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THE SYNERGISM OF SOIL SOLARIZATION WITH FUMIGANT NEMATICIDES AND STRAW FOR THE CONTROL OF *HETERODERA CAROTAE* AND *DITYLENCHUS DIPSACI*

by
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Summary. The synergism of soil solarization with applications of reduced rates of 1,3 D and dazomet and soil incorporation of wheat straw on the control of *Heterodera carotae* on carrot and *Ditylenchus dipsaci* on onion was investigated in 1990-1991 in six field trials in Italy. Fumigations with 25 or 50 1 1,3 D/ha followed by four or eight week solarization periods improved the control of *H. carotae* compared with either method alone, resulting in the near eradication of the nematode from the top 30 cm soil and suppression of carrot feeder root infestation. Significant increases in carrot yields were obtained with 50 l 1,3 D/ha in combination with soil solarization. Similar levels of egg mortality of H. *carotae* were obtained by a combination of soil application of 50 or 100 kg dazomet/ha and soil solarization, although the treatment had no effect on carrot yield and root infestation. More onion plants survived *Ditylenchus dipsaci* infestation and larger marketable yields of onions were obtained with a combination of soil solarization with 25 or 50 l 1,3 D/ha. Except for an application of 50 kg dazomet/ha followed by eight week solarization, both solarization periods and all rates of dazomet, alone or in combination, fenamiphos at 10 kg/ha and 1,3 D at 250 l/ha suppressed nematode infestation and increased onion yield. Soil incorporation of 5 and 10 t wheat straw/ha, or 5 t straw/ha followed by eight week solarization, also reduced nematode infestation and increased onion yield.

Among methods of pest and disease control that are alternatives to chemical treatments, soil solarization appears to be very promising (Katan, 1987; De Vay, 1991). Investigations undertaken in Italy (Greco et al., 1985, 1990; Cartia et al., 1989) and elsewhere (Grinstein et al., 1979; Porter and Merriman, 1982; Stapleton and De Vay, 1983) have shown that this technique can also be effective against nematodes. However, soil solarization is generally effective only in the top 20 cm soil under field conditions, whereas most of the crop roots develop at greater depths. Thus, in heavily infested fields soil solarization would not prevent nematode attack in the lower soil profile. However, soil solarization combined with chemical soil fumigation (Stapleton and De Vay, 1983; Cartia et al., 1989) could give protection for most, if not all, of the root zone. Trials were undertaken in 1990-1991, to investigate the effect of soil solarization combined with reduced rates of 1,3 D (1,3 dichloropropene), dazomet (3,5 dimethyl-1,3,5-thiadiazinane-2-thione) and with the incorporation of wheat straw, for the control of *Heterodera carotae* Jones on carrot and *Ditylenchus dipsaci* (Khuen) Filipjev on onion.

Materials and methods

Two sandy soil (98% sand) fields were chosen at Margherita di Savoia (Province of Foggia). One field had been planted to onion and in the previous year had suffered severe damage by *D. dipsaci*. The other field, infested with *H. carotae*, had been cropped with carrot two years before. Both fields were used to investigate the control of the nematode infestation by a combination of soil solarization with reduced rates of 1,3 D, dazomet or incorporation of wheat straw. The fields were irrigated, rototilled and then divided in plots of 4 m^2 each (m 2 x m 2) spaced 40 cm apart in a randomized block design. There were six replications per treatment except in the experiments with straw which consisted of only three replicates.

Soil temperatures were continously recorded at 10, 20 and 30 cm depth, in a solarized and in a non-solarized plot, for two months.

H. carotae

Experiment 1. Treatments were soil solarization periods of four and eight weeks and 25 and 50 1 1,3 D/ha, alone or in combination, 100 and 250 l 1,3 D/ha, and 10 kg a.i. fenamiphos (ethyl-4-methylthio-m-tolyl isopropylphosphoramidate)/ha, with an untreated control (Table I). 1,3 D was applied with a hand injector at 20 cm depth at the rate of 250 l/ha and at 35 cm depth at the other rates, on 18 June, 1990. All plots were then consolidated, lightly sprinkler irrigated and those to be solarized where covered with 50 µm thick polyethylene transparent film a day later. Fenamiphos was incorporated in the top 15 cm soil one day before sowing.

