Management of *Meloidogyne incognita* and *Rotylenchulus reniformis* in nursery-beds by soil solarization and organic soil amendment[(1)]

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SUMMARY

Soil solarization of nursery-beds by mulching with clear thin polythene sheet for 6 weeks in summer reduced the population densities of *Meloidogyne incognita* and *Rotylenchulus reniformis* significantly more than non-mulched fallow. The decline in population was greatest in the 0-10 cm deep soil layer where the temperature frequently exceeded 40 °C. The eggplant *(Solanum melongena)* seedlings grown on the solarized beds had very few galls confined to the distal root ends. The polythene mulching also reduced upward ionic movement to the top soil layer by preventing water loss. Amendment of soil with farm-yard manure or mahua *(Madhuca indica)* cake prior to polythene mulching did not increase the effect of solarization. Control of weeds and other soil borne pathogens was an additional advantage of solarization.

RÉSUMÉ

Contrôle de Meloidogyne incognita *et* Rotylenchulus reniformis *en pépinière par solarisation du sol et amendement organique*

La solarisation du sol de pépinières par application de feuilles de polyéthylène transparent pendant 6 semaines, en été, réduit la densité des populations de *Meloidogyne incognita* et de *Rotylenchulus reniformis* de façon significative par rapport au témoin. La diminution des populations est plus forte dans les 10 premiers centimètres du sol où la température dépasse fréquemment 40 °C. Les plants d'aubergine *(Solanum melongena)* croissant dans les planches solarisées ne montrent qu'un faible nombre de galles, localisées aux extrémités des racines. Le polyéthylène réduit également les déplacements des ions vers les couches supérieures du sol par suite de la diminution des pertes en eau. Un amendement à l'aide de fumier de ferme ou de tourteau de « mahua » *(Madhuca indica)* apporté avant la mise en place du polyéthylène n'augmente pas l'effet de la solarisation. Le contrôle des mauvaises herbes et d'autres agents pathogènes telluriques constitue un avantage supplémentaire de la solarisation.

The possibilities of using polythene mulching to increase soil temperature have raised new hopes in soil borne pest and disease control. This technique has been considered for some time (Bigelow, 1921; Grooshevoy, 1939) but has only recently been utilized (Miller & Waggoner, 1963; Miller, 1976; Katan *et al.*, 1976). Several studies have since proved the efficacy of soil solarization in many parts of the world (Katan, 1981; Cartia, 1985; Garibaldi, 1987; Chauhan *et al.*, 1988; Dhingra, 1989).

Significant decreases have been achieved in the population densities of plant parasitic nematodes such as *Pratylenchus thornei* (Katan *et al.*, 1976; Grinstein *et al.*, 1979), *Ditylenchus dipsaci* (Siti *et al.*, 1982), *Radopholus similis* (Bhattacharya & Rao, 1984), *Heterodera cajani*, *Rotylenchulus reniformis*, *Helicotylenchus retusus* (Sharma & Nene, 1985; Chauhan *et al.*, 1988) and *Hirschmanniella mucronata* (Sivakumar & Marimuthu, 1987). However, the results have been highly variable, especially with *Meloidogyne* species (Katan, 1981; Stapleton, Lear & De Vay, 1987) probably due to differences in soil characteristics, available solar radiation and survival mechanisms of these nematodes.

Adding organic amendment to soil reduces nematode populations (Singh & Sitaramaiah, 1970; Muller & Gooch, 1982; Vijayalakshmi, Gaur & Goswami, 1985). Katan (1981) suggested that solarization might increase the rate of degradation of organic matter to cause accumulation of toxic gases in the soil air. Solarization of large fields is expensive due to the cost of polythene

(1) Part of M. Sc. thesis submitted by the second author to I.A.R.I., New Dehli.

and the labour involved. The field has also to be kept uncropped for a considerable period which is often not possible in multiple cropping practices such as in vegetable cultivation in the tropics. Therefore, an attempt was made to study the effect of solarization on plant parasitic nematodes, weeds and fungi in nursery-beds in order to raise nematode free seedlings which might have greater tolerance to nematode invasion after transplant, and to test if the efficacy of solarization could be increased by integrating amendment of soil with farm-yard manure (FYM) or mahua *(Madhuca indica)* cake. The results on the effects of these treatments on the predominant plant parasitic nematodes, *Meloidogyne incognita* and *Rotylenchulus reniformis* are presented in this article.

