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Efficacy of different control methods applied separately and in combination in managing root-knot nematodes (*Meloidogyne* spp.) in common beans

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Abstract

Investigations on the efficacy of various methods of managing root-knot nematodes in microplots and under field conditions revealed that soil solarization, Furadan 5G and *Tagetes erecta* applied separately or in combination with other control methods, were the most effective in reducing the numbers of three root-knot nematodes, and root gall and egg mass indices. These management methods also resulted in significant increases ($P \leq 0.05$) in number of pods per plant, number of seeds per pod and 100-seed weight, and increased seed yield by up to 96.7 percent. Farmyard manure and *Crotalaria ochroleuca* were the least effective treatments. The use of *T. erecta* was the most economical root-knot nematode control method.

Introduction

Meloidogyne incognita and *M. javanica* are considered the most serious nematode pathogens of plants in the world and constitute about 64 and 28 percent, respectively, of plant parasitic nematode populations occurring in tropical countries (Sasser, 1979). These two root-knot nematode species, together with *M. hapla*, *M. arenaria* and *M. chitwoodi*, are important because of their world-wide distribution and wide host range on both cultivated plants and weeds. They can cause adverse effects on both crop yield and quality and can survive in a wide range of soil moisture and temperature conditions (Sasser, 1979).

The use of nematicides is still one of the most popular and effective methods of managing root-knot nematodes in beans. This is because the wide host range of *M. incognita* and the different biological races which exist within *M. incognita* make application of other management methods, such as rotational control difficult (Katan, 1981; Ngundo and Taylor, 1974; Ogallo, 1988; Saka, 1990; Smittle and Johnson, 1982; Wyatt et al., 1980). Several fumigants, including dazomet, and non-fumigants such as carbofuran, isazophos and fenamiphos have been recommended for use against root-knot nematodes (Ogallo, 1988). However, for field crops of low value such as beans, the use of nematicides is very expensive and not economically justified. This is because nematicides require special application techniques and equipment. In addition, some of them are not environmentally friendly. Therefore, cultural methods and resistant bean varieties remain the most practical root-knot nematode control methods, especially for small-holder farmers in Tanzania.

Some plants, such as *Tagetes* spp., *Crotalaria spectabilis* and *Ricinus communis*, have been reported to prevent root-knot nematode build up when grown alongside susceptible plants (Hackney and Dickerson, 1975; Rodriguez-Kabana, 1992). These plants are considered as biological control agents against root-knot nematodes (Barker and Cook, 1974). Intercropping tomato with *T. erecta* and *T. minuta* was effective in managing root-knot nematodes (Ijani and Mmbaga, 1988). However, the potential of *Tagetes* spp. in the management of root-knot nematodes in beans and other annual crops grown in Tanzania has not been investigated. Heating the soil by burning wood or covering it with polyethylene sheeting, as well as the use of organic matter amendments, have been reported to suppress populations of root-knot nematodes (Katan et al., 1976; Patel et al., 1989; Rodriguez-Kabana, 1986). Such management methods may be cost effective, especially for small-holder farmers in Tanzania, since materials used are readily available locally. However, proper knowledge on how to use such methods is still lacking in Tanzania and many other countries. Evaluation of the effectiveness and economics of combinations of such methods of managing root-knot nematodes in Tanzania is an important area of research.

Therefore, the objective of the current study was to investigate the efficacy of different methods separately and in combination in managing root-knot nematodes in common beans.

Materials and methods

Field experiments

A root-knot nematode (*M. incognita* race 2) infested bean field measuring 30.5 m × 14 m, located at Sokoine University of Agriculture, was cultivated and planted with two successive crops of *Lycopersicon esculentum*, cultivar Money Maker, to increase the population of root-knot nematodes in the soil. The field was then divided into three blocks, each block containing 15 plots of 1.5 m × 4 m spaced 0.5 m apart. Soil samples were collected systematically at equally-spaced areas between the rows in a zig-zag pattern covering the entire field. Soil samples were taken from 0–12 cm depth by using a core sampler of 5 cm diameter; eight cores were taken from each marked sampling point, mixed thoroughly and subdivided into four equal parts. The four soil samples were taken to the laboratory and processed to assess the initial nematode population one week prior to application of any control treatment. Nematodes were extracted from the soil samples using a modified Baerman funnel technique (Southey, 1986).

