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CONTROL OF ROOT-KNOT NEMATODES IN SRI LANKA

by
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Summary. Soil applications of granular nematicides, carbofuran, fenamiphos and oxamyl, or fumigant nematicides, 1,3 dichloropropene 1,2 dichloropropane, controlled *Meloidogyne javanica* on tomato, beans and soybeans and *M. arenaria* on tobacco and increased yields. Incorporation of coconut oil cakes into the soil also produced positive effects on control of *M. javanica* on tomato. Imported cultivars of tomato resistant to root-knot nematodes were only partially resistant to *M. javanica*. U.F.V_1 was the only one of five soybean cvs. which showed some resistance or tolerance to *M. javanica*. Diflubenzuron applied as a soil drench completely suppressed attacks of root-knot nematodes but was highly phytotoxic to soybeans. However, incorporation of the chemical into the soil just before sowing, or soaking seeds with a solution of the chemical in methyl sulphoxide gave excellent control of the nematode without suppressing plant growth.

Root-knot nematodes, *Meloidogyne* species, are widespread (Lamberti *et al.*, 1987) and affect several plant crops (Lamberti *et al.*, 1980a; Lamberti and Ekanayake, 1983b; Lamberti *et al.*, 1993) in Sri Lanka.

In trials, chemical nematicides gave satisfactory results on tomato in soil infested by *M. javanica* (Lamberti *et al.*, 1980b) and on soybean in soil infested by *M. incognita* (Lamberti *et al.*, 1983a) and less satisfactory results on snakegourd in soil infested by *M. javanica* (Lamberti *et al.*, 1982). The trials also tested the possibility of applying alternative methods of control such as oil cakes, soil amendments or resistant cultivars.

This paper reports the results of the various control methods against root-knot nematodes obtained with tomato (*Lycopersicon esculentum* Mill.), beans (*Phaseolus vulgaris* L.), tobacco (*Nicotiana tabacum* L.) and soybean [*Glycine max* (L.) Merr.].

Materials and methods

Three experiments were carried out with tomato in soil infested by *M. javanica* (Treub) Chitw. at Pallekele: *i.* chemical treatments, *ii.* soil amendments with coconut oil cakes and *iii.* resistant cultivars.

Nematicides and rates and times of application are reported in Table I. The field was ploughed 30 cm deep, rotavated and divided into 3x2 m plots distributed at random in six blocks. A space of 1 m between blocks and of 0.5 m between plots in the same block was left to avoid interactions between treatments. Plots were planted on 7 July, 1980 with tomato cv. Katugastota seedlings in four rows 50 cm apart and 30 cm apart in the row, raised in beds treated with 300 l/ha of 1,3 dichloropropene 1,2 dichloropropane (D-D). Normal irrigation, application of fertilizers and hand weeding were undertaken. Fruits were harvested and weighed as they became ripe between 28 August and 3 November. On 10 November ten plants at the centre of each plot were uprooted and graded for the degree of galling according to a scale from 0 to 5, with 0 representing no galling and 5 severe galling (Lamberti, 1971).

A field was similarly prepared for an experiment with soil amendments. The coconut oil cakes were incorporated at planting on 6 July 1980 in the top 30 cm of the soil at three different rates (Table II). Their effect was compared with that of fenamiphos, 40 kg a.i./ha, incorporated into the top 20 cm of the soil at the same time. There were six replicates per treatment including a control. Fruits were harvested from 29 August to 6 October and plants were dug out for gall rating on 8 October.

To test the reaction of resistant tomatoes to the Pallekele population of *M. javanica*, Italian imported seeds of the cvs Bush, Brech, Piersol, Rossol and VFN8 resistant and Roma susceptible, and of locally produced Roma and Katugastota, were sown in nursery beds that had been treated three weeks earlier with D-D. Four week old seedlings were transplanted into 3x3 m plots as in the first experiment. There were 36 plants per plot spaced 50 cm from each other. Each cultivar was planted into untreated plots and into plots treated three weeks earlier with 300 l/ha of D-D or the day before planting, with 40 kg a.i. of

fenamiphos. Planting was done on 17 December 1979 and fruit harvesting between 6 February and 18 March, 1980. On the latter date plants were uprooted for evaluating the degree of galling. There were six replicates for each cv./treatment.

