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RESEARCH ARTICLE

Effects of *Canavalia ensiformis* and *Mucuna pruriens* intercrops on *Pratylenchus zeae* damage and yield of maize in subsistence agriculture

O. J. Arim · J. W. Waceke · S. W. Waudo · J. W. Kimenju

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Abstract Host status of four leguminous cover crops [*Canavalia ensiformis* (L.) DC. (Jack bean), *Crotalaria ochroleuca* G. Don (Sunnhemp), *Lablab purpureus* L. (Hyacinth bean) and *Mucuna pruriens* (L.) DC. (velvet bean)] to *Pratylenchus zeae* Filipjev and effects of intercropping *C. ensiformis* and *M. pruriens* with Pan5195, H627 and Emap11 maize cultivars on *P. zeae* population and disease severity on maize were determined in greenhouse and field tests. *Pratylenchus zeae* significantly ($P < 0.05$) reduced growth of *C. ochroleuca* by 36% but had no effect on *C. ensiformis*, *M. pruriens* and *L. purpureus*. While *C. ensiformis, M. pruriens* and *L. purpureus* reduced *P. zeae* population, *C. ochroleuca* increased it. In the greenhouse test, intercropping maize with *C. ensiformis* significantly ($P < 0.05$) improved maize growth by up to 34%, Nematode populations in the roots of maize intercropped with either *C. ensiformis* or *M. pruriens* were significantly ($P < 0.05$) reduced by up to 32% while nematode disease severity in these intercropping systems was reduced by up to 26%. In the field test, intercropping Emap11, Pan5195 and H627 with *C. ensiformis* significantly ($P < 0.05$) increased maize grain yield by 190, 29 and 22%, respectively. Intercropping H627 with *M. pruriens* significantly ($P < 0.05$) increased maize grain yield by 12%, but grain yields of Pan5195 and Emap11 declined by 79 and 40%, respectively. Root necrosis and soil nematode populations in the *C. ensiformis*–maize intercrop declined by up to 50 and 30%, respectively. Under pure maize stands, soil nematode populations increased by up to 35% in 90 days relative to the initial nematode population of three nematodes g^{-1} of fresh soil.

Keywords Leguminous cover crops · Lesion nematodes · Subsistence agriculture · *Zea mays*

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Introduction

In Kenya, maize (*Zea mays* L.) is an important source of income, contributing 3% gross domestic product and a cheap source of carbohydrate with an average consumption of 120–125 kg per person per annum (contributing 40–45% of total calorie consumed) (Muhammad and Underwood 2004). The current average production of between 1.5 and 2 t ha^{-1} is far below the germplasm potential of 3–7 t ha^{-1} and cannot support the 2–3% per year increase in its demand (Muhammad and Underwood 2004).

Plant parasitic nematodes, insects and low soil fertility are some of the important maize production constraints causing yield losses of up to 5 t ha^{-1} annually (Muhammad and Underwood 2004). *Pratylenchus zeae*, a lesion nematode, is the most economically important nematode causing up to 50% yield losses in heavily infested fields (Kimenju et al. 1998; Waceke et al. 2002). These yield losses have continued unabated in subsistent farming systems due to low feasibility of conventional nematode management practices such as resistance, crop rotation, fallowing and use of nematicides. So far no resistant cultivars have been identified among existing maize germplasm in Kenya (Kimenju et al. 1998; Arim et al. 2002). While small land sizes make crop rotation and fallowing impractical, high costs and associated environmental hazards limit the use of nematicides on low value crops such as maize.

Although use of leguminous crops such as *Sesbania sesban* L., *Tephrosia volgelii* L. and *Crotalaria spectabilis* Roth. *C. juncea* L. *C. pumila* Hochst and Steud, *C. mucronata* Desv. as short season fallows has been reported to increase subsequent maize yield by up to 138% and reduce some plant parasitic nematodes, loss of season during fallowing has been reported to slow their adoption as fallow crops (Al-Rehiayani and Hafez 1998; Desaeger and Rao 2001). Due to the above shortcomings, intercropping of maize with leguminous crops such as *Crotalaria* spp., *L. purpureus*, *Vigna ungulata* L., *Phaseolus vulgaris* L. and *M. pruriens*, a common practice in maize-based cropping systems, would provide a viable alternative for nematode management. For besides acting as repellants, the intercrops may interfere with host–plant location by the pest, favor population build-up of nematode antagonists and enhance plant resistance to nematodes through improved nutrient status and growth vigor (Palm 1995; McIntyre et al. 2001). Information on host status of locally grown leguminous crops such as *C. ensiformis*, *C. ochroleuca*, *L. purpureus* and *M. pruriens* to *P. zeae*, and their impact when intercropped with maize is lacking. Besides supplying maize with N through atmospheric N fixation and preventing soil erosion, the cover crops are also used as green manures, cheap sources of food [grain (*L. purpureus*) and leaves (*C. ochroleuca*)], fodder (*M. pruriens*) and for controlling moles (*C. ensiformis*) (Palm 1995; Wortman et al. 2000). Greenhouse and on-farm tests, therefore, were conducted to determine the host status of the four cover crops to *P. zeae* and the effect of intercropping them with maize on *P. zeae* population build-up, disease severity and crop performance.