Experiments to evaluate the efficacy of various methods of controlling root-knot nematodes in common beans, cultivar Canadian Wonder, were laid out using a randomized complete block design with three replications. Treatments used included Furadan 5G (FUD), soil solarization (SOZ), farmyard manure (FYM), *Tagetes erecta* (TAE) and *Crotalaria ochroleuca* (COL). Various combinations of these management methods were also used: TAE + FUD, COL + FUD, SOZ + FUD, TAE + FYM, SOZ + FYM, COL + FYM, TAE + FYM + FUD, SOZ + FYM + FUD, COL + FYM + FUD; there was also a control without any treatment. Throughout the duration of the experiment soil samples were taken from the marked areas in each plot every 12 days. By the end of the experiment, eight sets of samples had been collected at eight different times from each of the marked areas within each plot. Data obtained were used to determine root-knot nematode population trends after the various treatments.

Three treatments, the use of TAE, COL, and SOZ, were pre-crop treatments. These three treatments were applied 7–9 weeks before the bean crop was planted. Plots marked for SOZ treatment alone, or in combination with other treatments, were levelled and furrowed at two of their four sides. The plots were then irrigated to field water holding capacity. Immediately after irrigation, each plot was covered with a polyethylene sheet of about 50 μm thickness and two edges of the sheet were inserted in the furrows and buried. The SOZ treated plots were covered for seven weeks and soil temperature was recorded every day at 15.00 hours using constantan thermocouples buried in the soil at 5 and 10 cm depths. While the SOZ treatments were being conducted, TAE and COL were planted in the plots marked for such treatments. These plants were planted at high densities and left to grow for 65 days to ensure that their roots spread evenly throughout the soil.

Plots marked for treatment with FUD and FYM, either separately or in combination with other treatments, were treated after cultivation. FUD was applied at the rate of 7.0 kg a.i./ha and mixed thoroughly with the soil to 10 cm depth. FYM was applied at the rate of 20 ton/ha, incorporated and mixed thoroughly within the top 10 cm layer of soil. After chemical and organic amendment applications, bean seeds of cultivar Canadian Wonder were planted on the same day in all 45 plots at a spacing of 20 cm × 50 cm, two seeds per hill. Weeding was done manually when necessary; fungal diseases and insect pests were controlled by spraying the bean crop with Dithane M45 and Dimethoate at the rates of 4 kg a.i./ha and 800 g a.i./ha, respectively.

At the mature pod stage, six bean plants were carefully uprooted at random from each plot, taken to the laboratory and assessed to determine root gall and egg mass indices and the number of rhizobial nodules using the procedures of Taylor and Sasser (1978). A root gall index scale of 0–5 was used, where: 0 = no gall per root system; 1 = 1–2 galls; 2 = 3–10 galls; 3 = 11–30 galls; 4 = 31–100 galls, and 5 = more than 100 galls per root system. Egg masses were stained in phloxine B for 20 min, rinsed in sterile distilled water and then counted under the stereo microscope using a scale of 0–5, where: 0 = no egg mass per root system; 1 = 1–2 egg masses; 2 = 3–10 egg masses; 3 = 11–30 egg masses; 4 = 31–100 egg masses, and 5 = more than 100 egg masses per root system (Taylor and Sasser, 1978). Data were also collected on pods per plant, seeds per pod, 100-seed weight and seed weight per plot. The experiments were conducted for 2 years, during the long rains (March–June), in 1994 and 1995.

Microplot experiment

The studies described above were duplicated in microplot experiments using 45 rectangular wooden boxes measuring 80 cm × 30 cm × 30 cm. The wooden boxes were laid out in a randomized complete block design with three replications. Each box was filled with sterile soil into which four 10-day-old tomato plants were transplanted. That soil was then infested with *M. javanica* juveniles which were produced from egg masses collected from Pinde in Mgeta Division. The juveniles were applied by pipetting 10 ml of a suspension containing 1000 juveniles per 10 cm^3 of water into holes in the soil 10 cm apart around the tomato plants and mixing the suspension thoroughly with the soil. A total of 9000 juveniles were added to each box. Seventy days after inoculation, soil samples were taken and tomato plants removed to assess the *M. javanica* population in the boxes, which was then considered the initial *M. javanica* population for the start of the experiment. One week after assessment of the initial population, the Furadan 5G and farmyard manure treatments previously described were applied. Pre-crop treatments were conducted with the same timings as described under field experiments.