An experiment with beans was also undertaken in soil infested by *M. javanica*, at Pallekele. A local population of beans was sown in 4x3 m plots treated as indicated in Table IV, with six replicates per treatment. On 24 December 1979 two seeds were sown in holes spaced at 10 cm in the row with 20 cm between the rows. Green pods were harvested and weighed from 13 February to 18 March, 1980. After completion of harvesting the root systems of ten plants, were dug from the centre of each plot and graded on the basis of the number of mature females developed in 1 g root aliquots of three samples per plot.

A trial with tobacco was carried out at Hunnasgiriya in soil infested by *M. arenaria* (Neal) Chitw. Six week old seedlings of cv. Sathan, produced in a D-D fumigated bed, were planted on 28 December, 1979 in 2x2 m plots, treated as indicated in Table V. There were 20 plants per plot spaced at 40 cm within and between rows, with six replicates per treatment. Mature leaves were harvested and weighed fresh from 28 March to 28 April, 1980. Plants were uprooted on 28 April for mature female counts of the nematode as indicated before.

Three experiments were undertaken with soybean. In the first, conducted at Pallekele in soil infested by *M. ja-*

TABLE I - *Effect of nematicidal treatments on yield and degree of root galling by* Meloidogyne javanica *of "Katugastota" tomato.*

Treatment	Rate of application kg a.i./ha	Time of application	Average yield kg/plot (6 m²)		% Increase with respect to control	Root-knot index	
Control	–	–	19.1	d	–	2.5	A
Fenamiphos	40	at planting	22.7	abc	18.8	0.0	B
Carbofuran	10	at planting	23.2	abc	21.5	0.2	B
"	10	1 week after planting	20.6	cd	7.8	0.2	B
"	10	2 " " "	21.3	bcd	11.5	0.0	B
"	10	3 " " "	22.4	abcd	17.3	0.8	B
"	10	4 " " "	22.7	abc	18.8	0.0	B
Oxamyl	10	at planting	20.0	cd	4.7	0.7	B
"	10	1 week after planting	23.3	abc	22.0	0.0	B
"	10	2 " " "	25.4	a	33.0	0.0	B
"	10	3 " " "	24.7	ab	29.3	1.2	B
"	10	4 " " "	20.5	cd	7.3	0.7	B

Data flanked in the columns by the same letters are not statistically different according to Duncan's multiple range test; small letters for P = 0.05 and capital letters for P = 0.01.

TABLE II - *Effect of coconut oil cake soil amendments on yield and degree of root galling by* M. javanica *of "Katugastota" tomato.*

Treatment	Rate of application (/ha)	Average yield kg/plot (6 m²)	% Increase with respect to control	Root-knot index
Control		16.4 a	–	2.5 A
Coconut oil cake	20 m tons	21.1 b	28	0.2 B
" " "	40 " "	21.4 b	30	0.2 B
" "	60 " "	21.7 b	32	0.0 B
Fenamiphos	40 kg a.i.	25.3 c	54	0.0 B

Data flanked in the columns by the same letters are not statistically different according to Duncan's multiple range test; small letters for P = 0.05 and capital letters for P = 0.01.

TABLE III - *Yield of tomato cultivars in soil infested by* M. javanica *(g/plant).*

Cultivar	Control		D-D		Fenamiphos	
	Average yield	Root-knot index	Average yield	% Increase	Average yield	% Increase
Katugastota	340 a	1.8 a	520 *	53	600 *	76
Roma local	320 a	1.5 a	480	50	520 *	62
Roma Italian	280 a	1.8 a	330	18	410	46
Bush	350 a	1.0 b	610 *	74	480	37
Brech	340 a	1.5 a	390	15	420	23
Piersol	320 a	1.0 b	340	6	530 *	66
Rossol	290 a	0.7 b	360	24	500 *	72
VFN 8	370 a	0.0 c	550 *	49	680 *	84

For each cv., data flanked in the columns by the same letters are not statistically different for P = 0.05, according to Duncan's multiple range test; * statistically different for P = 0.05 from control, according to Student's *t* test.

