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Distribution and management of root-knot nematodes (*Meloidogyne* spp.) in tomato (*Lycopersicum esculentum*) in North Shoa Zone, Ethiopia

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Abstract

A survey was conducted to assess the incidence and distribution of *Meloidogyne* spp., in major tomato growing districts (Kewet and Efratana Gidim) of the North Shoa Zone, Ethiopia. Soil and root samples were collected from 30 tomato farms represents six different localities of the two districts. The results revealed that the highest incidence percentage (80%) of the *Meloidogyne* species from root samples were recorded from three farms of district Kewet and three farms of district Efratana Gidim. *Meloidogyne incognita* and *M. javanica* were found infecting 70% of the surveyed tomato farms in mixture. *Meloidogyne incognita* was more prevalent than *M. javanica* from the surveyed tomato farms across the six localities. In a glasshouse experiment the intercropping of tomato with the antagonistic marigold followed by tomato with garlic intercropping was found highly reducing root galls, egg-mass and J_2 per plant as compared to the inoculated tomato-sole cropping and with other antagonistic plants. Further research is needed to evaluate the effectiveness of the antagonistic plants in the management of root-knot nematodes under farmer's field conditions.

Keywords: Antagonistic plants, distribution, incidence, intercropping, management

Tomato (*Lycopersicum esculentum* Miller) is cultivated as an annual crop in most regions of the world (Vossen van der *et al*., 2004). It is highly prized for its good financial returns and nutritional value especially for its richness in vitamins and minerals (Da Silva *et al*., 2008). The current world tomato production reached to more than 163.4 million tons cultivated on more than 4.6 million hectares of land (FAO, 2016). In Ethiopia, tomato is an important cash crop to the farmers and a widely cultivated vegetable crop both under irrigation and rain fed throughout the year (Lemma, 2002).

The production of tomato is influenced by both abiotic and biotic (pests and diseases) factors (Agrios, 2005). The latest statistics showed that the estimated losses due to plant parasitic nematodes (PPN) are worth US$ 118 billion worldwide (Atkinson *et al.*, 2012). The top most economically important obligate PPN genus is the root-knot nematode (RKN) distributed worldwide (Jones *et al*., 2013). RKN are the major pathogens of vegetables including tomato throughout the world (Sakhuja & Jain, 2001). There are over 101 described *Meloidogyne* species. The four commonly occurring RKN species are *M. incognita, M. javanica, M. hapla*

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and *M. arenaria* and have been reported from almost all the areas of tropical and temperate regions including Ethiopia (Seid *et al*., 2015; Seid *et al*., 2019). An average 10% yield loss is frequently cited for vegetables (Barker & Koenning, 1998; Koenning *et al*., 1999).

The occurrence of the RKN on tomato in Ethiopia was first reported by Stewart & Dagnachew (1967). Among these *M. incognita* is the most widespread species (Wondirad & Kifle, 2000). The occurrence of *M. incognita* had been reported on tomato in the eastern part of the country, particularly in eastern Hararghe where many vegetable crops were attacked by RKN (Tadele & Mengistu, 2000; Seid *et al*., 2019). Also the RKN, particularly *M. incognita*, was the major problem in tomato cultivation in the central and western parts reported by Mandefro & Mekete (2002); Seid *et al*., (2017). Hence, management of this nematode will remain an important objective of most nematology related researches.

As there is no study on the distribution, identification and management of *M. incognita* in the northern part of Ethiopia, the current study was designed with the following three objectives: 1) to identify *Meloidogyne* species from major tomato producing areas in North Shoa Zone; 2) to assess the distribution, incidence and occurrence of *Meloidogyne* species from major tomato producing areas in the North Shoa Zone and 3) to evaluate the effect of intercropping antagonistic crops with tomato crop to manage *M. incognita* under glasshouse condition.

Material and Methods

Study areas: Farm survey was conducted on two major vegetable (particularly tomato) producing districts (Kewet and Efratana Gidim) of North Shoa Zone, Amhara region, Ethiopia during the growing season of 2017/2018. Three kebeles or localities in each district were surveyed. The laboratory analysis and glasshouse experiment were conducted at Haramaya University, Plant Pathology Postgraduate laboratory East Hararghe, Ethiopia.

Sampling procedures: Ten root and soil samples were collected from five farms per locality. Soil samples along with roots were packed in labeled plastic bags and transported to Haramaya University, Plant Pathology Laboratory for further processing and identification. Extraction of nematodes from soil and root samples were done through modified Baermann funnel (Southey, 1970) and incubation with glass jar techniques (Mountain & Patrick, 1959), respectively.

Identification of *Meloidogyne* species: The root-knot species confirmation was based on the perineal pattern as described by Taylor & Sasser, 1978. Pure culture was maintained in the glasshouse as given by Seid *et al*., (2017).