Bean seeds of the cultivar Canadian Wonder were then planted in the boxes, one row per box, two seeds per hill, at a within-row spacing of 20 cm i.e. eight seeds per box. At the mature pod stage, two bean plants were uprooted from each box for the determination of root gall and egg mass indices and the number of rhizobial nodules. The remaining plants were harvested at maturity for yield determination. Soil samples from microplots were taken for analysis using procedures and sampling intervals used under field experiments and the experiments were conducted for two years.

Data analysis

Data were analysed using the MSTATC computer programme (Michigan State University, 1983). Treatment means which were significantly different from each other were compared using Tukey's Honestly Significant Difference Test (Steel and Torrie, 1980). Correlation coefficients between pairs of different variates of bean performance, nematode populations and seed yield were also determined using procedures outlined by Steel and Torrie (1980).

Results

Field experiments

The patterns of change of root-knot nematode populations as affected by the various treatments used in this study are shown in Figure 1. Before application of any treatment, the field used was highly and uniformly infested with root-knot nematodes. The mean population density of root-knot nematodes over all treatments was 1091 per 200 cm^3 of soil. The mean initial population densities in individual treatments were not statistically significantly different from each other ($P \leq 0.05$).

The population densities of root-knot nematodes were affected in different ways by the different management methods used. The highest root-knot nematode population densities were recorded in untreated plots and where FYM was applied, followed by plots where COL, FYM + COL, and TAE were used (Figure 1). In plots where these treatments were used, the root-knot nematode populations increased slowly up to 43 days but increases thereafter were very rapid up to 79 days after planting. Plots treated with TAE + FYM, FUD and COL + FUD had low to moderate root-knot nematode populations, although nematode populations in plots treated with TAE + FYM increased over the initial population to about 1500 per 200 cm^3 of soil.

In all plots treated with SOZ + FYM + FUD, SOZ + FYM, SOZ + FUD, and TAE + FYM + FUD, root-knot nematode populations were greatly reduced, to less than 500 nematodes per 200 cm^3 soil (Figure 1). In plots treated with SOZ, TAE + FUD and

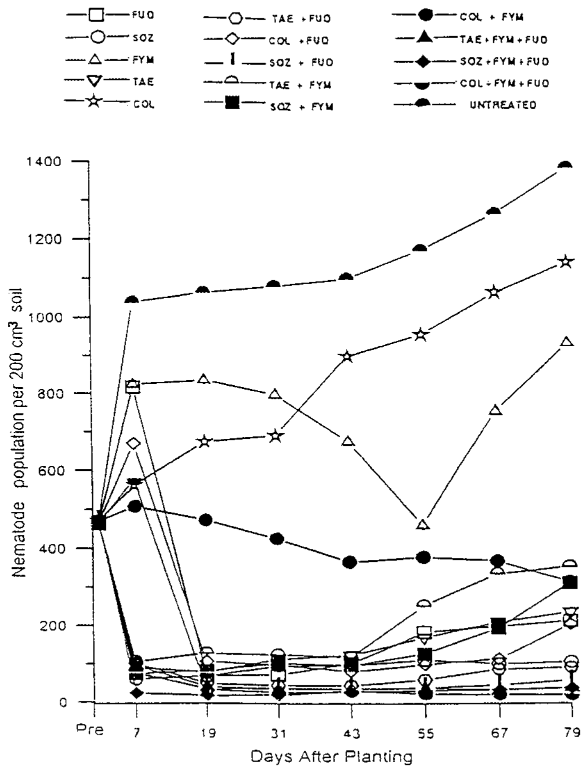

Figure 1. Population densities of root-knot nematodes recovered from soil taken from the rhizosphere of bean cultivar Canadian Wonder after application of different management methods in the field. FUD = Furadan 5G, SOZ = Soil solarization, FYM = Farmyard manure, TAE = *Tagetes erecta*, COL = *Crotalaria ochroleuca*, Pre = Prior to application of any treatment.