TABLE IV - *Effect of nematicidal treatments on yield of beans in soil infested by* M. javanica.

Treatment	Average yield kg/12 m^2	% increase with respect to control	No. of mature females in 1 g roots
Control	7.3 a	–	4.2
D-D 300 l/ha 3 weeks before planting	8.7 ab	19	0
Fenamiphos 40 kg/ha 1 day before planting	9.4 b	29	0
Carbofuran 10 kg/ha " " " "	9.5 b	30	0

Data flanked in the columns by the same letters are not statistically different for P = 0.05, according to Duncan's multiple range test.

vanica, five cultivars were tested (kindly provided by Dr. G. R. Noel of the United States Department of Agriculture, Agricultural Research Station at Urbana, Illinois). Seeds were sown on 18 May 1980 at the rate of two seeds spaced at 5 cm in the row and 40 cm between the rows in 2x2 m plots, untreated (control) or fumigated three weeks earlier with 400 l/ha of D-D. There were six replicates for each cultivar. Pods, dried on the plants, were harvested and weighed on 10 August when ten plants at the centre of each plot were uprooted and the roots systems graded for the degree of galling.

Two further experiments evaluated the effect of diflobenzuron, which according to Veech (1977) might provide a new approach to the chemical control of nematodes.

The first experiment was carried out in the field at Pallekele in soil infested by *M. javanica*. After the usual preparation of the soil, the field was divided into 1 m diameter plots. Diflobenzuron wettable powder (25% a.i.) was either suspended in water (20 g in 10 l), for soil drench treatments or dissolved in dimethyl sulphoxide (10 g in 1 l) for seed soaking treatments. Seeds were soaked for two hours in 1 l solution, and drenching undertaken by pouring 250 ml of suspension at each planting site. Combinations of the two formulations were applied as in Table VII. Controls were unsoaked seeds with water only drenching in the soil and seeds soaked in dimethyl sulphoxide without any drenching in the soil. Seeds, cv. Pb1, were sown with a space of 30 cm from each other at groups of three in each circle on 24 May, 1980. There were ten replicates for each treatment. On 7 September, two weeks after the last soil drench, plants were uprooted and weighed and the root systems evaluated for degree of galling. Numbers of egg masses and of eggs for each 2 g of roots selected at random from each plot were counted.

This experiment was complemented with a test carried out in 10 cm diameter plastic pots in a lath-house at Peradeniya. Pallekele field soil infested by *M. javanica* was thoroughly mixed with diflubenzuron (20 g of 25% wp per 10 kg soil) and then potted, about 0.5 kg/pot. In each pot two soybean seeds, cv. Pb1, were planted on 25 May, 1980 and 50 ml per pot of a water suspension (2 g/l) of the chemical were drenched at different times, as shown

in Table VIII. Pots with untreated soil and without any drench served as controls. There were ten replicates for each treatment. Two weeks after the last drench, plants were uprooted and weighed. The degree of galling was evaluated on the root systems and numbers of egg masses and eggs per 2 g of roots determined.

Results

Significant increases in yield occurred in the tomato plots treated at planting with either fenamiphos or carbofuran or with carbofuran applied four weeks after planting or with oxamyl applied one, two or three weeks after planting, compared with the untreated control (Table I). All treatments significantly reduced root-knot index and was nil on plants grown in the plots treated with fenamiphos at planting, with carbofuran two or four weeks after planting or with oxamyl one or two weeks after planting.

Coconut oil cakes soil amendments increased tomato yields to the same extent independently of rates of application; however, soil treatment with fenamiphos was more effective (Table II). Root gall indices were equally reduced by coconut oil cakes or fenamiphos applications.

An outbreak of viral infection, probably tomato yellow leaf curl virus (Fig. 1), caused stunted growth and/or yield losses in many tomato plants grown from imported seeds, which were supposed to be resistant to root-knot nematodes. Yield data were therefore collected from plants without symptoms of viral infection (Table III). However, there were no significant differences between yields when the various cultivars were grown in untreated soil. Conversely, there were yield differences between the control and plants grown in soil treated with one of the two nematicides. Applications of D-D significantly increased yields of cvs. Katugastota, Bush and VFN 8 while application of fenamiphos increased yields of Katugastota, Roma local, Piersol, Rossol and VFN 8. Root-knot indices for

TABLE V - *Effect of nematicidal treatments on yield of tobacco in soil infested by* Meloidogyne arenaria.