Experimental design and treatments: There were a total of twelve treatments viz., Marmande + garlic; Marmande + mustard; Marmande + marigold; Marmande + tobacco; Marmande sole with inoculation; Marmande without inoculation; Moneymaker + garlic; Moneymaker + mustard; Moneymaker + marigold; Moneymaker + tobacco; Moneymaker sole with inoculation; Moneymaker without inoculation. Seeds of the tomato cultivars (Marmande and Moneymaker) were sown and raised in a sterilized soil with 1:2:3 proportions of sand, compost and clay, respectively, in plastic trays in a glasshouse. Three kg of autoclaved soil was filled into pots of 25 cm diameter size. Seeds of mustard, garlic, tobacco and marigold were planted directly into plastic pots. Four-week-old-seedlings of the tomato cultivars (Marmande and Moneymaker) were then transplanted into the pots. The antagonistic plants (mustard, garlic, tobacco and marigold) were planted on either side of the tomato seedlings in line with the treatments. The seedlings were inoculated with the suspension of *M. incognita* at a rate of 3000 second stage juveniles (J_2) per pot one week after transplanting (Youssef & El-Nagdi, 2015) and light watering was done as deemed necessary. The experiment was laid out in a factorial completely randomized design (CRD) with four replications. All agronomic practices were maintained as recommended to tomato until termination of the experiment.

Inoculums preparations: The pure culture of the *M. incognita* population used in this experiment was maintained for 10 weeks on Marmande at Haramaya University, glasshouse and used in inoculums preparation to be utilized in the glasshouse experiment.

Data collected: The incidence and frequency of occurrence of RKN in the survey were calculated according to Norton (1978) and Hussain *et al*., (2011).

The following data was collected sixty days after nematode inoculation (DAI).

Plant related parameters include days to 50% flowering (50FL Plant height (PH); Number of flowers per plant (NFPP); Root length (Rl); number of leaves per plant (Nl); fresh shoot weight; fresh root weight; dry shoot weight. RKN related parameters include number of galls per root system; number of egg-masses per plant; number of eggs per egg-mass; root gall index (RGI) and egg-mass index (EMI) based on 0 to 5 scale; where, 0 = no galls or egg masses; 1 = 1-2 galls or egg-masses; 2 = 3-10 galls or egg-masses; 3 = 11-30 galls or egg-masses; 4 = 31-100 galls or egg masses and 5 = >100 galls or egg-masses (Taylor & Sasser, 1978); final population density per pot (Pf) and reproduction factor (RF).

Data analysis: The data was subjected to the standard descriptive statistical analysis and analysis of variance (ANOVA) procedures using the Genstat 16th edition statistical software package for survey and glasshouse experiment, respectively. The least significant difference (LSD) at 5% level of probability procedure was used to separate differences among treatment means using Fisher's protected LSD test.

Results and Discussion

Identification of RKN species: RKN were identified on the basis of characteristics of the adult females and the morphology of male and J_2 described by Taylor & Sasser (1978). Based on the results, two species of RKN (*M. incognita* and *M. javanica*), were identified from 300 samples of 30 farms at 6 kebeles at two districts of North Shoa Zone, Ethiopia. For confirmation, the J_2 and female shape of the *M. incognita* populations recovered from this survey were compared with the pure culture of *M. incognita* which was molecularly identified by Seid *et al*., (2017). Female was identified on the basis of perineal pattern (Eisenback *et al*., 1981). The male *M. incognita* was identified on the characteristics given by Jepson (1987).

Incidence % and distribution of RKN species: The RKN species were recorded with varying degrees of incidence (0-80%) in the surveyed tomato farms representing six localities of Kewet and Efratana Gidim districts. The highest incidence of *Meloidogyne* species (80%) in the surveyed tomato farms were observed at three farms of district Kewet and three farms of district Efratana Gidim. Localities wise overall highest incidence % (60%) was observed in L_3 (Kobo) followed by 58% and 52% at L_5 (= Laygnaw Ataye) and L_2 (Merye), respectively. The minimum incidence of 38% was recorded from L_4 (Feredwuha) and L_6 (Hora) (Fig. 1). *Meloidogyne incognita* and *M. javanica* were found infecting 70% of the surveyed tomato farms in mixture. The incidence of the *Meloidogyne* species in the Kewet district was 50.67 % while in the Efratana Gidim district it was 44.7%. The overall incidence of *Meloidogyne* species on tomato crop in the two districts was 47.67% (Table 1). The high incidence of RKNs in these areas is due to the cropping system of tomato at most of the farms that had been under vegetable cultivation continuously for several years (Table 1). *Meloidogyne incognita* was more prevalent than *M. javanica* from all the surveyed tomato farms.