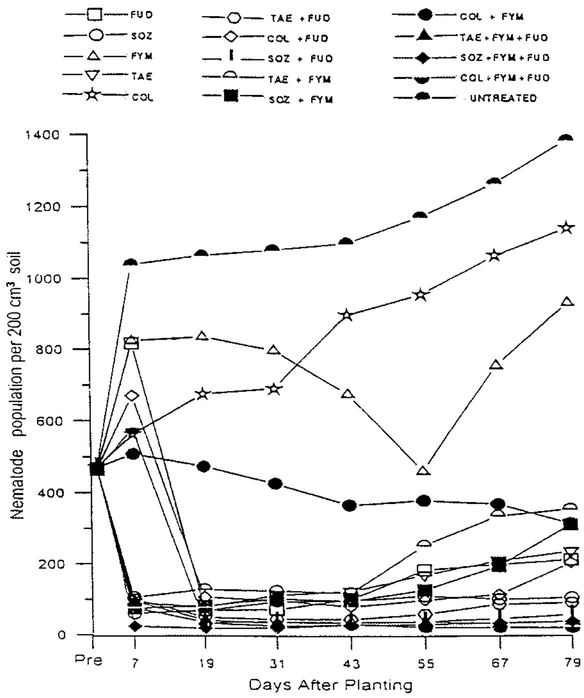

Figure 2. Population densities of root-knot nematodes recovered from soil taken from the rhizosphere of bean cultivar Canadian Wonder after application of different management under microplot conditions. FUD = Furadan 5G, SOZ = Soil solarization, FYM = Farmyard manure, TAE = *Tagetes erecta*, COL = *Crotalaria ochroleuca*, Pre = Prior to application of any treatment.

COL + FYM + FUD, almost the same final population as in SOZ + FUD treated plots was observed.

Microplot experiments

The mean initial population density of root-knot nematodes prior to application of any treatment in the microplots was 467 nematodes per 200 cm^3 soil and the mean initial population levels of individual treatments were not statistically significantly different from each other ($P \leq 0.05$).

The highest population of root-knot nematodes was recorded in the untreated control plots and microplots where COL and FYM were applied (Figure 2). Nematode population densities in all microplots where root-knot nematode control measures other than COL, FYM and COL + FYM were applied were significantly lower ($P \leq 0.05$) than in the COL, FYM and COL + FYM treated and the untreated microplots. Reductions in nematode population densities were recorded in microplots treated with FUD, COL + FUD and COL + FYM + FUD between 7 and 19 days after planting. Forty-three days after planting increases in root-knot nematode populations were observed in microplots treated with TAE + FYM, SOZ + FYM, TAE, FUD and COL + FUD (Figure 2). In microplots where other treatments were applied, root-knot nematode populations were highly suppressed throughout the period of the experiments. However, the effects of the various control measures on root-knot nematode populations in the microplot experiments were generally similar to those observed under field conditions (Figures 1 and 2).

Temperature changes during soil solarization

Temperature changes in plots which were treated with SOL in both field and microplot experiments are

Table 1. Effect of solarization treatment on soil temperatures recorded at 15.00 hours under field and microplot conditions

Days	Soil depth (cm)	Field experiment		Microplot experiment	
		Temperature range (°C)	Mean temperature over the period (°C)	Temperature range (°C)	Mean temperature over the period (°C)
1–5	5	34.0–40.0	36.8	36.0–42.0	38.0
6–10	5	36.0–42.0	38.2	37.0–43.0	38.8
11–15	5	35.0–43.0	38.8	39.0–46.0	40.2
16–20	5	38.0–46.0	40.6	42.0–49.0	44.4
21–25	5	40.0–47.0	44.4	43.0–50.0	45.4
26–30	5	40.0–48.0	45.6	44.0–52.0	47.6
31–35	5	41.0–50.0	45.1	45.0–52.0	49.2
36–40	5	42.0–49.0	46.4	46.0–53.0	49.8
41–45	5	44.0–52.0	46.8	48.0–55.0	50.8
46–49	5	44.0–53.0	47.4	48.0–55.0	51.8
1–5	10	28.0–35.0	31.2	31.0–38.0	34.4
6–10	10	27.0–37.0	31.8	34.0–40.0	34.2
11–15	10	29.0–39.0	32.6	34.0–40.0	35.6
16–20	10	30.0–40.0	33.2	34.0–41.0	38.0
21–25	10	33.0–40.0	35.6	36.0–42.0	39.8
26–30	10	34.0–42.0	38.8	36.0–44.0	39.4
31–35	10	36.0–45.0	39.4	37.0–44.0	39.8
36–40	10	36.0–44.0	39.6	39.0–45.0	40.0
41–45	10	36.0–45.0	40.6	38.0–45.0	40.1
46–49	10	37.0–45.0	40.4	38.0–46.0	40.1