Treatment	Average yield kg/4 m²	% increase with respect to control	No. of mature females in 1 g roots
Control	7.1 a	–	8
Fenamiphos 40 kg/ha at planting	8.9 b	25	0
D-D 200 l/ha 3 weeks before planting	9.1 b	28	0
D-D 300 l/ha " " " "	8.9 b	25	0
D-D 400 l/ha " " " "	8.6 b	21	0
Carbofuran 10 kg/ha at planting	8.5 b	20	0
Carbofuran 6 kg/ha at planting + 3 kg/ha 3 weeks after planting	8.7 b	23	0
Carbofuran 9 kg/ha 2 weeks after planting	8.3 b	17	1

Data flanked in the columns by the same letters are not statistically different for P = 0.05, according to Duncan's multiple range test.

TABLE VI - *Reaction of soybean cultivars to* M. javanica.

Cultivar	Weight of pods/plot (kg/4 m²)		% Increase	Root gall index of control plants
	Control	Treated with D-D		
Caribe	0.6 a	1.3 **	117	1.2 ab
Pb1	0.6 a	1.1 **	83	2.0 a
S. J. 2	0.6 a	0.9 *	50	0.8 b
Tunia	0.6 a	1.0 **	67	1.5 a
U.F.V$_1$	0.9 b	1.6 **	78	0.8 b

For each cv., data flanked in any column by the same letters are not statistically different according to Duncan's multiple range test; statistically different from control according to Student's *t* test * for P = 0.05; ** for P = 0.01.