Materials and methods

A field plot at I.A.R.I. farm, New Delhi, with sandy-loam soil infested with *M. incognita, R. reniformis, Tylenchorhynchus vulgaris* and *Hoplolaimus indicus*, the former two being predominant, was divided into 48 sub-plots. In each of these a raised nursery-bed measuring 1 m^2 was prepared leaving a 50 cm space between adjacent beds. A 2^4 factorial experiment in a randomized block design replicated three times was laid out to study the effect of mulching with clear thin (approx. 60 µm) polythene sheet for 3 or 6 weeks during April-May, 1989, application of FYM at 10 tonnes ha^{-1} and mahua cake at 1 tonne ha^{-1}. The beds mulched for 3 weeks were left bare for another 3 weeks. The non-mulched beds left bare for 6 weeks served as untreated controls. The nursery-beds were irrigated and the top-soil was thoroughly mixed using a spade two days prior to treatment. For mulching the individual beds were covered with polythene sheet (2.25 m^2) with its edges buried in the soil. Population densities of plant parasitic nematodes were estimated initially and after 3 and 6 weeks using the Cobb's modified sieving and centrifugal sugar flotation techniques (Jenkins, 1964).

Table 1

Effect of polythene mulching (M), time (T), farm-yard manure (O) and mahua cake (N) individually and in combinations on *Meloidogyne incognita* and *Rotylenchulus reniformis* in nursery-beds.

Treatment	*M. incognita*						*R. reniformis*		
	(J2)			(root galls)					
	No. of J2*	% change over control	Factorial F	No. of galls	% change over control	Factorial F	No. of nematodes*	% change over control	Factorial F
Initial population	350						426		
Control	127	0		2.7	0.0		213	− 0	
M	73	− 42	23.33**	3.0	11.1	2.99	107	− 50	1.08
T	60	− 53	4.55**	2.3	− 14.8	2.29	87	− 59	10.40**
MT	40	− 76	0.41	1.3	− 51.1	2.63	0	− 100	1.13
O	120	− 5	4.49**	4.6	70.4	2.63	153	− 28	0.18
MO	100	− 21	0.93	6.3	133.3	0.19	13	− 94	0.18
TO	113	− 11	0.54	5.7	111.1	0.42	140	− 34	3.61
MTO	60	− 53	0.51	3.0	11.1	0.57	13	− 94	1.87
N	120	− 5	2.44	6.0	1.2	1.17	127	− 40	0.00
MN	107	− 16	4.42**	5.0	85.2	1.41	87	− 59	40.69**
TN	137	8	0.17	4.3	59.3	0.01	93	− 56	0.01
MTN	33	− 74	3.87	2.0	− 25.9	0.05	13	94	0.00
ON	187	47	0.07	5.0	85.2	2.99	133	− 38	0.38
MON	80	− 37	0.93	3.7	37.0	0.11	93	− 56	0.97
TON	180	42	0.41	6.3	133.3	0.57	67	− 69	2.09
MTON	53	− 58	0.60	2.0	− 25.9	0.05	27	− 87	0.03

* Population densities per 100 cm^3 soil. ** Factorial effects significant at $P > 0.05$.