Values are means of two experiments conducted for two years.

summarized in Table 1. Within the top 5 cm of soil, solarization increased the soil temperature from a low of 34 °C to a high of 53 °C in the field and from 36 to 55 °C in microplots. The increase in temperature decreased with increase in soil depth (Table 1).

Root gall and egg mass indices

Application of FYM, COL and FYM + COL to field plots did not cause significant reductions in root gall and egg mass indices or significant increases in number of pods per plant, number of seeds per pod, 100-seed weight and seed yield (Table 2). However, significant ($P \leq 0.05$) reductions in root gall and egg mass indices and increases in number of pods per plant, number of seeds per pod, 100-seed weight and seed yield were recorded in beans where other management measures were applied.

The most effective control method against root-knot nematodes was SOZ+FYM+FUD followed by SOZ+FYM, SOZ + FUD and TAE + FYM + FUD (Figures 1 and 2). These treatments increased seed yield by 96.0; 85.1; 72.0 and 66.6 percent, respectively (Table 2). A combination of TAE, SOZ or FUD with other control methods did not generally cause significant reduction ($P \leq 0.05$) of root gall and egg mass indices (Table 2).

In microplot experiments, root gall and egg mass indices, the numbers of nodules and pods per plant, 100-seed weight and seed yield were not significantly affected ($P \leq 0.05$) by application of FYM, COL and COL + FYM (Table 3). There were higher numbers of pods per plant and seeds per pod in plots treated with FUD, TAE and SOZ alone or in combination with other management methods than in the non-treated control plots (Table 3). Similar trends were observed for 100-seed weight and seed yield.

Under field conditions, seed yields in plots treated with SOZ + FYM + FUD, SOZ + FUD, TAE + FUD, SOZ + FYM and TAE + FYM + FUD were increased by 71.8, 70.3, 60.6, 59.7 and 51.4 percent, respectively (Table 2). A decrease in the number of rhizobial nodules per plant was observed only in bean plots where SOZ was applied either alone or in combination with other root-knot nematode management methods.

Multiple regression analysis indicated that there was a very strong inverse relationship ($P \leq 0.01$) between seed yield and the number of root-knot nematode per 200 cm^3 soil, number of rhizobial nodules, and root gall

Table 2. Mean number of root galls, egg masses, rhizobial nodules per plant, yield components and percentage increase in seed yield of bean variety Canadian Wonder as affected by different root-knot management methods under field conditions