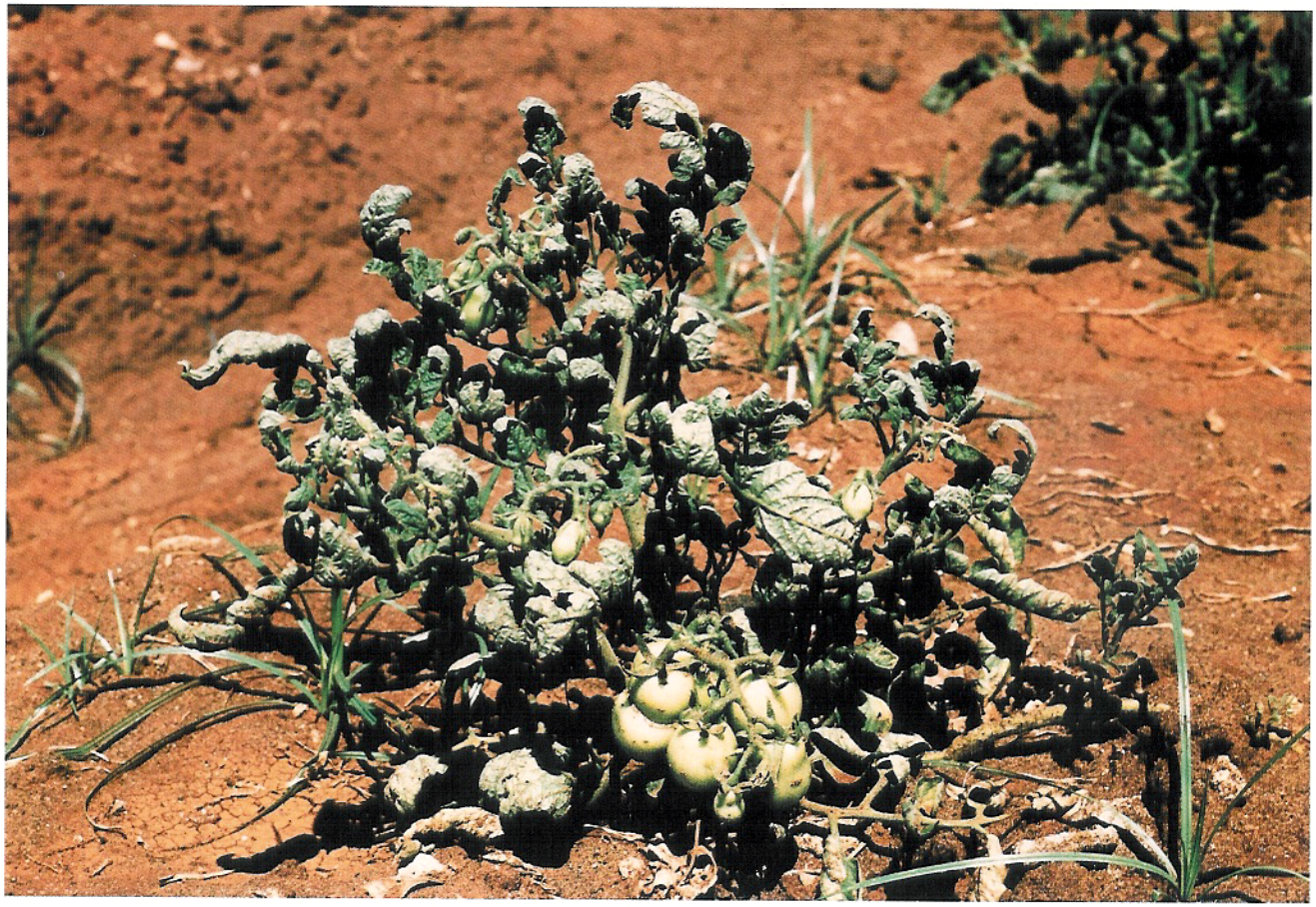

Fig. 1 - Tomato plant with viral infection, probably tomato yellow leaf curl virus.

plants grown in untreated soil were moderate for cvs. Katugastota, Roma local and Roma Italian (all susceptible) and Brech (resistant), small for Bush, Piersol and Rossol (all resistant) and nil for cv. VFN 8 (resistant). There were no root galls on plants grown in soil treated with either D-D or fenamiphos, independently of the cultivar, whether susceptible or reported as resistant in Europe.

Nematicidal treatments increased the yield of beans in soil infested by *M. javanica* compared with the control (Table IV) and the non-volatile chemicals carbofuran and fenamiphos (Fig. 2) were more effective than the fumigant D-D. However, all the chemicals prevented nematode invasion and/or nematode development within the roots.

Applications of either non-volatile nematicides, such as carbofuran and fenamiphos, or the fumigant D-D at different rates, gave increases in fresh weight of tobacco leaves and controlled *M. arenaria* attacks on roots (Table V), indepentently of rate (as for D-D) or time (as for carbofuran) of application. Application of carbofuran only two weeks after planting gave the least satisfactory results.

The soybean cultivars tested were all equally affected by *M. javanica*, except cv. U.F.V_1 which produced significantly higher yield in infested soil (Table VI). Root gall indices were significantly lower on cvs. U.F.V_1 and Tunia compared with Caribe, Pb1 and S.J.2.

In the field experiment, repeated soil drenches of diflubenzuron applied at 15 day intervals eradicated *M. javanica* on soybeans (Table VII). Excellent control of the nematode was also achieved by seed soaking with the chemical or by a single soil drench at planting time. It is interesting to note that seed soaked in methyl sulphoxide, without any further treatment, gave good control of the nematode. However, repeated soil drenches significantly inhibited plant growth (Table VII).

The pot experiment confirmed that soil drenches with diflubenzuron, although eradicating the root-knot nema-