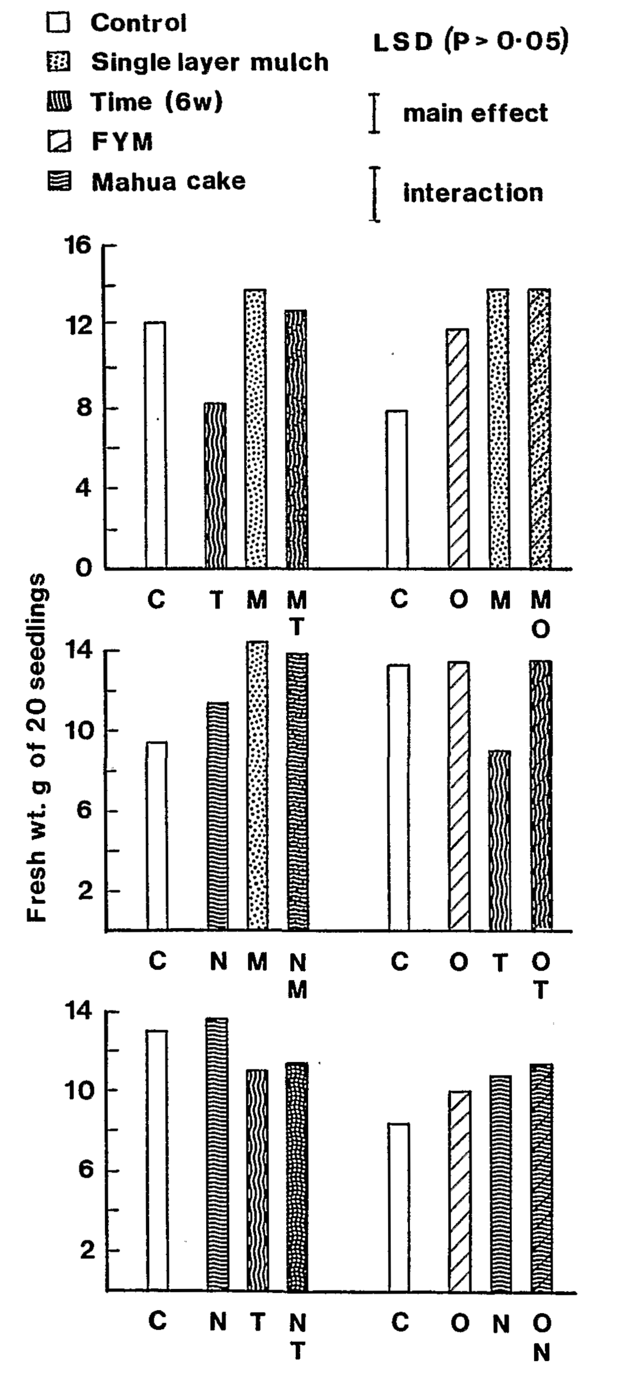

Fig. 1. The main and two factor interaction effects of polythene mulching (M), time (T), FYM (O) and mahua cake (N) on the population density of *Meloidogyne incognita* per 100 cm^3 soil in nursery-beds.

Soil temperature at 0, 10, 20 and 30 cm depths was monitored. The moisture content and salinity (electrical conductivity) of soil in mulched and non-mulched beds were also estimated at the beginning and end of the experiment. After 6 weeks the beds were irrigated, the top-soil was mixed with a spade and eggplant *(Solanum melongena)* cv. Pusa Kranti seed was sown. The seedlings were removed after 22 days and fresh weights of 20 seedlings and root galling were observed. The data were analyzed statistically using $\sqrt{x + 1}$ transformation for nematode numbers to determine the main and interaction effects of the treatments on nematode population densities and seedling growth.

Results

MELOIDOGYNE INCOGNITA

Polythene mulching had the greatest effect in reducing the *M. incognita* (J2) population in the soil (Table 1). Averaged over the other three factors, i.e. fallowing for 3 or 6 weeks, FYM or mahua cake, polythene mulching gave a reduction of 47.6 %. The main effect of fallowing for 6 weeks was a mean decline of 26.0 % which was also significant ($P > 0.05$). Fallowing for 6 weeks caused 11.4 % decline compared to the decline over 3 weeks whereas mulching for 3 and 6 weeks resulted in a population reduction of 34.9 % and 66.2 %, respectively. Although the greatest decline was seen with mulching for 6 weeks, the effects appear only additive since the interaction of these two factors was not significant ($P < 0.05$) (Fig. 1).

FYM alone reduced the numbers of *M. incognita* 28.2 % less than the combinations without it. Similarly, the population surviving in beds with mahua cake was 29.3 % higher than those without it. The two factor interaction of polythene mulching and mahua cake was also significant ($P > 0.05$). Without mulching, mahua cake left 48.4 % higher *M. incognita* (J2) population but mulching with or without it caused a decline of 35.0 % over the respective control. The other interaction effects were non-significant.