Materials and methods

Tests were conducted in a greenhouse at Kenyatta University, Nairobi and in a farmer's field, in Kibing'oti location (0°34′ S, 37°11′ E, 1354 masl) Kirinyaga district within the Central Highlands of Kenya.

Greenhouse tests

Four leguminous cover crops, *C. ensiformis* (L.) DC., *C. ochroleuca* G. Don, *L. purpureus* L. and *M. pruriens* (L.) DC. were evaluated for response to *P. zeae* Filipjev. Seeds were obtained from the Kenya Agriculture Research Centre (KARI)—Embu. Three commercial maize varieties; Pan5195, H627 and Emap11 grown in the study area were used.

Greenhouse test 1: host status of leguminous crops to *P. zeae*

Seeds of four leguminous crops were pre-germinated on petri-dishes lined with moistened filter paper and planted immediately after emergence into 15-cm-diameter plastic pots containing 2.0 kg of sterilized soil. The soil, a sandy-loam soil (60% sand, 24% silt, 16% clay, 0.6% organic matter, pH 5.4) obtained from Kenyatta University Botany Research Farm was sieved using a 2 mm sieve and autoclaved at 121°C and 11 kg cm^{-2} pressure for 1 h. The soil was mixed with 690 mg N kg^{-1} of soil before adding into the 15 cm-diameter plastic pots. One seedling was maintained in each pot and watered regularly to maintain soil moisture at field capacity.

Seven days after planting the seeds, six pots were inoculated with 2000 *P. zeae* per pot (1-nematode g^{-1} of soil) while the remaining ones were not inoculated and served as controls. The nematode inoculum was isolated from maize roots obtained from the field study area, identified by a local expert and multiplied

on a susceptible maize cultivar (H625) (Arim et al. 2002) in the greenhouse. The inoculum was extracted from 90-day-old maize roots using a maceration-filtration technique (Fallis 1943) and standardized to 200 nematodes ml^{-1} suspension. Inoculation involved making a 6 cm deep depression around the rhizosphere of the seedling and dispensing 10 ml of the nematode suspension into the depression and covering with soil. Pots were arranged in a Randomized Complete Block Design (RCBD).

The experiment was terminated 60 days after inoculation and plant growth (plant height, fresh shoot, dry shoot and fresh root weights) and disease assessment parameters (root necrosis, reproductive factor and number of nematodes in roots and soil) determined. Plant height was measured from the first leaf node to the shoot apex. Plants were gently uprooted, shoots were cut at the soil line and their fresh weights determined before oven drying them at 60°C for 3 days and determining their dry weights. Soil was gently shaken off from the roots to minimize damage of fine roots. Roots were gently washed, blotted dry and fresh weights determined. Clean roots were cut into 5 cm long segments and thoroughly mixed before taking a 10 g root sub-sample for root necrosis (disease severity) assessment using a 0–4 necrosis index scale where 0 = no root damage, 1 = light root damage, 2 = moderate root damage, 3 = severe root damage, 4 = very severe root damage (Bridge and Gowen 1993). After root necrosis was determined, the 10 g root sub-sample was divided into two equal sub-samples. One sub-sample was oven dried at 60°C for 3 days and nematodes were extracted from the other sub-sample using a maceration-filtration technique (Fallis 1943). The number of nematodes recovered was expressed per gram dry root.

The soil was thoroughly mixed before taking a 200 g soil sub-sample for assessing nematode population. The nematodes were extracted using extraction—tray method (Thomas 1959) before enumerating them. A nematode reproductive factor (Rf) was determined by expressing final nematode population (P_f) as a ratio of initial population (P_i). The P_f was determined by computing the total number of nematodes recovered from both the roots and soil. The cover crops were rated as excellent hosts (Rf > 10), good hosts ($10 \geq Rf \geq 1.5$), poor host ($1 \leq Rf < 1.5$) and non-host (Rf < 1) (Ferris et al. 1993).