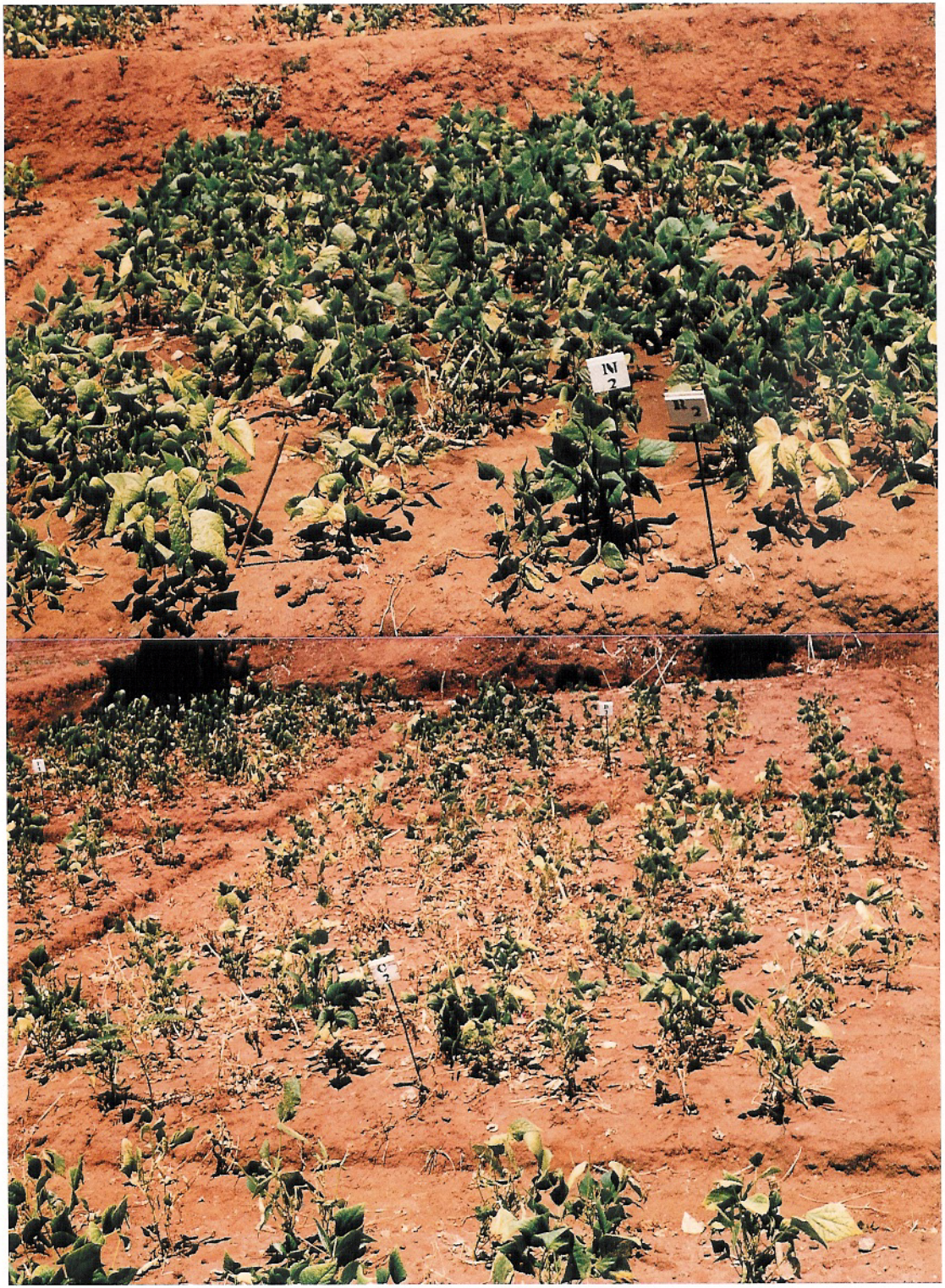

Fig. 2 - Effect of nematicidal treatments on growth of beans in soil infested by *Meloidogyne javanica*: (top) a plot treated with fenamiphos; (bottom) a control plot.