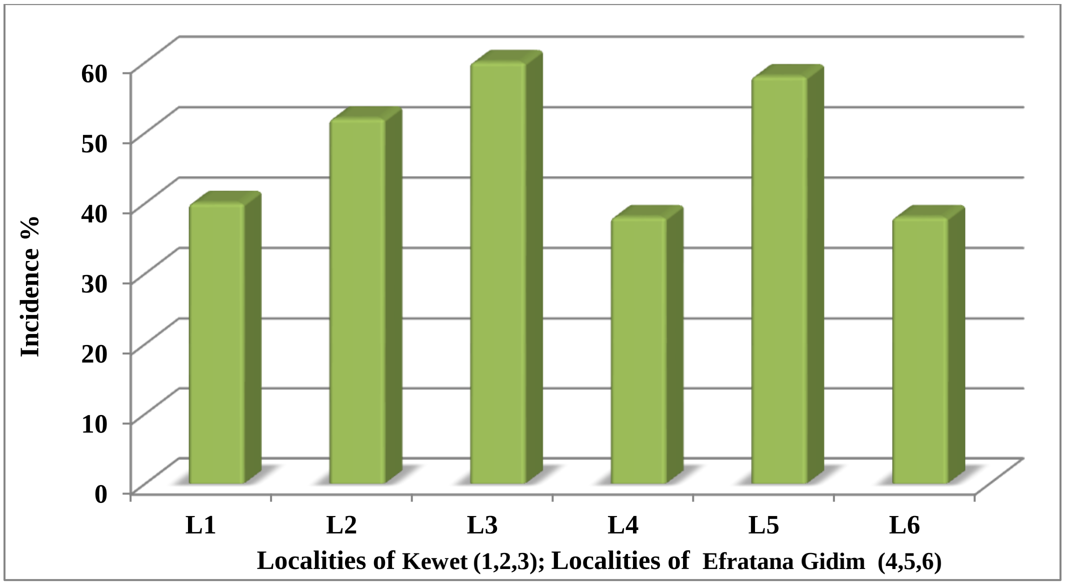

Fig. 1. Incidence % of RKN species at six localities of Kewet and Efratana Gidim Dictricts (Kewet: L_1= Wustibuay, L_2= Merye, L_3= Kobo; Efratana Gidim: L_4= Feredwuha, L_5= Laygnaw Ataye, L_6= Hora).

Table 1. Incidence and occurrence (%) of RKN species from Kewet and Efratana Gidim districts from the North Shoa Zone, Ethiopia during the 2017/ 2018.

Districts	Incidence (%)	Infected roots	Total samples	Occurrence (%) of RKN species		
				Mi +M j	Mi	Mj
Kewet	50.67	76	150	66.7	100	66.7
Efratana Gidim	44.7	67	150	60	100	60
Total	47.67	143	300	63.33	100	63.33

This finding was in complete agreement with the findings of Tadele & Mengistu (2000) who confirmed the presence of *M. incognita* dominantly in the vegetables crops of East Hararghe. Mandfro & Mekete (2002) reported the presence of *M. incognita* and *M. javanica* associated with several vegetable crops across the central rift valley and western Ethiopia using cytogenetic and perennial pattern identification and recently Seid *et al*., (2019) using DNA based identification confirmed the presence of *M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla* from major tomato growing areas of Ethiopia. The two species (*M. incognita* and *M. javanica*) were found dominantly distributed across major tomato growing areas in the rift valley, upper Awash and East Hararghe (Seid *et al*., 2019). The result of this study is also in complete agreement with Anamika & Devi (2010) where *M. incognita* was found predominantly in vegetable growing areas.

Occurrence % of RKN species: From the two species of RKN, *M. incognita* was found from all the 30 farms (100%) surveyed and *M. javanica* (63.33%) of the farms (Table 1). In cases where roots were found un-infected both *M. incognita* and *M. javanica* were also recovered from the soil samples indicating plants that is not infected does not necessarily imply absence of inoculum from soil. As the result indicated that in the Kewet district the percentage of *M. incognita* was higher than that of the Efratana Gidim district in North Shoa. The findings of this study have clearly demonstrated that *M. incognita* is widely distributed across the district of the North Shoa. During this study, the occurrence of *M. incognita* and *M. javanica* alone or in mixed populations recorded from all 30 tomato producing farms and considered the most common species in the studied area. The findings of this study are in agreement with that of the result of Anamika & Devi (2010). Based on the results of this survey, it could be hypothesized that *Meloidogyne incognita* is the most damaging pathogen of tomato crop in both districts of the North Shoa zone. This is also in agreement with the findings of Anwar & McKenry (2010).

The Glasshouse Experiment

Plant related parameters: Days to 50 % flowering and number of flowers per plant (NFPP). The analysis of variance revealed that in the un-inoculated control treatment early flowering (23.50) was recorded. The greatest number of days to attain 50% flowering was obtained from sole cropped tomato varieties Moneymaker (42.35%) and Marmande (42%) intercropped with mustard. The minimum number of flowers were recorded from the inoculated sole treatment of both tomato varieties Moneymaker and Marmande (6.50 and12.50), respectively. This result is in conformity with the finding of Ijoyah & Dzer (2012) who reported that greater number of days taken to achieve 50% flowering might have been a result of the inability of tomato plants intercropped with suppressive plants to accumulate enough thermal units required to induce early flowering (Table 2).

The result of this investigation revealed the two tomato varieties and nematode antagonistic intercrops had significantly higher effect on days to 50% flowering and number of flowers per plant as compared to the inoculated control of the two tomato varieties. These findings are related with the findings of Shahina *et al*., (2010) who had reported that tomato varieties/cultivars have been tested against RKN which shows its degree of susceptibility or resistance as well as genetic differences between nematode populations (Table 2).

Table 2. The interaction effect of intercropping of selected *Meloidogyne incognita* antagonistic plants with Moneymaker and Marmande tomato varieties on days to 50% flowering (50% DF), number of flowers per plant (NFPP) and fresh root weight (FRW) at Haramaya University in 2017/2018 under glasshouse conditions.

