.
Chen, J., Ferris, H., 2004. Growth and nitrogen mineralization of selected fungi and fungal-feeding nematodes on sand amended with organic matter. Plant Soil 218, 91–101.
Coyne, D.L., Nicol, J.M., Claudius-Cole, B., 2014. Practical Plant Nematology: A Field and Laboratory Guide, 2nd edition. SP-IPM Secretariat, IITA, Cotonou, Benin (pp 82).
D'Addabbo, T., Papajová, I., Sasanelli, N., Radicci, V., Renčo, M., 2011. Suppression of root-knot nematodes in potting mixes amended with different composted bio wastes. Helminthologia 48, 278–287.
De Mendiburu, F., 2015. agricolae: Statistical Procedures for Agricultural Research. R Package Version 1. pp. 2–3. https://CRAN.R-project.org/package=agricolae.
Devi, L.S., Hassan, M.G., 2002. Effect of organic manures singly and in combination with *Trichoderma viride* against root knot nematode, *Meloidogyne incognita* of soybean (*Glycine max* L. Mrill). Indian J. Nematol. 32, 190–192.
Duncan, L.W., 1986. Effects of bare fallow on plant-parasitic nematodes in the Sahelian zone of Senegal. Revue de nematology 9, 75–81.
Ferris, H., Bongers, T., de Goede, R.G.M., 2001. A framework for soil food web diagnostics, extension of the nematode faunal analysis concept. Appl. Soil Ecol. 18, 13–29.
Gaur, H.S., Perry, R.N., 1991. The use of soil solarization for control of plant parasitic nematodes. Nematol. Abstracts 60, 153–167.
Hamida, A., Ameen, H.H., Mohamed, M.M., Alkelany, U.S., 2015. Effect of integrating inorganic fertilizer with either micronema, compost, or oxamyl on suppressing plant parasitic nematode *Meloidogyne incognita* infecting tomato plants under field conditions. Middle East J. Agric. Res. 4, 707–711.
Hockland, S., Niere, B., Grenier, E., Blok, V., Phillips, M., Nijs, L., Anthoine, L., Pickup, J., Viaene, N., 2012. An evaluation of the implications of virulence in non-European populations of *Globodera pallida* and *G. rostochiensis* for potato cultivation in Europe. Nematology 14, 1–13.
IUSS Working Group WRB, 2006. World Reference Base for Soil Resources 2006, World Soil Resources Reports No.103. 2nd edition. FAO, Rome.
KSU. Nematodes of Konza Prairie - Research Natural Area, Manhattan, Kansas. Kansas State University. (Access 01 July 2015), http://nematode.unl.edu/konzlistbutt.htm.
Kamidi, M., Cheruiyot, D., Osore, P., Barasa, G., 1999. Verification of the effect of organic manures and inorganic fertilizers on the yield of maize. In: A Key to Sustainable Land Use. Proceedings of the 17th Conference of the Soil Science Society of East Africa. 6–10 September.
Karanja, N.K., Kimenju, J.W., Macharia, I., Muiru, D.M., 2002. Plant parasitic nematodes associated with common bean (*Phaseolus vulgaris* L.) and integrated management approaches. In: 17 World Congress of Soil Science, Bangkok (Thailand). 14–21 Aug 2002.
Kaskavalci, G., 2007. Effects of soil solarization and organic amendment treatments for controlling *Meloidogyne incognita* in tomato cultivars in Western Anatolia. Turk. J. Agric. For. 31, 159–167.
Kimenju, J.W., Karanja, N.K., Macharia, I., 1999. Plant parasitic nematodes associated with common bean in Kenya and the effect on *Meloidogyne* infection on bean nodulation. Afr. Crop Sci. J. 7, 323–345.