TABLE I - *Effect of soil solarization and 1.3 D, alone or in combination, on the mortality of* Heterodera carotae, *its soil population density, carrot feeder roots infestation and carrot yield*

Treatment	Eggs/g soil		% nematode mortality	Nematodes/g roots			Marketable yield (kg/m 2)
	before sowing	after harvest		Eggs and J2 [2]	Females and cysts	Other stages	
Sol. 4 weeks	11 a	2* [1] b	86 bc	4,003 ab	287 a	89 bc	1.4 abc
Sol. 8 weeks	13 a	2** b	93 bc	2,995 abc	122 bc	54 bc	1.4 ab
1,3 D 50 l/ha	14 a	1** b	80 b	2,218 bcd	66 c	27 c	2.0 abc
1,3 D 25 l/ha	16 a	3** a	52 a	2,294 abc	90 c	218 a	1.1 a
Sol. 4 weeks + 1,3 D 50 l/ha	14 a	2** ab	99 c	1,200 cde	119 bc	76 bc	2.2 bc
Sol. 4 weeks + 1,3 D 25 l/ha	13 a	3 ab	96 c	1,445 cde	47 c	13 c	1.9 abc
Sol. 8 weeks + 1,3 D 50 l/ha	14 a	2** b	100 c	495 e	23 c	8 c	2.5 c
Sol. 8 weeks + 1,3 D 25 l/ha	16 a	2** ab	99 c	1,090 cde	86 c	43 bc	2.0 abc
1,3 D 250 l/ha	13 a	1** b	99 c	832 de	27 c	6 c	2.0 abc
1,3 D 100 l/ha	14 a	2** ab	100 c	454 e	15 c	4 c	2.3 bc
Fenam. 10 kg/ha	17 a	3** ab	58 a	4,825 a	142 b	81 bc	2.0 abc
Control	13 a	1** b	57 a	4,433 ab	250 ab	158 ab	1.1 a

Figures are means of six replicates. Numbers in the same column followed by the same letter are not signficantly different for P = 0.05, according to Duncan's multiple range test.

[1] Significantly different at P = 0.05 (*) or P = 0.01 (**) level, according to Student's *t* test.

[2] J2 = Nematode second stage juveniles.

Experiment 2. Treatments were the same solarization periods as in Expt. 1 and 50 and 100 kg dazomet/ha, alone or in various combinations, 500 kg/ha dazomet, 250 l 1,3 D/ha, 10 kg a.i./ha of fenamiphos, and untreated control (Table II). 1,3 D was injected at 20 cm depth and dazomet was broadcast on the plot surface and rototilled in the top 20 cm soil on 18 June, 1990. The soil was then compacted, irrigated and the solarized plots covered as in expt. 1 a day later. Fenamiphos was applied one day before sowing. Non treated plots served as a control.

Experiment 3. Treatments were an eight week solarization period and 5 and 10 t of wheat straw/ha incorporated in the top 20 cm soil on 22 June, alone or in combination, and a non-treated control (Table III). The solarized plots were then irrigated and mulched.

Plots in the three experiments were rotavated on 4 September, 1990 to disperse any residues of the soil fumigants and to incorporate fertilizer and Fenamiphos in those plots receiving this treatment. Carrot cv 91 was then sown on 5 September, 1990. All plots were sprinkler-irrigated twice a week until October when the first rain occurred and normal crop practices were undertaken during the growing season.

Soil samples, each a composite of 36 cores, were collected with an auger, 1.5 cm diameter and 30 cm long, in the centre square metre of each plot, at the end of the longest solarization period (21 August, 1990) and soon after the harvest (1 February for Experiment 1 and 6 February, 1991 for Experiments 2 and 3). To assess the effect of the treatments on *H. carotae*, cysts were extracted with a Fenwick can from 200 cm^3 soil of the samples collected in August and incubated at 20 °C for eight weeks in a root leachate prepared from four week old carrots (Greco et al., 1982; Greco and Brandonisio, 1986). Emerging juveniles were counted and removed weekly and the hatching agent changed at the same time. The cysts were crushed at the end of the hatching test by the Bijloo's modified method (Seinhorst and Ouden, 1966) and unhatched eggs counted. Totals of these and emerged nematode juveniles were considered as number of eggs present in the cysts at the beginning of the test. Unhatched eggs were considered dead and used to calculate the per cent nematode mortality.