Treatment	50% DF		NFPP		FRW	
	Tomato varieties					
	Moneymaker	Marmande	Moneymaker	Marmande	Moneymaker	Marmande
Garlic	32.75b	34.00bcd	20.25d	27.75e	34.31e	38.19e
Tobacco	34.75bcd	33.25bc	11.50b	18.75d	22.21c	26.86d
Marigold	35.50cd	36.00d	20.75d	20.00d	23.14cd	14.22a
Mustard	43.25e	42.00e	10.50ab	14.25bc	20.83bc	14.84a
IC	43.00e	32.50b	6.50a	12.50b	15.06a	16.65ab
UIC	24.50a	23.50a	18.00cd	27.00e	22.17c	27.00d
LSD (5%)	2.43		4.14		4.42	
CV%	4.90		16.70		13.40	

Means followed by the same letter(s) within row and column in each character are not significantly different at 5% level of significance. LSD (5%) = Least significant difference; CV (%) = Coefficient of variation, UIC = Un-inoculated control treatment, IC = Inoculated control treatment with *M. incognita*, DF=days to 50% flowering, NFPP=Number of flowers per plant and FRW = Fresh root weight

Fresh root weight (FRW): The lowest FRW obtained from the inoculated sole treatment of both tomato varieties. Intercropping of Marmande and Moneymaker with garlic recorded the highest FRW (38.19 and 34.31 g), respectively. The FRW of tomato varieties was found to be high with all *M. incognita* suppressing plants as compared to their respective control due to formation of galls, egg-masses and longer extension of roots and more branches roots. This might be due to the effect of *M. incognita* on growth and reduction of biomasses by adversely affecting transportation and translocation of nutrients in tomato plant through roots. The result of this present study is in line with the finding of Facknath & Jadunundan (1990) who stated the efficacy of garlic as intercrop in improving the plant growth parameters especially FRW against *M. incognita* on tomato. When population density of *M. incognita* increased, root weight decreased significantly. The result of present study is similar with the study of Ameen (1996) who reported that the population of the *M. incognita* was significantly reduced when garlic was intercropped with tomato resulting by increasing root weight (Table 2).

Plant height (pH): The result showed that there were no significant differences between the tomato varieties (Moneymaker and Marmande). The highest pH (108.88 cm) was recorded in un-inoculated tomato sole cropping treatment followed by intercropping with marigold (108.25 cm) then with mustard (99.62 cm) (Table 3). The shortness of the plant height might be due to the stunting action of *M. incognita*. Jinfa *et al*., (2006) also reported the height reduction caused by the *M. incognita.* Among the tested antagonistic plant marigold was proved effective as shown with improved growth of the tomato varieties. This result is in agreement with the findings of Richard & Dupree (1998) who revealed that growing of marigold cultivars results in improved growth by reducing root galling in tomato. Similarly, Rangaswamy & Parvathareddy (1993) also reported that maximum shoot height was observed in tomato grown with marigold cultivars.

Table 3. **The effect of *Meloidogyne incognita*, antagonistic plant on plant height, number of leaves per plant, root length, fresh shoot weight and dry shoot weight of Moneymaker and Marmande tomato varieties at Haramaya University in 2017/18.**

Treatments	Plant Parameters				
	PH	**NL**	**RL**	**FSW**	**DSW**
Garlic	98.65b	37.75de	32.56b	147.20bc	19.66d
Tobacco	95.39b	32.88c	31.30b	120.70b	14.27b
Marigold	108.25c	35.5d	32.06b	152.90c	18.11cd
Mustard	99.62b	24.50b	23.87a	125.9bc	15.35bc
IC	74.20a	20.62a	21.62a	57.40a	5.67a
UIC	108.88c	41.00e	40.59c	132.70bc	19.92d
LSD at 5%	5.34	3.50	3.70	29.15	3.01
CV%	5.40	10.80	12.00	23.40	19.10
	Tomato Varieties				
Moneymaker	99.01	32.33	29.11a	122.20	15.00
Marmande	95.98	31.75	31.56b	123.40	15.99
LSD at 5%	3.083	2.02	2.136	16.83	1.737
CV%	5.40	10.80	12.00	23.40	19.10

Means followed by the same letter(s) within row and column in each character are not significantly different at 5% level of significance. LSD (5%) = Least significant difference; CV (%) = Coefficient of variation, UIC = Un-inoculated control treatment with *M. incognita*, IC = Inoculated control treatment with *M. incognita*, PH= Plant height, NL= Number of leaf, RL= Root length, FSW= Fresh shoot weight, DSW= Dry shoot weight

Number of leaves per plant: As showed in the result intercropping of garlic with tomato had significantly more influence on the number of leaves per plant next to un-inoculated sole cropping plant in comparison to the other treatments (Table 3). This study is similar with the study of Ali *et al*., (1995) who reported that garlic was effective in improving the number of leaves particularly shoot growth of the infected tomato.

Root length (RL): The result indicated that the un-inoculated plant had the greatest RL with no growth restriction due to the absence of *M. incognita*. The antagonistic plant garlic also had an effective performance on RL compared to the other antagonistic plants which could be due to the fact that garlic induced phytochemicals through its root for inhibiting infection, growth and development of *M. incognita*. These findings were similar with the finding of Zasada *et al*., (2002) who reported that allicin is phytotoxic to nematodes. The volatile antimicrobial substance allicin produced in garlic is active against several plant pathogenic bacteria and fungi and suppressed different PPN (Curtis *et al*., 2004; Agbenin *et al*., 2005).