Greenhouse test 2: intercropping maize with cover crops

The experimental procedures, design and growth medium used in this test were as described in greenhouse test 1. *Canavalia ensiformis* and *M. pruriens*, non-hosts to *P. zeae* as revealed in experiment 1 were intercropped with H627, Pan5195 and Emap11. The nine treatment combinations were Pan5195 alone, Pan5195+*C. ensiformis*, Pan5195+*M. pruriens*, H627 alone, H627+ *C. ensiformis*, H627+ *M. pruriens*, Emap11 alone, Emap11+ *C. ensiformis* and Emap11+ *M. pruriens* with sole maize treatments serving as controls for the respective intercropping systems. The pre-germinated seeds were planted into 25-cm-diameter plastic pot containing 4 kg of the growth medium. Seven days after planting the seeds, each treatment was inoculated with 4000 *P. zeae* per pot except for the controls. The treatments were arranged in a RCBD.

The experiment was terminated 90 days after inoculation and maize plant growth and nematode disease assessment parameters determined. Maize root necrosis index was determined from 20 g root samples while nematode populations in root were determined from two 10 g sub-samples as described for experiment 1. The final nematode population (P_f) for sole maize stands was determined as in experiment 1 while for the intercropped maize, P_f was based on number of nematodes recovered from 10 g of maize roots, 10 g of cover crop roots and 200 g soil sub-sample. Based on Rf values, sole stands and intercropping systems were rated as most suppressive (Rf < 1), suppressive ($1 \leq Rf < 1.5$) and least suppressive ($Rf \geq 1.5$) to *P. zeae* (Ferris et al. 1993).

Field experiment: Intercropping of maize with cover crops

The treatment combinations in greenhouse test 2, Pan5195 alone, Pan5195+*C. ensiformis*, Pan5195+*M. pruriens*, H627 alone, H627+ *C. ensiformis*, H627+ *M. pruriens*, Emap11 alone, Emap11+ *C. ensiformis* and Emap11+ *M. pruriens* were repeated in the field on 3×4 m plots. Each cropping system was replicated thrice in a RCBD. Maize seeds were planted at a spacing of 25×75 cm. *Canavalia ensiformis* and *M. pruriens* seeds were planted in single rows between two maize rows in appropriate plots at an intra-row

spacing of 25 cm, 2 weeks after planting the maize. For both maize and cover crops, one seed was planted per hill and P fertilizer applied at the recommended rate of 60 kg P_2O_5 ha^{-1}. Four weeks after planting, maize was top-dressed with N at the recommended rate of 60 kg N ha^{-1}. The plots were irrigated once per week using overhead irrigation and kept weed—free throughout the experimental period.

The initial soil nematode population per 200 g soil sub-sample was determined before maize and cover crops were sown. The soil was randomly sampled from each plot and thoroughly mixed before taking the soil sub-sample. Soil nematode population changes were also determined by obtaining samples from around the rhizosphere of maize 45 and 90 days after planting. The soil was composited and a 200 g sub-sample taken for nematode population determination. Root necrosis and nematode population in roots of maize were determined 90 days after planting. Maize from each cropping system was dried, shelled and yields determined 150 days after planting.

Data analysis

For experiment 1, Student *t*-test statistics were used to test for significant differences between plant growth parameters of non-inoculated and inoculated plants. Treatment effects in greenhouse test 2 and field test were assessed by an Analysis of Variance (ANOVA) using Genstat 5 Release 3.2 while Fisher's Least Significant Difference (LSD) was used to compare treatment means.

Results

Greenhouse test 1

Nematode-inoculated *C. ochroleuca* plants were significantly ($P < 0.001$) shorter, had lower fresh root, dry shoot and fresh shoot weights than non-inoculated plants by 14, 43, 36 and 25%, respectively (Table 1). While there were no significant differences between plant heights and dry shoot weights of *P. zeae*-inoculated and non-inoculated *L. purpureus* plants, the inoculated plants had significantly ($P < 0.05$) lighter fresh root and shoot weights than non-inoculated plants by 18 and 5%, respectively. No significant differences in plant growth were noted between inoculated and non-inoculated *C. ensiformis* and *M. pruriens* plants (Table 1).

Root necrosis of *C. ensiformis* was significantly lower ($P < 0.05$) than of *C. ochroleuca* and *L. purpureus* by 30 and 22%, respectively (Table 2). Nematode populations in roots of *C. ensiformis* were significantly ($P < 0.05$) lower than in roots of *C. ochroleuca* (66%) and *L. purpureus* (44%). Similarly, *P. zeae* populations in root of *M. pruriens* were significantly ($P < 0.05$) lower than in *C. ochroleuca* (60%) and *L. purpureus* (34%). *Crotalaria ochroleuca* supported significantly ($P < 0.05$) higher soil nematode populations than those supported by *C. ensiformis*, *M. pruriens* and *L. purpureus* by 146, 121 and 65%, respectively. *Canavalia ensiformis* and *M. pruriens* supported soil nematode populations that were not significantly ($P > 0.05$) different from each other. *Canavalia ensiformis* had a significantly ($P < 0.05$) lower Rf than *M. pruriens*, *L. purpureus* and *C. ochroleuca* by 11, 33 and 62%, respectively. While *C. ensiformis* and *M. pruriens* were non-host to *P. zeae* (Rf=0.8–0.9), *L. purpureus* and *C. ochroleuca* were poor (Rf=1.2) and good hosts (Rf=2.1), respectively (Table 2).