Amongst the individual treatments summer fallowing for 6 weeks with and without mulching reduced *M. incognita* by 76 and 53 %, respectively compared to the control with non-mulched fallow for 3 weeks only. From the initial population density of 350 J2 per 100 cm^3 soil the non-mulched fallow for 3 and 6 weeks caused a decline of 60.5 and 65.0 % respectively, whereas the decline in mulched beds was 74.3 and 86.7 % (Table 1).

The results on the number of galls per egg-plant seedling root (Table 1) indicated 51.8 % fewer galls in the treatment with mulching for 6 weeks compared to mulching for 3 weeks. However, owing to the great variability, neither the main nor the interaction effects were significant ($P > 0.05$). Some of the treatments with FYM or mahua cake resulted in more galls per root than

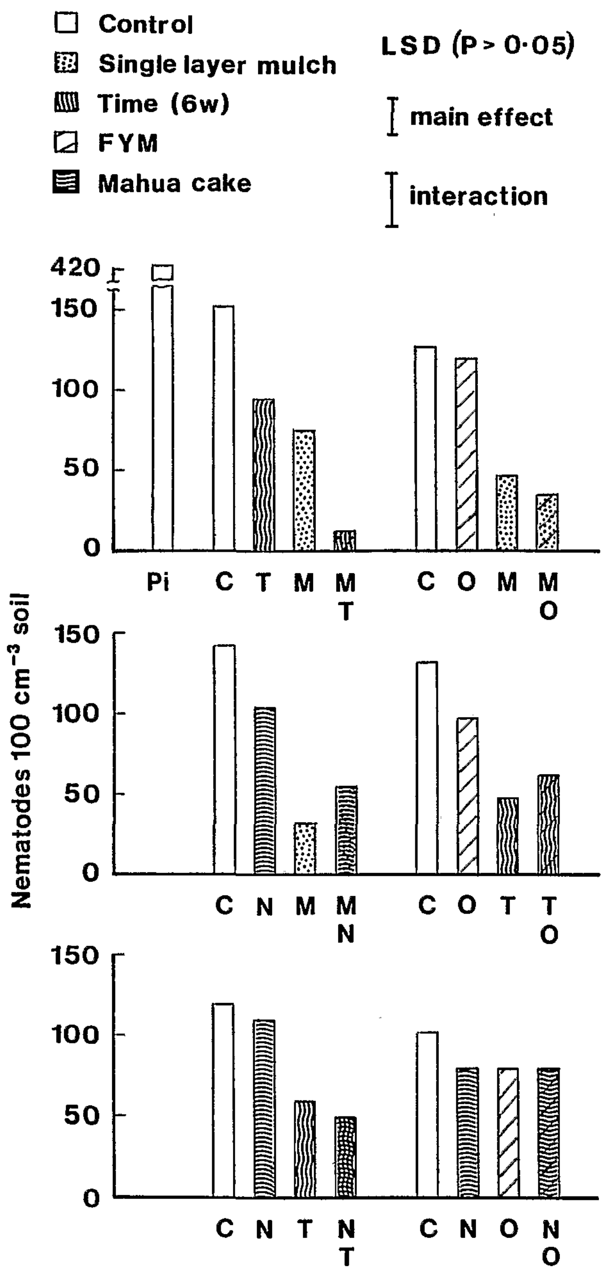

Fig. 2. The main and two factor interaction effects of polythene mulching (M), time (T), TYM (O) and mahua cake (N) on the population density of *Rotylenchulus reniformis* per 100 cm³ soil in nursery-beds.

treatments without them. In seedlings from the beds mulched for 3 or 6 weeks, galls were mostly confined to the deeper distal roots about 6-7 cm away from the root-shoot junction. In the non-mulched beds the roots were additionally galled nearer the junction.