To ascertain the effect of the treatments on the changes of the nematode population densities, cysts were extracted from soil samples collected after harvest. Two hundred

TABLE II - *Effect of soil solarization and dazomet, alone or in combination, on the mortality of* Heterodera carotae, *its soil population density, carrot feeder roots infestation and carrot yield*

Treatment	Eggs/g soil		% nematode mortality	Nematodes/g roots			Marketable yield (kg/m [2])
	before sowing	after harvest		Eggs and J2 [2]	Females and cysts	Other stages	
Sol. 4 weeks	15 a	4*[1] ab	87 ab	7,921 abc	628 ab	830 a	1.0 abc
Sol. 8 weeks	13 a	5* ab	97 a	4,470 abc	260 ab	110 b	1.8 abc
Dazomet 100 kg/ha	16 a	8* a	91 a	13,790 a	472 ab	237 ab	0.4 c
Dazomet 50 kg/ha	15 a	2* b	85 ab	7,066 abc	287 ab	205 b	1.5 abc
Sol. 8 weeks + dazomet 100 kg/ha	13 a	3 ab	98 a	1,098 bc	75 ab	22 b	2.9 ab
Sol. 8 weeks + dazomet 50 kg/ha	10 a	4 ab	92 a	9,031 ab	676 a	570 ab	0.9 bc
Sol. 4 weeks + dazomet 100 kg/ha	9 a	6 ab	100 a	1,506 bc	187 ab	16 b	2.1 abc
Sol. 4 weeks + dazomet 50 kg/ha	12 a	5 ab	96 a	4,873 abc	384 ab	132 b	1.7 abc
Dazomet 500 kg/ha	13 a	7 ab	98 a	1,230 bc	76 ab	29 b	1.9 abc
Fenamiphos 10 kg/ha	12 a	8 ab	50 c	4,127 abc	145 ab	248 ab	2.0 abc
1,3 D 250 l/ha	18 a	6 ab	100 a	526 c	37 b	10 b	3.0 a
Control	13 a	4 ab	60 bc	4,340 abc	115 ab	167 b	1.1 abc

Figures are means of three replicates. Numbers in the same column followed by the same letter are not signficantly different for P = 0.05, according to Duncan's multiple range test.

[1] Significantly different at P = 0.05 level, according to Student's *t* test.

[2] J2 = Nematode second stage juveniles.

TABLE III - *Effect of soil solarization and wheat straw, alone or in combination, on the soil population density of* Heterodera carotae, *carrot feeder roots infestation and carrot yield*

Treatment	Eggs/g soil		Nematodes/g roots			Marketable yield (kg/m [2])
	before sowing	after harvest	Eggs and J2 [2]	Females and cysts	Other stages	
Sol. 8 weeks	9 ab	0*[1] b	31 b	2 b	0 a	2.9 ab
Sol. 8 weeks + straw 5 t/ha	6 b	0* b	23 b	0 b	3 a	2.5 ab
Sol. 8 weeks + Straw 10 t/ha	6 b	1 b	125 b	5 b	6 a	3.4 b
Straw 10 t/ha	5 b	0* b	446 a	10 a	3 a	2.9 ab
Straw 5 t/ha	9 ab	0* b	230 ab	2 b	2 a	2.4 ab
Control	10 a	2** a	285 ab	1 b	1 a	2.1 a

Figures are means of three replicates. Numbers in the same column followed by the same letter are not signficantly different for P = 0.05, according to Duncan's multiple range test.

[1] Significantly different at P = 0.05 (*) or P = 0.01 (**) level, according to Student's *t* test.

[2] J2 = Nematode second stage juveniles.

grams of air dried soil were processed combining the Fenwick can with the ethanol flotation method (Seinhorst, 1974), in which ethanol had been substituted with a 1.25 sp. g. magnesium sulphate solution. The cysts were then crushed, as above, and their egg content determined.

At harvest (30 January for Experiment 1 and 5 February, 1991 for second and third Experiments) the total yield of marketable carrots in the centre square metre of each plot were measured. At the same time about 3 g of feeder roots were collected from the harvested carrots, processed by Coolen's method (Coolen, 1979) and the different life stages of the nematode were counted.

D. dipsaci

Solarization periods, nematicides and wheat straw rates, treatments combinations and procedures, were the same as in the *H. carotae* experiments, unless otherwise specified (Tables IV, V, VI). Dazomet at 50 and 100 kg/ha was applied on 21 June, 1990 and solarized plots were mulched a day later. Dazomet at 500 kg/ha was applied on 4 October and 1,3 D at 100 and 250 l/ha was injected on 15 October, 1990. Fenamiphos was rototilled on 12 November, two days before planting. Two month old onion cv. Bianca di maggio seedlings free of nematodes, were transplanted on 14-17 November 1990, at the rate of 289 seedlings per plot. Normal crop practices were applied throughout the growing season. Because of shortage of rain onions were irrigated from March 1991 onwards as required. Onion bulbs were harvested from the central square metre of each plot on 16 May 1991 and weighed.