Treatment	Root galls per plant	Egg masses per plant	Root nodules per plant	Pods per plant	Seeds per pod	100-seed weight (g)	Seed yield (kg per ha^{-1})	Yield increase (kg per ha)	Percentage yield increase
FUD*	2.7b–e	2.0a	149.0a	7.4c–d	4.3ab	43.3ab	917.6a-d	206.6	29.3
SOZ	2.3c–f	1.7cd	93.0bc	8.1b–f	4.3ab	44.1ab	991.0a–d	286.0	40.6
FYM	3.7ab	3.7ab	135.0ab	6.3fg	3.8b	40.1b	728.7cd	23.7	3.4
TAE	2.7bcd	2.7bc	145.0a	7.1d–g	4.0ab	43.4ab	900.5a–d	195.5	27.7
COL	3.7abc	4.0ab	142.7a	6.4fg	3.7b	40.7b	745.0cd	40.0	5.7
TAE + FUD	1.7def	1.7cd	144.3a	8.4a–e	4.3ab	46.3ab	1008.0a–d	303.0	43.0
COL + FUD	2.3c–f	2.3bcd	137.7a	7.4c–f	4.3ab	44.0ab	945.9a–d	240.9	34.2
SOZ + FUD	1.3ef	1.3cd	80.7c	9.5ab	4.7a	46.5ab	1212.7abc	507.7	72.0
TAE + FYM	2.7d–e	2.7bc	131.7ab	7.9b–f	4.1ab	46.5a–d	1086.4a–d	381.4	54.1
SOZ + FYM	1.7def	1.3cd	82.3c	9.3abc	4.7a	48.7a	1305.2ab	600.2	85.1
COL + FYM	3.3abc	3.7ab	123.7abc	6.5efg	3.9b	43.3ab	837.2bcd	132.1	18.7
TAE + FYM + FUD	1.7ef	1.7cd	146.7a	8.8a–d	4.4ab	46.5ab	1174.3a–d	469.2	66.6
SOZ + FYM + FUD	1.0f	0.7d	82.7c	10.1a	4.6a	49.1a	1382.2a	677.2	96.0
COL + FYM + FUD	2.0def	2.0cd	146.7a	9.1a–d	4.6a	47.8ab	1166.3a–d	461.2	65.4
Nontreated (control)	5.0a	4.7a	150.7a	5.5g	3.7b	40.4b	705.0d		
Total	112.0	108.0	5675.0	353.8	190.3	2012.5	45318.2		
Mean	2.5	2.4	126.1	7.9	4.2	44.7	1007.0		
CV	19.9	26.8	11.4	8.2	9.0	5.8	16.2		
SE	0.3	0.4	8.3	0.4	0.2	1.5	94.3		

Within a column, means followed by the same letter do not differ significantly ($P \leq 0.05$) according to Tukey's honestly Significant Difference test. Data are means of three replicates. *FUD = Furadan 5G, SOZ = Soil solarization, FYM = Farmyard manure, TAE = *Tagetes erecta*, COL = *Crotalaria ochroleuca*.

Table 3. Mean number of root galls, egg masses, rhizobial nodules per plant, yield components and percentage increase in seed yield of bean variety Canadian Wonder as affected by different root-knot management methods under microplot conditions

Treatment	Root galls per plant	Egg masses per plant	Root nodules per plant	Pods per plant	Seeds per pod	100-seed weight (g)	Seed yield (kg per ha)	Yield increase (kg per ha)	Percentage yield increase
FUD*	1.7c	1.7cde	271.0b	8.4e	3.9c–f	40.2gh	1064.0de	273.8	34.6
SOZ	1.7c	1.3de	162.0c	8.6cde	4.5a–d	41.6d–h	1114.7cd	324.4	41.0
FYM	5.0a	4.0a	268.7b	6.4f	3.1efg	35.9ij	851.9f	61.6	7.8
TAE	1.7c	2.0cd	285.3ab	8.5cde	3.9b–e	40.9e–h	104.3de	252.1	31.9
COL	4.3ab	4.0a	302.7ab	5.9f	3.1fg	34.3jk	820.8f	30.6	3.9
TAE + FUD	1.3c	2.0cd	324.3a	9.4abc	4.7ab	44.5cde	1269.3ab	479.0	60.6
COL + FUD	1.3c	2.0cd	284.3ab	8.9bcd	4.5a–d	43.0c–g	1151.3cd	361.0	45.7
SOZ + FUD	1.0c	1.0de	149.0c	9.4abc	4.6abc	48.4ab	1345.9a	555.6	70.3
TAE + FYM	1.7c	2.7bc	305.0ab	8.4de	4.1bcd	40.3fgh	1139.7cd	349.5	44.2
SOZ + FYM	1.3c	1.7cde	149.0c	9.6ab	4.3a–d	44.0c–f	1262.0ab	471.8	59.7
COL + FYM	3.3b	3.7ab	292.7ab	7.8e	3.7d–g	38.6hi	978.7e	188.4	23.8
TAE + FYM + FUD	1.3c	1.7e	308.3ab	9.7ab	4.3a–d	45.2bcd	1196.5bc	406.2	51.4
SOZ + FYM + FUD	0.7c	0.7e	166.3c	10.0a	5.0a	50.1a	1357.9a	567.6	71.8
COL + FYM + FUD	1.3c	2.0cd	316.0ab	9.4abc	4.7abc	45.7bc	1151.7cd	361.4	45.7
Nontreated (control)	5.0a	4.7a	293.3ab	6.0f	3.0g	31.9k	790.3f		
Total	98.0	105.0	11634.0	379.9	184.6	1873.6	49610.8		
Mean	2.2	2.3	258.5	8.4	4.1	44.6	1102.5		
CV	24.5	18.0	6.2	3.6	6.4	3.0	3.25		
SE	0.3	0.2	9.3	0.2	0.2	0.7	20.7		