ROTYLENCHULUS RENIFORMIS

All the treatments singly or in combination caused more decline in *R. reniformis* population densities compared to non-mulched fallow (with weeds) for 3 weeks, but to varying degrees (Table 1, Fig. 2). The non-mulched fallow for 6 weeks gave a 38.3 % decline whereas mulching for 3 and 6 weeks reduced the population by 52.1 and 94.5 % respectively. This amounted to a reduction of the initial 426 individuals (all stages and both sexes in soil except eggs) to 213 per 100 cm³ soil (— 50.0 %) with non-mulched fallow for 3 weeks; 107 (— 74,9 %) with mulching for 3 weeks; 87 (— 79.6 %) with non-mulched fallow for 6 weeks and to undetectable levels with mulching for 6 weeks. However, there was considerable variability between replicates and the analysis of variance indicated that only the main effect of fallowing and the two factor interaction of mulching and mahua cake were significant ($P < 0.05$).

The main effects of mulching, fallowing for 6 weeks, FYM and mahua cake caused population declines of 65.1, 52.5, 11.9 and 12.0 % respectively, compared to the non-mulched fallow for 3 weeks (Fig. 2). Although the combinations of these treatments did not always show additive or synergistic effects they gave greater reduction than the individual treatments. Data on the number of *R. reniformis* females per seedling root were unreliable since several females were often detached while freeing the root from the soil.

EGGPLANT SEEDLING GROWTH

Fresh weights of the 20 randomly selected seedlings showed that the polythene mulching and/or FYM provided significantly ($P < 0.05$) healthier seedlings. The main effects of mulching and FYM improved seedling weight by 35.4 and 20.7 % respectively, whereas non-mulched fallow significantly ($P > 0.05$) reduced the seedling weight by 17.7 % compared to the mean of other treatments (Fig. 3). This was possibly due to the depletion of nutrients and moisture caused by weed growth and solar heat. The electrical conductivity was also increased from the initial value of 0.60 to 0.90 in non-mulched beds and 0.75 mmhos/cm in mulched beds. The interaction effects were non-significant ($P > 0.05$) with the exception of the two factor interaction of mulching and FYM where mulching without FYM improved seedling weight by 71.8 % while the vice-versa effected an increase of 54.8 %; their combination causing 73.2 % increase in seedling weight.

SOIL TEMPERATURE AND MOISTURE

The surface soil temperature at 1 430 h ranged from 38 to 51 °C in the non-mulched soil and from 44 to 54 °C under the polythene mulch. Averaged over the period 22 April to 3 June the maximum surface temperature