TABLE VII - *Effect of diflubenzuron on reproduction of* M. javanica *and growth of soybeans in the field.*

Treatments	Nematode reproduction (No. in 2 g root)		Root gall index	Average plant weight (g)	
	Egg-masses	Eggs		Top	Root
Seed soaking only	1.7 ab A	328 ab A	0.8 bc	3.8 A	0.9 A
Seed soaking + soil drench at sowing	1.9 ab A	332 ab A	0.5 b	4.0 A	0.5 B
Seed soaking + soil drench at sowing and 15 days later	0 a A	0	0 a	2.1 B	0.5 B
Seed soaking + soil drench at sowing and 15 and 30 days later	0 a A	0	0 a	1.7 BC	0.6 B
Seed soaking + soil drench at sowing and 15, 30 and 45 days later	0 a A	0	0 a	2.5 B	0.6 B
Seed soaking + soil drench at sowing and 15, 30, 45 and 60 days later	0 a A	0	0 a	2.5 B	0.6 B
Seed soaking + soil drench at sowing and 15, 30, 45, 60 and 75 days later	0 a A	0	0 a	1.0 C	0.6 B
Seed soaking + soil drench at sowing and 15, 30, 45, 60, 75 and 90 days later	0 a A	0	0 a	1.6 BC	0.5 B
Seed soaking only in dimethyl sulphoxide and no soil drench	5.5 b A	756 b A	1.2 c	3.0 A	0.7 AB
Soil drench at sowing only	2.5 ab A	323 ab A	0.9 bc	3.8 A	0.9 A
Soil drench at sowing and 15 days later	0 a A	0 a A	0. a	4.1 A	0.8 AB
Soil drench at sowing and 15 and 30 days later	0 a A	0 a A	0 a	3.2 A	0.5 B
Soil drench at sowing and 15, 30 and 45 days later	0 a A	0 a A	0 a	1.4 BC	0.6 B
Soil drench at sowing and 15, 30, 45 and 60 days later	0 a A	0 a A	0 a	1.3 BC	0.6 B
Soil drench at sowing and 15, 30, 45, 60 and 75 days later	0 a A	0 a A	0 a	1.2 BC	0.6 B
Soil drench at sowing and 15, 30, 45, 60, 75 and 90 days later	0 a A	0 a A	0 a	1.1 C	0.7 AB
Control	28.3 c B	4.779 c B	2.2 d	3.3 A	0.8 AB

Data flanked in any column by the same letters are not statistically different according to Duncan's multiple range test (small letters for P = 0.05; capital letters for P = 0.01).

tode, were phytotoxic when repeated at forthnight intervals at the concentration tested in our trials (Table VIII).

Discussion and conclusions

Soil application of granular non-volatile nematicides such as fenamiphos, carbofuran or oxamyl were effective in controlling *M. javanica* on tomato and beans and *M. arenaria* on tobacco. Yields were also increased by the treatments, but perhaps not always as much as expected (Lamberti *et al.*, 1980; 1982; 1983a) probably because of modest initial populations of the nematodes.

Treatments with the fumigant D-D totally suppressed root infestation by *Meloidogyne* species on tomato, beans, tobacco and soybeans and produced yield increases of susceptible and resistant cvs. of tomato and of susceptible cvs. of tobacco and soybeans but not of beans.

Incorporation of coconut oil cakes into the soil produced positive effects on control of *M. javanica* on tomato and on yield; however, yield increase was much higher in the plots treated with fenamiphos and it is not known yet whether in more heavely infested soil oil cakes would give the same results.

The use of imported cvs. of tomato resistant to root-knot nematodes in Europe was not successful. They were greatly affected by infection of local virus strains, for which had not undergone any selection, and infested by the Sri Lanka population of *M. javanica.*

The occurrence of galls on the root system of the to-

TABLE VIII - *Effect of diflubenzuron on reproduction of* M. javanica *and growth of soybeans in pots.*

Treatments	Nematode reproduction (No. in 2 g root)		Root gall index	Average plant weight (g)	
	Egg-masses	Eggs		Top	Root
Soil incorporation only	0 A	0 A	0 A	5.4 A	1.0 ab
Soil incorporation + soil drench 15 days after sowing	0 A	0 A	0 A	5.2 A	1.0 ab
Soil incorporation + soil drench 15 and 30 days after sowing	0 A	0 A	0 A	0.8 B	0.8 ab
Soil incorporation + soil drench 15, 30 and 45 days after sowing	0 A	0 A	0 A	0.9 B	0.9 ab
Soil incorporation + soil drench 15, 30, 45 and 60 days after sowing	0 A	0 A	0 A	0.7 B	0.7 a
Soil incorporation + soil drench 15, 30, 45, 60 and 75 days after sowing	0 A	0 A	0 A	0.7 B	0.7 a
Soil incorporation + soil drench 15, 30, 45, 60, 75 days after sowing	0 A	0 A	0 A	0.9 B	0.8 ab
Control	12 B	667 B	1.9 B	4.3 A	1.4 b