Kimenju, J.W., Muiru, D.M., Karanja, N.K., Nyongesa, W.M., Miano, D.W., Mutua, G.K., 2004. Assessing the role of organic soil amendments in management of root knot nematodes on common bean, *Phaseolus vulgaris* L. J. Trop. Microbiol. Biotechnol. 3, 14–23.
Kimenju, J.W., Kagundu, A.M., Nderitu, J.H., Mambala, F., Mutua, G.K., Kariuki, G.M., 2008. Incorporation of green manure plants into bean cropping systems contribute to root- knot nematode suppression. Asian J. Plant. Sci. 7, 404–408.
Kimpinski, J., Gallant, C.E., Henry, R., Macleod, J.A., Sanderson, J.B., Sturz, A.V., 2003. Effect of compost and manure soil amendments on nematode and on yields of potato and barley: a 7-years study. J. Nematol. 35, 289–293.
Korthals, G.W., Thoden, T.C., Van den Berg, W., Visser, J.H.M., 2014. Long-term effects of eight soil health treatments to control plant-parasitic nematodes and *Verticillium dahliae* in agro-ecosystems. Appl. Soil Ecol. 76, 112–123.
Luc, M., Sikora, R.A., Bridge, J., 2005. Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, 2nd edition. CABI Publishing, Wallingford, UK (pp 896).
MacFarlane, S.A., Robinson, D.J., 2004. Transmission of plant viruses by nematode vectors in microbe- vector interactions. In: Gillespie, S.H., Smith, G.L., Osbourn, A. (Eds.), Vector-borne Diseases. Cambridge University Press, pp. 263–283.
McCann, J.C., 2005. Maize and Grace; Africa's Encounter with a New World Crop, 1500–2000. Harvard University Press, Cambridge, MA, pp. 1–15.
McDonald, A.H., Nicol, J.M., 2005. Nematode parasites of cereals. In: Luc, M., Sikora, R.A., Bridge, J. (Eds.), Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, 2nd edition. CABI Publishing, Wallingford, UK, pp. 131–192.
McSorley, R., 1999. Host suitability of potential cover crops for root-knot nematodes. J. Nematol . 31 (4S), 619.
McSorley, R., Gallaher, R.N., 1996. Nematode population changes and forage yields of six corn and sorghum cultivars. Suppl. J. Nematol. 23, 673–677.
McSorley, R., 2011. Overview of organic amendments for management of plant-parasitic nematodes, with case studies from Florida. J. Nematol. 43, 69–81.
Ministry of Agriculture, 2013. Economic Review of Agriculture. Central Planning and Monitoring Unit, MoA. Nairobi, Kenya: Ministry of Agriculture.
Neher, D.A., 1999. Nematode communities in organically and conventionally managed agricultural soils. J. Nematol. 31, 142–154.
Nyongesa, W.M., Miano, D.W., Mutua, G.K., 2004. Assessing the role of organic soil amendments in management of root knot nematodes on common bean, *Phaseolus vulgaris* L. J. Trop. Microbiol. 3, 14–23.
Odeyemi, I.S., Adewale, K.A., 2011. Phytonematoxic properties and nematicidal potential of *Tithonia diversifolia diversifolia* extract and residue on *Meloidogyne incognita* infecting yam (*Dioscorea rotundata*). Arch. Phytopathol. Plant Prot. 44, 1745–1753.
Odeyemi, I.S., Afolami, S.O., Daramola, F.Y., 2014. Evaluation of *Tithonia diversifolia diversifolia* and *Chromolaena odorata* residues as potential organic compost materials for the management of *Meloidogyne incognita* on cowpea (*Vigna unguiculata* L. Walp). J. Agric. Sci. Environ. 14, 73–81.
Oka, Y.H., 2010. New strategies for the control of plant parasitic nematodes. Pest Manag. Sci. 56, 983–988.
Okada, H., Harada, H., 2007. Effects of tillage and fertilizer on nematode communities in Japanese soybean field. Appl. Soil Ecol. 35, 582–598.
Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H.H., Wagner, H., 2016. Vegan: Community Ecology Package. R Package Version 2.3-5. https://CRAN.R-project.org/package=vegan.
Olabiyi, T.I., Oladeji, O.O., 2014. Assessment of four compost types on the nematode population dynamics in the soil sown with okra. Int. J. Org. Agric. Res. Dev. 9, 146–155.
Olaniyi, M.O., 2015. The use of botanicals in the management of plant parasitic nematodes. Int. J. Sci. Technol. 3, 300–309.
Ononuju, C.C., Nzenwa, P.O., 2011. Nematicidal effects of some plant extracts on egg hatchability and control of *Meloidogyne* spp. in cowpea (*Vigna unguiculata* (L:) Walp). Afr. J. Plant Sci. 5, 176–182.
Osei, K., Moss, R., Nafeo, A., Addico, R., Agyemang, A., Danso, Y., Asante, J.S., 2011. Management of plant parasitic nematodes with antagonistic plants in the forest-savanna transitional zone of Ghana. J. Appl. Biosci. 37, 2491–2495.
Perry, R.N., Moens, M., 2013. Plant Nematology, 2nd edition. CAB International, Oxford Shire, UK (pp 542).
R Core Team, 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org (Accessed February 2016).
Ragasa, C.Y., Tempora, M.M., Rideout, J.A., 2007. Terpenoids from *Tithonia diversifolia*. J. Res. Sci. Comput. Eng. 4, 1–7.
Renčo, M., Sasanelli, N., Kováčik, P., 2011. The effect of soil compost treatments on potato cyst nematodes *Globodera rostochiensis* and *Globodera pallida*. Helminthologia 3, 184–194.
Renco, M., Kovacik, P., 2012. Response of plant parasitic and free living soil nematodes to composted animal manure soil amendments. J. Nematol. 44, 329–336.
Rizvi, R., Mahmood, I., Tiyagi, S.A., Khan, Z., 2012. Effect of some botanicals for the management of plant-parasitic nematodes and soil-inhabiting fungi infesting chickpea. Turk. J. Agric. For. 36, 710–719.
Roberts, P.A., 1992. Current status of the availability, development, and use of host plant resistance to nematodes. J. Nematol. 24, 213–227.
Rodriguez-Kabana, R., 1986. Organic and inorganic nitrogen amendments to soil as nematode suppressants. J. Nematol. 18, 129–135.
Sasanelli, N., Ferri, D., Convertini, G., D'Addabbo, T., 2006. Nematicidal and agronomical effects of composted olive pomace amendments. In: Proceedings of the 12th Congress of the Phytopathological Union. 11-15 June. Rhodos Island, Greece. pp. 565–567.
Scow, K.M., Somasco, O., Gunapala, N., Lau, S., Venette, R., Ferris, H., Miller, R., Shennan, C., 1994. Transition from conventional to low-input agriculture changes soil fertility and biology. California Agric. 48, 20–26.
Sharma, S.B., 2001. Plant parasitic nematodes in Rice-Wheat Based Cropping Systems in Asia. In: Kataki, P. (Ed.), Rice-Wheat Based Cropping Systems in South Asia Present Status and Future Thrust. Haworth Press, London and Oxford, New York, pp. 227–247 239-251.
Sharma, S.K., Silva, J.D., Resck, D.V.S., Gomes, A., 2000. Nematode population dynamics in sewage sludge amended soil under maize cultivation. Nematol. Brasileira 24, 37–40.
Siddiqui, M.A., Alam, M.M., 1997. Integrated control of plant parasitic nematodes with organic soil amendments/nematicides and ploughing on okra. Proceedings-Indian National Science Academy Part B 63 545–550.
Sikora, R.A., Greco, N., Silva, J.F.V., 2005. Nematode parasites of food legumes. In: Luc, M., Sikora, R.A., Bridge, J. (Eds.), Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, 2nd edition. CABI Publishing, Wallingford, UK, pp. 259–318.