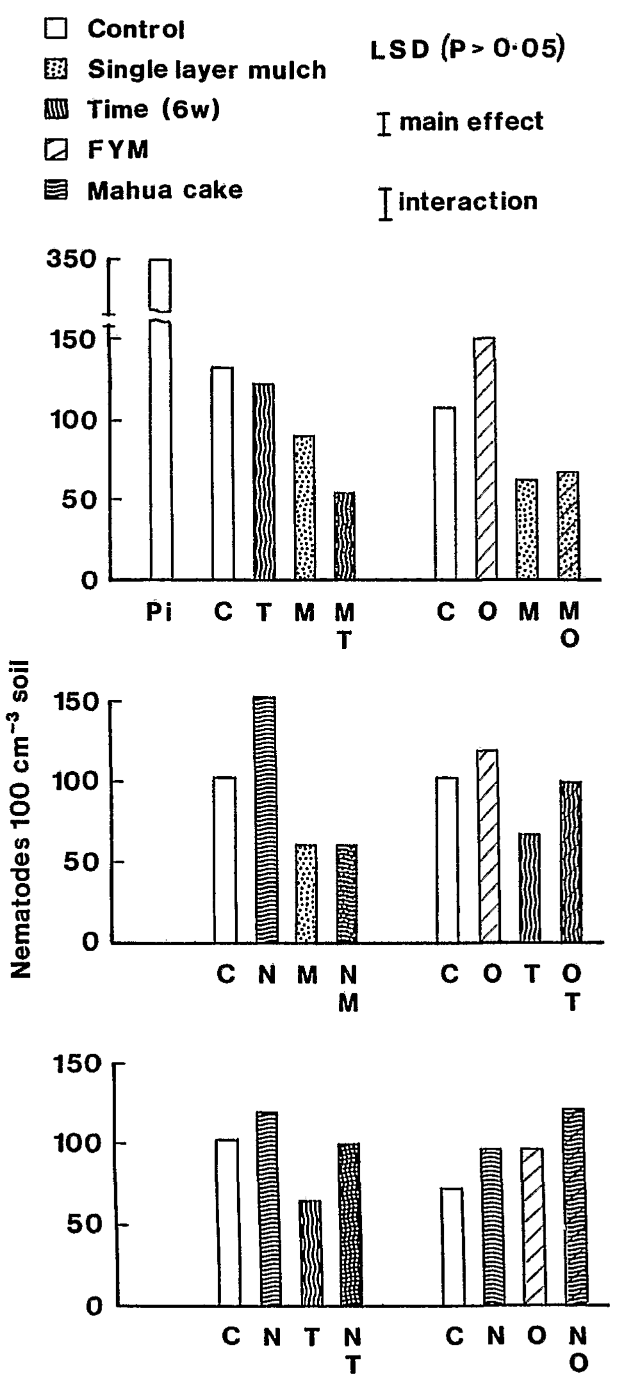

Fig. 3. The main and two factors interaction effects of polythene mulching (M), time (T), FYM (O) and mahua cake (O) on the fresh weight of eggplant seedlings grown in nursery-beds.

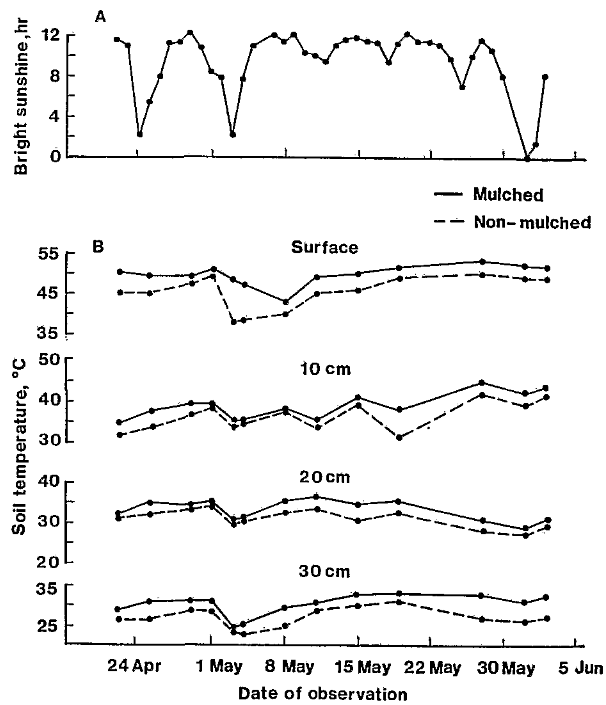

Fig 4. A. Bright sunshine hours per day, and B. soil temperature in mulched and non-mulched beds at 0, 10, 20 and 30 cm depths.

was 4.14 °C higher under the mulch (Fig. 4). At the depth of 10 cm the ranges of maximum temperature were 32-43 and 35-46 °C without and with mulching, respectively. The average soil temperature 10 cm below surface was increased by 2.1 °C in the mulched beds. Similarly, these temperature ranges were 27 and 34 and 30-36 °C at the depth of 20 cm, the average being 2.36 °C higher in the mulched beds. At 30 cm depth the soil temperature still remained higher in the mulched beds by an average of 3.27 °C. However, the temperature seldom exceeded 30 and 33 °C in the non-mulched and mulched beds, respectively, at the 30 cm depth (Fig. 4).

The soil moisture content was measured after 3 weeks from the start of the experiment. In the 0-10, 10-20 and 20-30 cm deep soil layers, the soil moisture content was 7.15, 10.40 and 20.2 % w/w respectively, in the non-mulched beds compared to 14.15, 14.32 and 20.41 % in the polythene mulched beds. Thus, more moisture was conserved under the polythene mulch, the differences being apparent in the 0-20 cm deep soil layer.