Data flanked in any column by the same letters are not statistically different according to Duncan's multiple range test (small letters for P = 0.05; capital letters for P = 0.01).

mato cvs. considered to be resistant to root-knot nematodes, confirms results of a previous experiment (Lamberti *et al.*, 1983) with the hypothesis that resistance breaking is not due to features of the nematode population, which looks as a typical *M. javanica* (Ekanayake and Di Vito, 1984), but more likely to environmental conditions; in fact, during the growing season in which the experiment was conducted, air temperature often exceeded for many hours 35-36 °C.

The reaction of soybean cvs. to *M. javanica* did not vary much. Possibly the cv. U.F.V_1 has some tolerance or resistance to the nematode; however further work is needed for more conclusive response.

Diflubenzuron was very effective in controlling root-knot nematodes but was highly phytotoxic on soybeans when applied as repeated soil drenches. As suggested by Veech (1977), it inhibited egg-mass formation. Since this author had indicated that its effect would last for two to three weeks only and that juveniles in the soil would not be affected and their penetration into roots not prevented, we used forthnightly drenches of the chemical for three months. Our results, however, indicated that incorporation of the chemical into the soil, just before sowing, would eradicate root-knot nematodes and seed soaking with a solution of diflubenzuron in methyl sulphoxide would reduce much egg-mass production without, in both cases, suppressing plant growth. These data, nevertheless, need confirmation in field experiments also taking yields into account.

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Literature cited

EKANAYAKE H. R. M. K. and DI VITO M., 1984. Identification of *Meloidogyne* species from Sri Lanka. *CNR CP Int. Nematol. Netw. Newsl.*, *1*: 13-14.

LAMBERTI F., 1971. Primi risultati di prove di lotta nematocida su tabacchi levantini in provincia di Lecce. *Il Tabacco*, *738*: 5-10.

LAMBERTI F. and HEKANAYAKE H. M. R. K., 1982. Chemical control of root-knot nematodes on snakegourd in Sri Lanka. *Nematol. medit.*, *10*: 227-228.

LAMBERTI F. and EKANAYAKE H. M. R. K., 1983a. Control of plant parasitic nematodes on soybean in Sri Lanka. *FAO Plant Prot. Bull.*, *31*: 127-129.

LAMBERTI F. and EKANAYAKE H. M. R. K., 1983b. Effect of some plant parasitic nematodes on the growth of black pepper in Sri Lanka. *FAO Plant Prot. Bull.*, *31*: 163-166.

LAMBERTI F., EKANAYAKE H. M. R. K. and DI VITO M., 1987. The root-knot nematodes, *Meloidogyne* spp. in Sri Lanka. *FAO Plant Prot. Bull.*, *35*: 27-31.

LAMBERTI F., EKANAYAKE H. M. R. K. and SASANELLI N., 1993. Effect of some plant parasitic nematodes on the growth of selected crops in Sri Lanka. *Nematol. medit.*, *21*: 27-43.

LAMBERTI F., EKANAYAKE H. M. R. K. and ZACHEO F., 1980a. Effect of two *Meloidogyne* species on the growht of papaya seedlings. *Indian J. Nematol.*, *10*: 225-230.

LAMBERTI F., EKANAYAKE H. M. R. K. and ZACHEO F., 1983. Reaction of six tomato cultivars to two Sri Lanka populations of *Meloidogyne* spp. *Pak. J. Nematol.*, *1*: 43-48.

LAMBERTI F., EKANAYAKE H. M. R. K., ZACHEO F. and ABEYKOON M. B., 1980b. Yield response of tomato to nematicidal treatments in soil infested by *Meloidogyne javanica* in Sri Lanka. *Nematol. medit.*, *8*: 131-135.

VEECH J. A., 1977. A possible new approach to the chemical control of nematodes. *J. Nematol.*, *9*: 184-185.