Greenhouse test 2

While significant differences ($P < 0.05$) in plant heights, fresh and dry shoot weights were observed in Emap11 cropping systems, in H627 and Pan5195 cropping systems, significant differences ($P < 0.05$) were noted only in fresh and dry shoot weights, respectively (Table 3). Intercropping Emap11 with *C. ensiformis* significantly ($P < 0.05$) increased plant height and fresh shoot weight by 5 and 8%, respectively. *Canavalia ensiformis* and *M. pruriens* significantly ($P < 0.05$) increased dry shoot weight of Emap11 by 34 and 21%, respectively. Fresh shoot weights of H627 intercropped with *C. ensiformis* were significantly ($P < 0.05$) higher than those of pure stand by 4%. Intercropping Pan5195 with either *C. ensiformis* or *M. pruriens* significantly ($P < 0.05$) increased its dry shoot weight by up to 11%. In most cropping systems, *C. ensiformis* and *M. pruriens* were equally effective in increasing plant growth (Table 3).

Table 1 Mean[a] plant heights (cm), fresh shoot, dry shoot and fresh root weights (g) of leguminous cover crops, 60 days after inoculation, greenhouse test 1

Cover crops	Plant parameters	Inoculated	Non-inoculated	% change	*t*-test (means)
Canavalia ensiformis	Plant height	179.00	179.50	−0.3	NS
	Fresh shoot weight	45.22	45.75	−1.0	NS
	Dry shoot weight	10.19	11.05	−8.0	NS
	Fresh root weight	2.89	2.97	−3.0	NS
Mucuna pruriens	Plant height	277.50	278.83	−1.0	NS
	Fresh shoot weight	63.05	64.00	−1.0	NS
	Dry shoot weight	12.30	13.33	−8.0	NS
	Fresh root weight	13.61	14.42	−6.0	NS
Lablab purpureus	Plant height	199.60	203.25	−2.0	NS
	Fresh shoot weight	37.14	39.10	−5.0	S
	Dry shoot weight	7.97	9.09	−12.0	NS
	Fresh root weight	7.50	9.13	−18.0	S
Crotalaria ochroleuca	Plant height	110.00	127.26	−14.0	HS
	Fresh shoot weight	21.54	28.90	−25.0	HS
	Dry shoot weight	5.32	8.27	−36.0	HS
	Fresh root weight	5.62	9.92	−43.0	HS

[a]Mean of six replications

NS—Not significant ($P > 0.05$), S—significant ($P < 0.05$) and HS—Highly significant ($P < 0.001$)

Table 2 Mean[a] root necrosis, nematode population in root and, soil and nematode reproductive factor (Rf) of cover crops, 60 days after inoculation, greenhouse test 1

Cover crops	Root necrosis index[b]	Nem.g^{-1} dry roots	Nem. 200 g $^{-1}$ soil	Rf [c]	Host status[d]
C. ensiformis	0.7	125	194	0.8	N
M. pruriens	0.8	147	216	0.9	N
L. purpureus	0.9	222	288	1.2	P
C. ochroleuca	1.0	371	477	2.1	G
$LSD_{(0.05)}$	0.13	40	28	0.11	

[a]Mean of six replications

[b]Root necrosis index: 0=no root damage, 1=slight root damage, 2=moderate root damage, 3=severe root damage, 4=very severe root damage (Bridge and Gowen 1993)

[c]Rf (nematode reproductive factor) = ratio of final nematode population (P_f) to initial nematode population (P_i) (Ferris et al. 1993)

[d]Excellent host (E)=Rf>10, Good host (G)=10 ≥ Rf ≥ 1.5, Poor host (P)=1 ≤ Rf < 1.5 and Non-host (N)=Rf < 1 (Ferris et al. 1993)

Table 3 Mean[a] plant heights, fresh shoot, dry shoot and fresh root weights of Pan5195, H627 and Emap11 in sole stands and in intercroppings with either *C. ensiformis* (CE) or *M. pruriens* (MP), 90 days after inoculation, greenhouse test 2