Fresh shoot weight (FSW) and dry shoot weight (DSW): Among the treatments, the maximum (152.90 g) FSW was recorded from tomato varieties intercropped with marigold. The minimum (57.40 g) FSW was recorded from *M. incognita* inoculated sole tomato varieties. The result showed that the antagonistic crops had the higher FSW and suppressive effect in comparison to nematode inoculation tomato sole cropping (Table 3). This might be due to the interference of intercropping of bioactive plants which induced and released their own naturally contained chemicals. These results agreed with findings of Gommers & Bakker (1988) who stated that marigold roots release the chemical alpha-terthienyl which is one of the most naturally occurring toxic compounds against nematodes. This compound is nematicidal, insecticidal, antiviral and cytotoxic (Marles *et al*., 1992). The presence of alpha-terthienyl inhibits the hatching of nematode eggs (Siddiqui & Alam, 1988).

Glasshouse Experiment: Nematode Related Parameters

Number of root galls per plant: Root galling was significantly less in tomato intercropped with marigold (542.10) followed by with mustard (565.00) as compared to tomato sole cropping in inoculated treatment and intercropped with tobacco (923.0) which sets in the least gall reduction but in the highest tomato gall forming (Table 4). Larger-sized gall was observed on inoculated control treatment than to all cropping patterns of tomato plants (Fig. 2). These results were similar with the findings of Handoo *et al*., (1994) who reported that galls produced by *M. javanica* and *M. incognita* are large and irregular which are at some distance from the root tips. When the two tomato varieties intercropped with marigold and mustard resulted in a significant reduction on the number of RGPP compared to the *M. incognita* inoculated tomato sole cropping. The result showed that there was a significant reduction on root galls when marigold intercropped with tomato varieties (38%) which indicated that marigold had a great suppressive effect on *M. incognita* in comparison to the inoculated control. These findings are in conformity with the findings of Otipa *et al*., (2003) who revealed root galls were lower in tomato grown in association with marigold and higher nematode-suppressive effect than the other antagonistic plants. Ali *et al.*, (1995) reported that marigold planted with infested tomato plants had significantly declined the number of root galling and root galling indices. The root gall indices were equal in all other treatments based on the 0-5 scale (Taylor & Sasser, 1978) and have more than 100 galls in each treatment per root system except on the un-inoculated control treatment.

Table 4. The main effect of *Meloidogyne incognita* antagonistic plants on number of root galls, number egg-masses, egg-mass indices, final population density and reproduction factor of Moneymaker and Marmande tomato varieties at Haramaya University, Raree Research Station glasshouse in 2017/18.

Treatments	Nematode parameters								
	RGPP	% Red. over IC	EMPP	% Red. over IC	EMI	% Red. over IC	*Pf*	RF	% Red. over IC
Garlic	(2.76bc) 607.00	31	(2.22b) 187.80	57	4.75c	2	1320.00b	0.66b	57
Tobacco	(2.93d) 923.00	-5	(2.26b) 196.90	54	4.88c	-0.4	1561.00bc	0.78bc	48
Marigold	(2.72b) 542.10	38	(2.06b) 166.50	61	4.13b	15	1164.00b	0.58b	62
Mustard	(2.74b) 565.00	36	(2.32bc) 230.00	47	5.00c	-3	1766.00c	0.88c	42
IC	(2.91cd) 876.80	-	(2.56c) 431.80	-	4.86c	-	3056.00d	1.53d	-
UIC	0.00a	-	0.00a	-	0.00a	-	0.00a	0.00a	-
LSD at 5%	0.16		0.28		0.57		425	0.21	
CV%	6.6		14.3		14.2		28.4	28.4	
	Tomato varieties								
Moneymaker	(2.31) 531.00		(1.89) 188.00		4.00		1338.00a	0.67a	
Marmande	(2.37) 640.00		(1.91) 216.00		3.88		1617.00b	0.81b	
LSD at 5%	0.09		0.16		0.33		245.4	0.12	
CV%	6.6		14.3		14.2		28.4	28.4	

Number in the brackets was logarithmic transformations (logy+1), where y, original value. Where, Means followed by the same letter(s) within row and column in each character are not significantly different at 5% level of significance. LSD (5%) = Least significant difference; CV (%) = Coefficient of variation, UIC= Un-inoculated control treatment with *M. incognita*, IC = Inoculated control treatment with *M. incognita*, RGPP= Root galls per plant, EMPP= Egg-masses per plant, EMI= Egg-mass indexes, FPD= Final population density R= Reduction, RF= Reproduction factor