Within a column, means followed by the same letter do not differ significantly ($P \leq 0.05$) according to Tukey's honestly Significant Difference test. Data are means of three replicates. *FUD = Furadan 5G, SOZ = Soil solarization, FYM = Farmyard manure, TAE = *Tagetes erecta*, COL = *Crotalaria ochroleuca*.

Table 4. Correlation coefficients between pairs of root-knot nematode populations and different variates measured on bean cultivar Canadian Wonder under field conditions

Parameter	1	2	3	4	5	6	7	8
1. Number of galls per plant	1.000							
2. Number of egg mass per plant	0.844**	1.000						
3. Number of nodules per plant	0.460**	0.519**	1.000					
4. Number of pods per plant	−0.814**	−0.740**	−0.527**	1.000				
5. Number of seeds per pod	−0.594**	−0.658**	−0.427**	0.591**	1.000			
6. 100-seed weight (g)	−0.636**	−0.636**	−0.387**	0.694**	0.571**	1.000		
7. Number of nematodes per 200 cm^3 soil	0.807**	0.839**	0.371*	−0.782**	−0.866**	−0.633**	1.000	
8. Seed yield (kg per ha)	−0.729**	−0.605**	−0.403**	0.771**	0.664**	0.730**	−0.669**	1.000

NS = Not significant. *Significant at $P \leq 0.05$. **Significant at $P \leq 0.01$.

Table 5. Correlation coefficients between pairs of root-knot nematode populations and different variates measured on bean cultivar Canadian Wonder under microplot conditions

Parameter	1	2	3	4	5	6	7	8
1. Number of galls per plant	1.000							
2. Number of egg mass per plant	0.909**	1.000						
3. Number of nodules per plant	0.312*	0.500**	1.000					
4. Number of pods per plant	− 0.905**	− 0.872**	− 0.551*	1.000				
5. Number of seeds per pod	− 0.853**	− 0.808**	− 0.352*	0.891**	1.000			
6. 100-seed weight (g)	− 0.864**	− 0.849**	− 0.440**	0.928**	0.878**	1.000		
7. Number of nematodes per 200 cm^3 soil	0.939**	0.886**	0.279NS	− 0.908**	− 0.832**	− 0.842**	1.000	
8. Seed yield (kg per ha)	− 0.873**	− 0.866**	− 0.470**	0.932**	0.874**	0.933**	− 0.854**	1.000

NS = Not significant. *Significant at $P \leq 0.05$. **Significant at $P \leq 0.01$.

and egg mass indices. In addition, there were strong direct relationships ($P \leq 0.01$) between seed yield and the number of pods per plant, number of seeds per pod and 100-seed weight (Tables 4 and 5).

Discussion

The current study indicates that effective control of root-knot nematodes, especially *M. javanica* and *M. incognita*, which are known to be widely distributed in Tanzania (Ijani, 1998), will increase yield of susceptible bean varieties. Small field plots and microplots have been reported to give good data on the efficacy of root-knot nematode management methods (Barker, 1985). However, for practical purposes, microplot results need to be supported by data from field experiments. This study has shown that most of the root-knot nematode management methods tested were similarly effective in microplots and under field conditions (Figures 1 and 2). The reductions in root-knot nematode populations were generally accompanied by reductions in root damage and increases in seed yield components and seed yield (Tables 1 and 2).