Stanton, J.M., Stirling, G.R., 1997. Nematodes as Plant Parasites. Plant Pathogens and Plant Diseases. In: Brown, J.F., Ogle, H.J. (Eds.), Rockvale Publications, Australia, pp. 127–142.
Stephan, Z.A., Hassan, M.S., Hassoon, I.K., 2002. Efficacy of fenamiphos, *Trichoderma harzianum*, *Paecilomyces lilacinus* and some organic soil amendments in the control of root knot and root-rot/wilt disease complex of eggplant. Arab J. Plant Prot. 20, 1–5.
Stirling, G.R., Halpin, N.V., Bell, M.J., 2011. A surface mulch of crop residues enhances suppressiveness to plant-parasitic nematodes in sugarcane soils. Nematropica 41, 107–119.
Summers, H., 2011. Effects of organic manure on nematode control. J. Dis. Pests Control Tropics 7, 190–191.
Thornton, C.W., Matlack, G.R., 2002. Long-term disturbance effects in the nematode communities of south Mississippi woodlands. J. Nematol. 34, 88.
Van den Brink, P.J., Ter Braak, C.J.F., 1998. Multivariate analysis of stress in experimental ecosystems by Principal Response Curves and similarity analysis. Aquat. Ecol. 32, 163–178.
Wachira, P.M., Kimenju, J.W., Okoth, S.A., Mibey, R.K., 2009. Stimulation of nematode destroying fungi by organic amendments applied in management of plant-parasitic nematode. Asian J. Plant Sci. 8, 153–159.
Wagate, P.N., Njoroge, C.R.K., Macharia, P.N., Chek, A.L., 2010. The Soil Conditions of the ICIPE Experimental Farm at Kiereni Primary School, Chuka (Meru South District). Kenya Soil Survey Detailed Report D85. pp. 125. http://www.kari.org/node/.

Wani, A.H., Bhat, M.Y., 2012. Control of root-knot nematode, *Meloidogyne incognita* by urea coated with Nimin or other natural oils on mung, *Vigna radiata* (L.) R. Wilczek. J. Biopesticides 5, 255–258.
Widmer, T.L., Abawi, G.S., 2000. Mechanism of suppression of *Meloidogyne hapla* and its damage by a green manure of Sudan grass. Plant Dis. 84, 562–568.
Wu, H.Y., He, Q., Liu, J., Luo, J., Peng, D.L., 2014. Occurrence and development of the cereal cyst nematode (*Heterodera avenae*) in Shandong, China. Plant Dis. 98, 1654–1660.
Yasmin, L., Rashid, M.H., Uddin, M.N., Hossain, M.S., Hossain, M.E., Ahmed, M.U., 2003. Use of neem extract in controlling root-knot nematode (*Meloidogyne javanica*) of sweet-gourd. J. Plant Pathol. 2, 161–168.
Yeates, G.W., Bongers, T., de Goede, R.G., Freckman, D.W., Georgieva, S., 1993. Feeding habits in soil nematode families and genera – an outline for soil ecologists. J. Nematol. 25, 315–331.
Zhang, S., Zhang, X., 2009. Effects of two composted plant pesticide residues incorporated with *Trichoderma viride* on root-knot nematode in ballon flower. Agric. Sci. China 8, 447–454.
Zhang, Y., Qiao, M., Xu, J., Cao, Y., Zhang, K.-H., Yu, Z.-F., 2013. Genetic diversity and recombination in natural populations of the nematode-trapping fungus *Arthrobotrys oligospora* from China. Ecol. Evol. 3, 312–325.
Zhong, W., Gu, T., Wang, W., Zhang, B., Lin, X., Huang, Q., Shen, W., 2010. The effects of mineral fertilizer and organic manure on soil microbial community and diversity. Plant Soil 326, 511–522.