Discussion

The results clearly establish that, although the summer fallowing for 6 weeks during April-May by itself caused significant reduction in the population densities of root-knot and reniform nematodes, the use of polythene sheet mulch could substantially accentuate the reduction. The *M. incognita* (J2) population density was reduced by 60.5 and 65.0 % in the non-mulched fallow beds for 3 and 6 weeks respectively. In the mulched beds the corresponding reductions were 74.3 and 86.7 %. Similar trends were seen in the population densities of *R. reniformis* which appears to be relatively more susceptible to heat than *M. incognita* during summer fallow and mulching.

The infectivity of the root-knot and reniform nematodes was also reduced due to solarization as indicated by the fewer galls and the very few *R. reniformis* females which developed on the eggplant seedling roots in the mulched beds. The occurrence of root galls only on the distal ends of the roots in these beds indicates that *M. incognita* survived in the soil layer deeper than 6-7 cm whereas in the non-mulched beds some survived in the upper layers as well. The main effects of summer fallowing and polythene mulching were 14.8 and 51.1 % reduction in root galling, respectively.

The reduction in galling was less marked than the reduction in numbers of *M. incognita* juveniles; this was probably due to the survival of some of the population in the egg stage (which was not estimated in the present study). The persistence of *M. incognita* in the non-mulched soil could be due to anhydrobiotic survival (Freckman, 1978; Evans & Perry, 1976; Gaur & Sehgal, 1988; Sehgal & Gaur, 1988).

The number of occasions on which the temperature exceeded 40 °C at the 0-10 cm depth was much greater in the mulched beds and can be related to the reduction in nematode population densities. These findings are similar to those of Garibaldi (1987) and Chauhan *et al.* (1988). The temperature never exceeded 40 °C at the 20 and 30 cm depths.

The main effects of FYM and mahua cake used as organic amendments during the summer fallow for 6 weeks with or without mulching were not very marked. Probably the high summer temperature and short experimental period did not permit sufficient decomposition for antagonistic activity. The slightly higher population densities observed in these treatments could be due to better moisture retention in the organic amended soil. Hence, application of FYM or mahua cake during soil solarization for 3-6 weeks may not significantly influence the effects of summer fallowing and mulching, contrary to the suggestion of Katan (1981). However, these amendments may have an effect on nematode population densities after periods longer than 6 weeks.

The differences in the treatment effects on the population densities of *M. incognita* and *R. reniformis* indicate some variation in the thermal susceptibility of these species. The results on the suppression of nematodes by polythene mulching and the consequent improvement in plant growth generally conform with those reported by Katan *et al.* (1976), Cartia and Greco (1987), Braun, Koch and Stiefvater (1987) and Chauhan *et al.* (1988). Slight variations in the degree of nematode control achieved may be explained by differences between experimental locations and time-specific environmental factors, especially the duration and intensity of available solar radiation.

Interestingly the main effect of fallowing for 6 weeks, especially without mulching was to reduce the seedling weight by about 19 %, despite significant reduction in nematode population and root galling. This indicates some deleterious effects on soil fertility, perhaps depletion of nutrients by weeds and/or increased salinity (EC) due to upward ionic movement during water evaporation. The increase in EC was 25 % in mulched beds compared to 56 % in the non-mulched beds. Stapleton Quick and De Vay (1985) also made some similar observations.

These results show that summer fallowing of nursery-beds for about 6 weeks before sowing may greatly help in reducing the population densities of root-knot and reniform nematodes. Polythene mulching significantly improves the effect of summer fallowing and has further benefits in decreasing the growth of weeds and other soil borne pests and diseases. It also helps in moisture conservation and reduces excessive ionic movement to top-soil layer. Soil solarization can significantly reduce the nematode infestation and improve the growth of seedlings. The polythene mulching of nursery-beds can be more practical and economic than that of the main field due to reduced material and labour costs. Thus, it may be advisable to practise summer fallowing and ploughing, preferably with alternate wetting and drying in the main field (Sethi & Gaur, 1986), and polythene mulching of the moist nursery-beds to manage the root-knot and reniform nematodes in transplant crops such as vegetables and ornamentals.

ACKNOWLEDGEMENTS

The authors are grateful to Dr R. N. Perry and Mr Jack Beane of the Department of Entomology and Nematology, Rothamsted Experimental Station, Harpenden, Herts., U.K. for their valuable suggestions.

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Accepté pour publication le 31 janvier 1990.

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