Treatment	Plant height(cm)	Fresh shoot weight(g)	Dry shoot weight(g)	Fresh root weight(g)
Pan5195	99.8	97.7	14.9	28.1
Pan5195+MP	100.8	99.0	15.7	28.4
Pan5195+CE	101.3	99.9	16.6	28.8
H627	117.7	95.0	14.5	33.8
H627+MP	119.3	97.5	15.5	34.1
H627+CE	120.0	99.2	15.9	34.4
Emap11	91.2	86.2	10.8	30.1
Emap11+MP	94.0	90.2	13.1	30.6
Emap11+CE	96.2	92.7	14.5	30.8
$LSD_{(0.05)}$	2.96	3.70	1.49	1.27

[a]Mean for six replications

Canavalia ensiformis and *M. pruriens* significantly ($P < 0.05$) reduced root necrosis of Emap11 by 26 and 23%, respectively, but not of Pan5195 and H627 (Table 4). Likewise *C. ensiformis* and *M. pruriens* significantly ($P < 0.05$) reduced root and soil nematode populations in Emap11 by up to 30 and 86%, respectively. *Canavalia ensiformis* was significantly ($P < 0.05$) more effective in reducing root nematode population in Emap11 than *M. pruriens* by 4%. Pan5195 intercropped with *C. ensiformis* had a significantly ($P < 0.05$) lower root nematode population than sole Pan5195 (7%) and Pan5195—*M. pruriens* intercrop (5%). The two cover crops significantly ($P < 0.05$) reduced soil nematode population in Pan5195 by up to 56%. *Canavalia ensiformis* significantly ($P < 0.05$) reduced root and soil nematode populations of H627 by 32 and 63%, respectively, while *M. pruriens* reduced the populations by 18 and 62%, respectively (Table 4).

Intercropping Emap11, H627 and Pan5195 with either *C. ensiformis* or *M. pruriens* significantly ($P < 0.05$) reduced nematode Rf by up to 70, 55 and 37%, respectively, compared to sole maize. *Canavalia ensiformis*, however, was significantly ($P < 0.05$) more effective than *M. pruriens* in reducing nematode reproduction by up to 10%. The efficacy of *C. ensiformis* and *M. pruriens* to reduce nematode damage was higher in Emap11 cropping systems than in Pan5195 or H627 cropping systems (Table 4).

Field study

Intercropping *C. ensiformis* with Emap11 or Pan5195 significantly ($P < 0.05$) increased maize grain yield by 190 and 29%, respectively (Table 5). Maize grain yield of Pan5195 and Emap11 intercropped with *M. pruriens* was significantly ($P < 0.05$) lower than their respective monocrops by 79 and 40%, respectively. Intercropping H627 with either *C. ensiformis* or *M. pruriens* significantly ($P < 0.05$) increased maize yield by up to 22% (Table 5).

While *C. ensiformis* significantly ($P < 0.05$) reduced root necrosis of Emap11 by 23%, *M. pruriens* had no significant effects (Table 5). *Canavalia ensiformis* and *M. pruriens* significantly ($P < 0.05$) reduced root nematode population of Emap11 by 26 and 25%, respectively, compared to sole maize. Pan5195 intercropped with either *C. ensiformis* or *M. pruriens* had a significantly ($P < 0.05$) lower root necrosis index than sole Pan5195 by up to 50%. Intercropping *C. ensiformis* and *M. pruriens* with H627 significantly ($P < 0.05$) reduced root necrosis by 43 and 26%, respectively, and root nematode population by 30 and 23%, respectively. No significant differences were noted between the efficacy of *C. ensiformis* and *M. pruriens* in reducing root necrosis among all the three cropping systems (Table 5).

Intercropping *C. ensiformis* with Emap11, Pan5195 and H627 significantly ($P < 0.05$) reduced soil nematode population by a respective 6, 13 and 10%,

Table 4 Mean[a] root necrosis, nematode population in roots and soil, nematode reproductive factor (Rf) and nematode suppressive ability (NSA) of Pan5195, H627 and Emap11 as sole stands or as intercrops of *C. ensiformis* (CE) or *M. pruriens* (MP), 90 days after infestation, greenhouse experiment 2

Treatments	Root necrosis index[b]	Nem.g^{-1} dry root	Nem. 200 g^{-1} soil	Rf[c]	NSA[d]
Pan5195	0.96	419	378	1.34	S
Pan5195+MP	0.81	410	194	0.93	MS
Pan5195+CE	0.76	390	167	0.84	MS
H627	0.90	305	626	1.91	LS
H627+MP	0.86	255	239	0.95	MS
H627+CE	0.81	208	234	0.86	MS
Emap11	1.17	652	864	2.93	LS
Emap11+MP	0.90	476	131	0.95	MS
Emap11+CE	0.86	456	117	0.87	MS
$LSD_{(0.05)}$	0.23	16	17	0.03	

[a]Mean for six replications

[b]Root necrosis index: 0=no root damage, 1=slight root damage, 2=moderate root damage, 3=severe root damage, 4=very severe root damage (Bridge and Gowen 1993).