The highest population densities of root-knot nematodes were recorded in field plots and microplots treated with FYM and COL (Figures 1 and 2). FYM has been reported to have nematicidal effects during its decomposition and to stimulate soil microbial populations which might be antagonistic to root-knot nematodes (Sayre, 1980; Godoy et al., 1983). In addition, FYM has soil fertilizing properties. However, in this study, nematicidal effect and biological suppressive effects of FYM on root-knot nematode populations in beans were not significantly expressed. This may have been due to incomplete decomposition of FYM and the amount used. Since this is the first study to examine the effect of FYM on root-knot nematodes in beans in Tanzania, more studies are needed under different environmental conditions to verify its effectiveness in managing root-knot nematodes.

It has been reported that COL improves soil fertility and suppresses weeds, root-knot nematodes and other pests in the field in Tanzania (Mphuru and Mushobozy, 1987). In addition, *C. spectabilis* has been reported to control multiplication of root-knot nematodes in other countries (Rodriguez-Kabana, 1992). However, in the current investigations the use of COL alone did not significantly reduce root-knot nematode populations under either microplot or field conditions (Figures 1 and 2). Such discrepancies may be caused by differences in environmental conditions and nutritional factors which may affect the composition of exudates or leachates released to the rhizosphere. Therefore, more studies are needed to test the efficacy of various *Crotalaria* species found in Tanzania in managing root-knot nematodes and to determine the actual mechanisms involved.

The effects of TAE, when applied alone or in combination with other methods, on the reduction of root damage and on the increase in bean seed yield were highly significant (Tables 1 and 2). Similar effects of TAE on root-knot nematode have been reported in tomato (Ijani and Mmbaga, 1988). TAE has been reported to have antagonistic or trapping effects on root-knot nematodes (Belcher and Hussey, 1977). However, the nematicidal effect of the chemical compound extracted from *Tagetes* spp. on root-knot nematodes has not been well established. *Tagetes* spp. are more effectively used against root-knot nematodes when they are intercropped or grown in rotation with root-knot nematode susceptible crops. In this study, TAE was more effective than SOZ and sometimes FUD in controlling root-knot nematodes in beans (Figures 1 and 2). However, the use of TAE is more environmental friendly than chemical pesticides. Like other biological control methods, TAE may work more slowly than FUD and SOZ, but is likely to provide more stable and long lasting control of root-knot nematodes. In addition, the use of TAE does not require special techniques and the plant grows widely throughout the country, and thus is easily available for use by small-holder farmers.

SOZ, using 50 μm clear polyethylene sheets for seven weeks, raised soil temperatures over the range of 34–53 °C in the field and 36–55 °C in microplots at 5 cm depth; it also significantly reduced root damage and increased bean yield by 40.6 and 41.0 percent, respectively (Tables 2 and 3). SOZ has been reported to reduce the number of root-knot nematodes in the soil and to stimulate various biological and physico-chemical changes in the soil which have negative effects on root-knot nematode populations (Katan, 1981; Katan et al., 1976; Stapleton et al., 1987). When combined with FYM or FUD, SOZ was more effective in reducing root-knot nematode populations and in increasing bean seed yield both in microplots and under field conditions (Tables 2 and 3). Because of its high efficacy, SOZ is a promising method for the management of root-knot nematodes in Tanzania and many other tropical countries. Therefore, more research on the feasibility and economical ways of using this method alone or in combination with other methods is urgently needed.

This study has also shown that the use of several control methods in combination can be more effective than single methods, both in microplots and under field conditions, in reducing root-knot nematode populations and bean root damage (Figures 1 and 2; Tables 2 and 3). Under field conditions, the highest yield increase (96 percent) was observed when SOL was used in combination with FYM and FUD; this was followed by SOL + FYM (85 percent) and SOL + FUD (72 percent) (Table 2). In the microplot experiments, similar effects were observed except that a combination of TAE and FUD ranked third, causing a yield increase of 61 percent (Table 3). Such combinations of control methods offer much promise for bean producers in managing root-knot nematodes.

In field plots where FYM and COL were applied either separately or in combination, significant increases ($P \leq 0.05$) in root-knot nematode populations were observed (Figure 1). However, in microplots where such control methods were applied, there was a non-significant decrease in root-knot nematode populations (Figure 2). Such results suggest that there is a need to conduct field experiments to compare and support data obtained from microplot experiments before they are recommended for use.

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