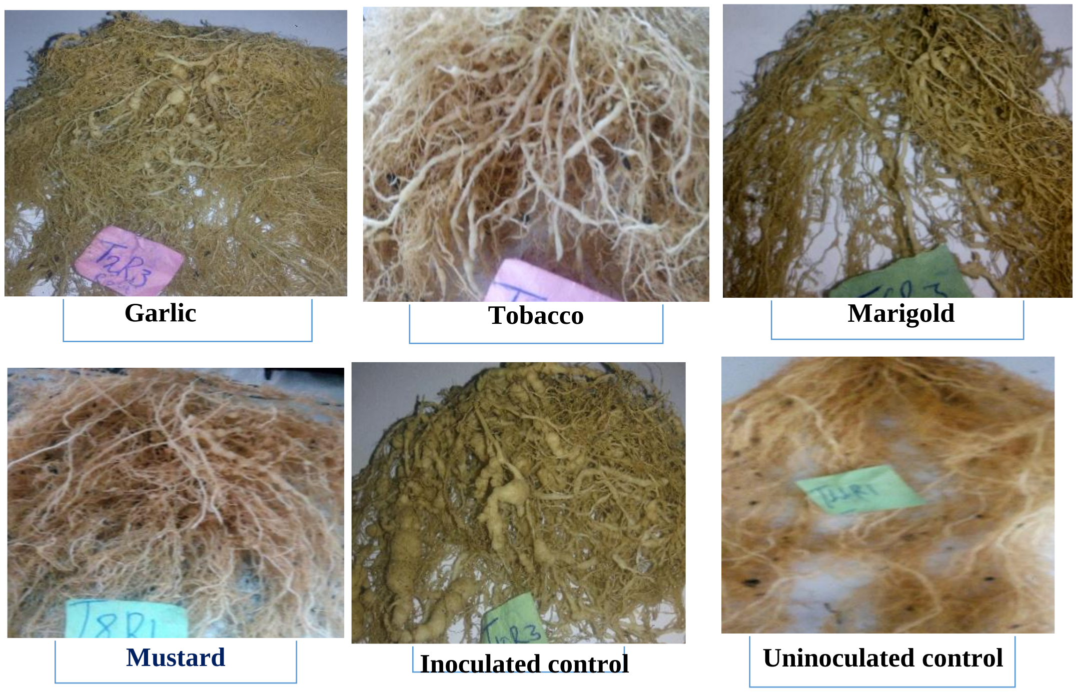

Fig. 2. Root damage and size of root-galls on the tomato variety Marmande intercropped with different *M. incognita* antagonistic plants at Haramaya University glasshouse in 2017/18.

Number of egg-masses per plant (EMPP) and egg-mass index (EMI): The maximum (431.80) mean number of EMPP but the least suppressive effect to *M. incognita* was observed in the inoculated tomato sole cropping treatment. The lowest (166.50) mean number of EMPP was recorded in the tomato varieties intercropped with marigold treatment except the un-inoculated control (Table 4). The EMI was highest (5.00) in the treatments where tomato was grown with mustard inoculated with *M. incognita*, while the lowest EMI (4.12) were from tomato intercropped with marigold except the un-inoculated control. This finding is in agreement with the finding of Otipa *et al*., (2003) who reported egg-mass indices were lower in tomato grown in association with marigold and higher nematode-suppressive effect than the other antagonistic plants. In this study the egg-mass indices, number of nematode population and reproduction factors had direct relation with the number of egg-masses in all treatments except one treatment on the egg-mass index (Fig. 2). This is in line with the result of Karssen & Moens (2006) who revealed that the root-knot index, nematode population and damage to the crop were found directly proportional to the egg-mass or nematode reproduction.

Final population density (Pf) and reproduction factor (RF): From the result Moneymaker was found lower *Pf* and RF than Marmande. The lowest *Pf* and RF (1164.00 and 0.58, respectively) was recorded from tomato intercropped with marigold, whereas the highest *M. incognita Pf* and RF (3056.00 and 1.53, respectively) was recorded from tomato varieties sole cropping inoculated with *M. incognita* (Table 4). Marigold was found to have the highest level of nematode suppression potential and limited population measured by number of juveniles in the soil. In *Pf* and RF the result obtained from marigold reduced a maximum number of hatched juveniles in the soil and infected roots. This might be due to the inhibition of *M. incognita* egg hatching and killing by inducing nematode suppressing chemicals through their roots. This finding is in agreement with the finding of Otipa *et al*., (2003) who reported a decline in nematode numbers and was observed in plots where tomato was intercropped with marigold cultivars. Similarly, Bello *et al.,* (2014) reported that marigold reduced the population of the species of RKN in vegetables. Species of marigold (*Tagetes* spp.) can successfully reduce populations of *Meloidogyne* species as well as other species (Viaene *et al*., 2006).

Conclusion

In this study, the incidence of RKN ranged from 0 to 80% with an average of 44%. The results showed that 70% of the tomato farms were infested. The occurrence of *M. incognita* was 100% and *M. javanica* 63.33%. Based on the survey, *Meloidogyne incognita* and *M. javanica* were found singly or in mixture and the former was the predominantly found species from the survey. From the glasshouse study intercropping antagonistic plants with tomato varieties had a significant improvement on tomato growth, biomass and showed suppressive effect on galling intensity and nematode population. Among the tested treatments, the intercropping of tomato varieties with the antagonistic marigold plant followed by with garlic was the most effective in reducing galling intensity, egg-masses per plant and nematode population per pot. In general, intercropping antagonistic plants with tomato varieties could be used as an alternative method for the management of *M. incognita* in tomato production. However, further research is needed to evaluate their efficacies under farmer's field conditions.

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References

Agbenin, N. O., Emechebe, A. M., Marley, P. S. & Akpa, A. D. (2005). Evaluation of nematicidal action of some botanicals on *Meloidogyne incognita in vivo* and *in vitro*. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 106, 29-39.

Agrios, G. N. (2005). *Plant pathology*, 5th Edition. Elsevier Academic Press, Burlington, M. A., USA.

Ali, E. M., EI-Eraki, S., Anter, E. A. & EI-Gindi, A.Y. (1995). Comparative effect of garlic and marigold (*Tagetes erecta*) on *M. incognita* by intercropping or rotation with infected tomato. *Egyptian Journal of Agriculture Research*, 73, 935-942.