[c]Rf (nematode reproductive factor)=ratio of final nematode population (P_f) to initial nematode population (P_i) (Ferris et al. 1993)

[d]Most suppressive (MS)=Rf < 1, Suppressive (S)=1 ≤ Rf < 1.5 and Least suppressive (LS)=Rf ≥ 1.5 (Ferris et al. 1993)

Table 5 Mean[a] maize grain yield, root necrosis and nematode population in roots of Pan5195, H627 and Emap11 as sole stands or as intercrops with either *C. ensiformis* (CE) or *M. pruriens* (MP), on-farm test

Treatments	Grain yield (t ha^{-1})	Root necrosis index[b]	Nem.g^{-1} dry root
Pan5195	3.97	2.0	470
Pan5195+MP	0.85	1.3	439
Pan5195+CE	5.12	1.0	417
H627	4.45	2.3	350
H627+MP	5.16	1.7	271
H627+CE	5.42	1.3	245
Emap11	1.39	3.0	656
Emap11+MP	0.85	2.7	491
Emap11+CE	4.03	2.3	488
$LSD_{(0.05)}$	0.69	0.6	78

[a]Mean for six replications

[b]Root necrosis index: 0=no root damage, 1=slight root damage, 2=moderate root damage, 3=severe root damage, 4=very severe root damage (Bridge and Gowen 1993)

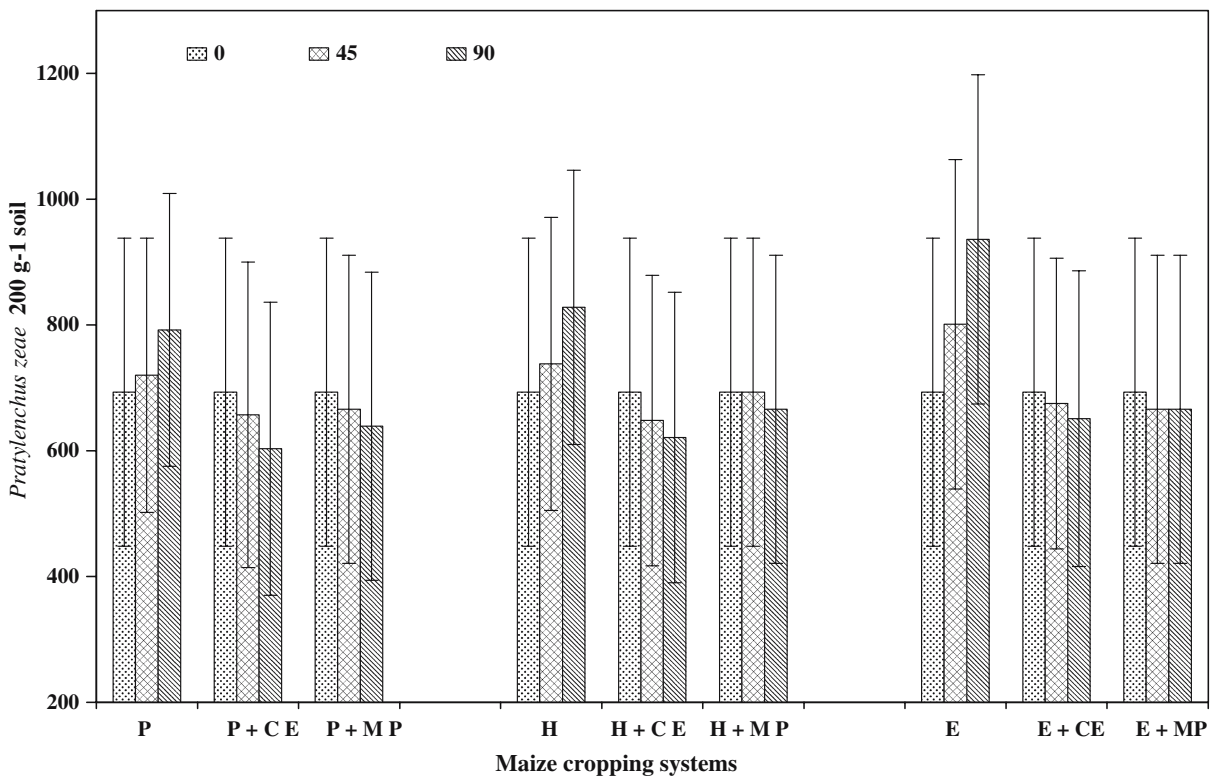

Fig. 1 Mean soil nematode population at 0, 45 and 90 days after planting Pan5195 (P), H627 (H) and Emap11 (E) intercropped with either *Canavalia ensiformis* (CE) or *Mucuna pruriens* (MP), in Kibing'oti (0°34′ S, 37°11′ E) location during the Long Rain Season (March–May 2005)

while *M. pruriens* significantly ($P < 0.05$) reduced the nematode population by 4, 8 and 4%, respectively, 90 days after planting (Fig. 1). Soil nematode population in Emap11, Pan5195 and H627 monocrops increased significantly ($P < 0.05$) from the initial 3.4 nematodes g^{-1} of fresh soil to 4.7, 4.1 and 3.9

nematodes, respectively, 90 days after planting, representing a respective 35, 19 and 14% increase (Fig. 1).

Discussion

The highly significant differences between *P. zeae*-inoculated and non-inoculated *C. ochroleuca* plant growth parameters confirm the pathogenic effects of the lesion nematode on growth of some *Crotalaria* spp. The ability of *C. ochroleuca* to support a high nematode reproduction (Rf=2.1) suggests that it is a good host to *P. zeae*. Besides *C. ochroleuca*, *C. agatiflora* L. and *C. grahamiana* L. have also been reported to be good hosts of *P. zeae*, *Pratylenchus thornei* Sher & Allen and *Pratylenchus pseudopratensis* Seinhorst (Desaeger and Rao 2003). Lack of significant differences between dry shoot weights of inoculated and non-inoculated *L. purpureus* and the cover crop's ability to support relatively low nematode reproduction (Rf=1.2) is an indication that it is a poor host to *P. zeae* (Al- Rehiayani and Hafez 1998).

The non-significant differences between growth of *P. zeae*-inoculated and non-inoculated *C. ensiformis* and *M. pruriens* plants, the low nematode reproduction coupled with low root and soil nematode populations supported by both cover crops indicate that they are non-hosts to *P. zeae*. This corroborates findings by several authors that *C. ensiformis* and *M. pruriens* are non-hosts to several plant parasitic nematodes including *Pratylenchus* spp. (Sundararaj and Mehta 1990; McSorley et al. 1994; McSorley and Gallaher 1997; Al-Rehiayani and Hafez 1998). The low nematode populations and low disease severity associated with both cover crops could be attributed to the production of nematicidal compounds that affect the nematode's ability to infect, reproduce and damage the plants (Chitwood 2002; Marisa et al. 1996).

The improved growth and grain yield of maize accompanied by reduced root necrosis and, low root and soil nematode populations in the intercropping systems both in the greenhouse and field tests could have been due to increased supply of N (Sanginga et al. 1996; Wortmann et al. 2000), reduced impact of *P. zeae* by the cover crops (Marisa et al. 1996; McSorley and Gallaher 1997; Al-Rehiayani and Hafez 1998; Chitwood 2002) and inherent ability of the H627 and Pan5195 maize varieties to suppress nematode reproduction (Arim et al. 2002). Increased N supply has been associated with increased maize yields in several maize–legume intercrops (Sanginga et al. 1996; Wortmann et al. 2000). The increased N supply could also have enhanced the resistance of maize to *P. zeae* through improved growth vigor (Sundararaj and Mehta 1990). The nematicidal compounds produced by *C. ensiformis and M. pruriens* could have further reduced the *P. zeae* population and its ability to reproduce on maize (Marisa et al. 1996; Chitwood 2002). Besides, alternating a single row of cover crop with a maize row produced maximum contact between the root systems (RAFR 1991) and this might have interfered with the nematode's ability to locate the maize roots and hence the low root necrosis. This speculation is supported by the fact that the root zone of *C. ensiformis*, *M. pruriens* and maize is concentrated within 30 cm of the plow layer (Palm 1995; Wortmann et al. 2000). The genotypic differences of the maize varieties might partly explain the differences in their response to *P. zeae.* A study conducted earlier revealed that Emap11 was a good host (Rf=2.9) while H627 and Pan5195 were poor hosts to *P. zeae* (Rf=1.3–1.8) (Arim et al. 2002). The high efficacy of combining non-host cover crops with poor hosts of maize to reduce nematode damage on maize compared to the monocrops underscores the importance of applying integrated approach in nematode management as opposed to a single strategy.

The results of this study indicated that *C. ensiformis* was more effective than *M. pruriens* in reducing *P. zeae* damage on maize. *Canavalia ensiformis* takes up more P from the soil than *M. pruriens* (Wortmann et al. 2000) and this is likely to impede nematode reproduction and population increase since low levels of P favors a decrease in lesion nematode population (Yeates 1976). In addition, when intercropped with maize, *C. ensiformis* fixes relatively more nitrogen compared with *M. pruriens* (Wortmann et al. 2000), a phenomenon that could have enhanced maize resistance to nematodes.