Ameen, H. H. (1996). Influence of garlic *Allium sativum* on populations of *Rotylenchulus reniformis* and *Meloidogyne incognita* infecting cowpea and tomato. *Al-Azhar Journal of Agricultural Research*, 23, 77-85.

Anamika, S. S. & Devi, J. (2010). Survey report on incidence and intensity of root-knot nematode (*Meloidogyne incognita*) on spinach (*Spinacea oleracea*) in U. P. and Bihar. *European Journal of Applied Sciences*, 2, 51-54.

Anwar, S. A. & McKenry, M. V. (2010). Incidence and reproduction of *Meloidogyne incognita* on vegetable crop genotype. *Pakistan Journal of Zoology*, 42, 135-141.

Atkinson, H. J., Lilley, C. J. & Urwin, P. E. (2012). Strategies for transgenic nematode control in developed and developing world crops. *Current Opinion in Biotechnol*ogy, 23, 251-256.

Barker, K. R. & Koenning, S. R. (1998). Developing sustainable systems for nematode management. *Annual Review of Phytopathology*, 36, 165-205.

Bello, T. T., Fawole, B. & Claudius-Cole, A. (2014). Management of root-knot nematodes (*Meloidogyne* spp.) on tomato using antagonistic plants. *Journal of Biology, Agriculture and Healthcare*, 4, 97-100.

Curtis, H., Noll, U., Stormann, J. & Slusarenko, A. J. (2004). Broad-spectrum activity of the volatile *Phytoanticipin allicin* in extracts of garlic (*Allium sativum* L.) against plant pathogenic bacteria, fungi and oomycetes. *Physiological and Molecular Plant Pathology*, 65, 9-89.

Da Silva, H. D. J., Abreu, F. B., Caliman, F. R. B., Antonio, A. C. & Vinood , B. P. (2008). Tomatoes: Origin, Cultivation Techniques and Germplasm Resources. In: *Tomatoes and Tomato Products, Nutritional, Medicinal and Therapeutic Properties*. New Hampshire, USA: Enfarm.

Eisenback, J. D., Hirschmann, H., Sasser, J. N. & Triantaphyllou, A. A. (1981). *A guide to the four most common species of root-knot nematodes,* (*Meloidogyne species) with a pictorial key*. A Coop. Publication, Department of Plant Pathology and Genetics, North Carolina State University, and U.S. Agency for International Development, Raleigh, North Carolina, 48 pp.

Facknath, S. & Jadunundan, J. K. (1990). Potential of neem and tagetes plants as nematicides against *Meloidogyne incognita* infesting tomato. *Reveue Agricole ed sueriese de I'ile Maurice*, 69, 75-85.

Food & Agricultural Organization (2016). Food and Agricultural Organization statistics book on national crop production. Rome, Italy, Food and Agriculture Organization of the United Nations.

Gommers, F. J. & Bakker, J. (1988). Physiological diseases induced by plant responses or products. In: Poinar, G. O. & Jansson, H. B. (Eds.) *Diseases of nematodes*, Vol. 1. CRC Press, Boca Raton, Florida. 3-22 pp.

Handoo, Z. A., Golden, A. M., Chitwood, D. J., Haglund, W. A., Inglis, D. A., Santo, G. S., Baldwin, J. G. & Williams, D. J. (1994). Detection of pea cyst nematode (*Heterodera goettingiana*) in pea in western Washington. *Plant Diseases*, 78, 831.

Hussain, M. A., Mukhtar T. & Kayani M. Z. (2011). Assessment of the damage caused by *Meloidogyne incognita* on okra. *Journal of Animal and Plant Science*, 21, 857-861.

Ijoyah, M. O. & Dzer, D. M. (2012). Yield performance of okra (*Abelmoschus esculentus* L. Moench) and Maize (*Zea mays* L.) as affected by time of planting maize in Makurdi, Nigeria. *International Scholarly Research Network ISRN Agronomy*, Article ID 485810, 1-7.

Jepson, W. P. (1987). The flow characteristics in horizontal slug flow. In: *Proceedings of Third International Conference on Multiphase Flow*, The Hague, Netherlands, pp. 187-198.

Jinfa, Z., Waddell, C., Sengupta, G. C., Potenza, C. & Cantrell, R. G. (2006). Relationships between root-knot nematode resistance and plant growth in upland cotton galling index as a criterion. *Crop Science*, 46, 81-86.

Jones, J. T., Haegemen, A., Danchin, E. G. J., Gaur, H. S., Helder, J., Jones, M. G. K., Kikuchi, T., Palomares-Rius, J. E., Wesemael, W. M. L. & Perry, R. N. (2013). Top 10 plant-parasitic nematodes in molecular plant pathology. *Molecular Plant Pathology*, 14, 946- 961.

Karssen, G. & Moens, M. (2006). The plant-parasitic nematode genus *Meloidogyne* Göldi, 1892 (Tylenchida) in Europe. Leiden, The Netherlands: Brill.

Koenning, S. R., Overstreet, C., Noling, J. W., Donald, P. A., Becker, J. O. & Fortnum, B. A. (1999). Survey of crop losses in response to phytoparasitic nematodes in the United States for 1994. *Journal of Nematology*, 31, 587-618.