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References

Al-Rehiayani S, Hafez S (1998) Host status and green manure effect of selected crops on *Meloidogyne chitwoodi* Race 2 and *Pratylenchus neglectus*. Nematropica 28(2):213–230

Arim OJ, Waceke JW, Waudo SW, Kimenju JW (2002) Response of cover crops and commercial maize (*Zea may* L.) varieties cultivated in Central highlands of Kenya to *Pratylenchus* spp. (lesion nematodes). In: Proceedings of the Fifth Regional Forum for Agricultural Resource Husbandry 12–16th August 2002, Entebbe, Uganda, pp 318–319

Bridge J, Gowen J (1993) Root necrosis chart. In: Sutherland JA Kibata GN, Farrell G (eds) Field sampling methods for crops pests and diseases in Kenya. Nairobi, Kenya, pp 34–37

Chitwood D (2002) Phytochemical based strategies for nematode control. Ann Rev Phytopathol 40:221–249

Desaeger J, Rao MR (2003) Significance of lesion and spiral nematodes in crotalaria—maize rotation in western Kenya. Nematropica 33(1):27–40

Desaeger J, Rao MR (2001) The potential of mixed covers of *Sesbania*, *Tephrosia* and *Crotalaria* to minimize nematode problems on subsequent crops. Field crops Res 70:111–125

Fallis AM (1943) Use of the Waring blender to separate small parasites from tissue. Can J Public Health 34:44

Ferris H, Carlson H, Viglierchio D, Westerdahl BWF, Anderson C, Juurma A, Kirby D (1993) Host status of selected crops to *Meloidogyne chitwoodi*. Ann Appl Nematol 25:849–857

Kimenju JW, Waudo SW, Mwang'ombe AW, Sikora RA, Schuster RP (1998) Distribution of lesion nematodes associated with maize in Kenya and susceptibility of maize cultivars to *Pratylenchus zeae*. African Crop Sci J 6(4):367–375

Marisa A, Nogueira Joao S, De Oliveira, Silamar F (1996) Nematicidal hydrocarbons from *Mucuna aterrima*. Phytochemistry 42(4):997–998

McIntyre BD, Gold CS, Kashaija IN, Ssali H, Night G, Bwamiki DP (2001) Effects of legume inter-crops on soil-borne pests, biomass, nutrients and soil water in banana. Biol Fertility Soils 34:349–356

McSorley R, Gallaher RN (1997) Methods for managing nematodes in sustainable agriculture. In: Proceedings of the 20th Annual Southern Conservation Tillage for sustainable agriculture. 24–26th June 1997, Gainesville, Florida

McSorley R, Dickson DW, Brito JA, Hewlett TE, Frederick JJ (1994) Effects of tropical rotational crops on *Meloidogyne arenaria* population densities and vegetable yields in microplots. J Nematol 26(2):175–181

Muhammad L, Underwood E (2004) The maize agricultural context in Kenya. In: Hilbeck A, Andow DA (eds) Environmental risk assessment of genetically modified organisms, vol. 1. A case study of Bt maize in Kenya. CAB International, Wallingford, UK, pp 21–56

Palm CA (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. Agroforestry Syst 30:105–124

Regional office for Africa (RAFR) Technical series (1991) No. 1. Review of literature on Agro-Socio-Economic Aspects of mixed cropping in sub-Saharan Africa. Food and Agriculture Organization of the United Nations, Rome

Sanginga N, Ibewiro B, Houngnandan P, Vanlauwe B, Okogun JA, Akobund IO, Versteeg M (1996) Evaluation of symbiotic properties and nitrogen contribution of mucuna to maize grown in the derived Savannah of West Africa. Plant Soil 179(1):119–129

Sundararaj P, Mehta K (1990) Host status of some economic crops to *Pratylenchus zeae* and their influence on subsequent sugar cane crops. Ind J Nematol 20(2):165–169

Thomas HA (1959) On *Criconemoides xenoplax* Raski, with special reference to its biology under laboratory conditions. Proc Helminthol Soc Washington 26:55–59

Waceke JW, Arim OJ, Waudo SW, Kimenju JW (2002) Plant parasitic nematodes of maize (*Zea mays* L.) in low input agriculture in Kenya. Fourth International Congress of Nematology 8–13 June 2002. Tenerife, Canary Islands, Spain

Wortmann CS, McIntyre BD, Kaizzi CK (2000) Annual soil improving legumes: agronomic effectiveness, nutrient uptake, nitrogen fixation and water use. Field Crop Res 68:75–83

Yeates GW (1976) Effect of fertilizer treatment and stocking rate on pasture nematode populations in a yellow–grey earth. New Zealand J Agricult Res 19:405–408