Lemma, D. (2002). Research experience and production prospects. In: *Proceeding of Ethiopian Agricultural Research Organization (EARO*), Addis Ababa, Ethiopia, pp 20-28.

Mandefro, W. & Mekete, T. (2002). Root-knot nematodes on vegetable crops in central and western Ethiopia. *Pest Management Journal of Ethiopia*, 6, 37-44.

Marles, R. J., Hudson, J. B., Graham, E. A., Breau, C. S., Morand, P., Compadre, R. L., Compadre, C. M., Towers, G. H. N. & Arnason, J. T. (1992). Structure-activity studies of photoactivated antiviral and cytotoxic thiophenes. *Phytochemistry and Phytobiology*, 56, 479-487.

Mountain, W. B. & Patrick, Z. A. (1959). The peach replant problem in Ontario: VII. The Pathogenicity of *Pratylenchus penetrans* (Cobb, 1917) Filipjev and Schuurmans Stekhoven, 1941. *Canadian Journal of Botany*, 37, 459-470.

Norton, D. C. (1978). *Ecology of plant parasitic nematodes*. New York: John Willey and Sons, New York, 268 pp.

Otipa, M. J., Kimenju, J. W., Mutitu, E. W. & Karanja, N. K. (2003). Potential rotation crops and cropping cycles for root-knot (*Meloidogyne* spp.) nematode control in tomato. *African Crop Science Conference Proceedings*, 6, 191-197.

Rangaswamy, S. D. & Parvathareddy, P. (1993). Effect of leaf extracts of trap crops on the growth of tomato and development of *Meloidogyne incognita*. *Current Nematology*, 4, 7-10.

Richard, D. A. & Dupree, A. W. (1998). The effectiveness of ten kinds of marigolds and five other treatments for the control of four species of *Meloidogyne*. *Journal of Nematology*, 10, 296-297.

Sakhuja, P. K. & Jain, R. K. (2001). Nematode diseases of vegetable crops and their management. In: *Diseases of fruits and vegetables and their management* (Ed.) T. S. Thind, Kalyani Pub, Ludhiana (India), 439-459 pp.

Seid, A., Fininsa, C., Mekete, T., Decraemer, W. & Wesemael, W. M. L. (2015). Tomato (*Lycopersicon esculentum* L.) and root-knot nematodes (*Meloidogyne* spp.) – century old battle. *Nematology*, 17, 995-1009.

Seid, A., Fininsa, C., Mekete, T., Decraemer, W. & Wesemael, W. M. L. (2017). Resistance screening of clones and commercial tomato cultivars against *Meloidogyne incognita* and *M. javanica* populations (Nematoda) from Ethiopia. *Euphytica*, 213, 97.

Seid, A., Fininsa, C., Mekete, T., Decraemer, W. & Wesemael, W. M. L. (2019). Biodiversity of *Meloidogyne* spp. from major tomato growing areas of Ethiopia. *European Journal of Plant Pathology*, 153, 1-16.

Shahina, F., Zarina, B., Firoza, K., Soomro, M. H. & Javed, N. (2010). Research on root-knot nematode, *Meloidogyne* by Pakistani Scientists: A review with description of species prevalent in Pakistan. *Pakistan Journal of Nematology*, 27, 1-115.

Siddiqui, M. A. & Alam, M. M. (1988). Control of root-knot, reniform and stunt nematodes by nimbin seed dressing. *Nematologia Mediterranea*, 18, 19-22.

Southey, J. E. (1970). *Laboratory methods for work with plant and soil nematodes*. Ministry of Agriculture, Fisheries and Food, Her Majesty's Stationery Office, London, 148 pp.

Stewart, B. & Dagnachew, Y. (1967). Index of Plant diseases in Ethiopia. Haileselassie I University, College of Agricultural Experimental Station Bulletin. No. 30. Debrezeit, *Ethiopia*, p. 95.

Tadele, T. & Mengistu, H. (2000). Distribution of *Meloidogyne incognita* (Root-knot nematode) in some vegetables farms in eastern Ethiopia. *Pest Management Journal of Ethiopia*, 4, 77-78.

Taylor, A. & Sasser, J. (1978). Biology, identification and control of root-knot nematodes (*Meloidogyne* species). Department of Plant Pathology, North Carolina State University and U.S. Agency for International Development, Raleigh, NC, USA, 111pp

Viaene, N., Coyne, L. D. & Kerry, B. R. (2006). Biological and cultural management..In: Perry, R. N. and Moens, M. (Eds.). *Plant Nematology*. CAB International, Wallingford, UK. pp. 346-369

Vossen van der, H. A. M., Nono-Wondin, R. & Messiaen, C. M. (2004). *Lycopersicon esculentum* Mill. The Netherlands: CTA; Leiden.

Wondirad, M. & Kifle, D. (2000). Morphological Variations of root-knot nematode population from Ethiopia. *Pest Management Journal of Ethiopia*, 4: 19-28.

Youssef, M. M. A. & El-Nagdi, W. M. A. (2015). Host status of some imported sugar beet varieties to *Meloidogyne incognita* in Egypt. *Pakistan Journal of Nematology*, 33, 167-171.

Zasada, I. A., Ferris, H. & Zheng, L. (2002). Plant sources of Chinese herbal remedies: Laboratory efficacy, suppression of *Meloidogyne javanica* in soil and phytotoxicity assays. *Journal of Nematology*, 34, 124-129.