Soil samples were collected as in the previous experiments, one day before applying the treatments (20 June), before transplanting (8 November) and soon after harvest. Samples were processed by the centrifuge method (Coolen, 1979) and nematodes in two 5 ml aliquots were counted.

Numbers of onion plants surviving nematode attack were counted on 8 March, 8 April, and 13 May, 1991.

All data were statistically analyzed and compared with the Duncan's multiple range test or Student's *t* test.

TABLE IV - *Effect of soil solarization and 1,3 D, alone or in combination, on the population of* Ditylenchus dipsaci, *number of onion plants survived to the nematode infestation and marketable onion bulbs*

Treatment	Nematodes/100 cc soil		Survived onion plants/4 m^2 [1]			Marketable bulbs (kg/m^2)
	before sowing	after harvest	8/3/91	8/4/91	13/5/91	
Sol. 4 weeks	20 ab	77 bc	114 bcd	87 abcde	81 abcd	2.8 abcd
Sol. 8 weeks	67 a	69 bc	80 abc	66 abc	61 abc	2.8 abcd
1,3 D 50 l/ha	41 ab	85 bc	105 abcd	93 abcde	89 abcd	2.6 abcd
1,3 D 25 l/ha	40 ab	96 abc	30 a	23 a	19 a	0.6 a
Sol. 4 weeks + 1,3 D 50 l/ha	23 ab	143 ab	71 ab	63 abcd	58 abc	2.1 abc
Sol. 4 weeks + 1,3 D 25 l/ha	60 ab	46 bc	181 d	157 e	149 d	4.8 cd
Sol. 8 weeks + 1,3 D 50 l/ha	53 ab	134 abc	167 cd	130 cde	121 cd	3.7 bcd
Sol. 8 weeks + 1,3 D 25 l/ha	19 ab	71 bc	167 cd	145 de	134 cd	5.2 d
1,3 D 250 l/ha	54 ab	26 c	132 bcd	127 bcde	120 cd	4.5 cd
1,3 D 100 l/ha	8 b	195 a	68 ab	60 abc	57 abc	2.3 abcd
Fenam. 10 kg/ha	26 ab	34 bc	113 bcd	101 bcde	97 bcd	3.1 abcd
Control	11 b	87 bc	69 ab	47 ab	40 ab	1.2 ab

[1] Number of plants per plot = 289.

Figures are means of three replicates. Numbers in the same column followed by the same letter are not significantly different for P = 0.05, according to Duncan's multiple range test.

TABLE V - *Effect of soil solarization and dazomet, alone or in combination, on the population of* Ditylenchus dipsaci, *number of onion plants survived to the nematode infestation and marketable onion bulbs*

Treatment	Nematodes/100 cc soil		Survived onion plants/4 m² [(1)]			Marketable bulbs (kg/m²)
	before sowing	after harvest	8/3/91	8/4/91	13/5/91	
Sol. 4 weeks	51 ab	71 ab	125 bc	102 b	96 b	2.9 bc
Sol. 8 weeks	89 a	35 b	158 cdef	132 bcde	123 bcd	3.7 bcd
Dazomet 100 kg/ha	39 b	46 ab	131 cd	113 bc	108 bc	2.6 b
Dazomet 50 kg/ha	57 ab	38 ab	167 cdef	140 cdef	131 bcde	3.8 bcd
Sol. 8 weeks + dazomet 100 kg/ha	41 b	31 b	155 cde	128 bcd	122 bcd	4.1 cde
Sol. 8 weeks + dazomet 50 kg/ha	63 ab	32 b	146 cde	126 bcd	117 bc	3.6 bcd
Sol. 4 weeks + dazomet 100 kg/ha	32 b	58 ab	142 cde	119 bcd	113 bc	2.7 bc
Sol. 4 weeks + dazomet 50 kg/ha	46 b	77 a	90 ab	46 a	41 a	0.8 a
Dazomet 500 kg/ha	70 ab	30 b	173 cdef	168 ef	160 de	5.2 e
Fenamiphos 10 kg/ha	26 b	44 ab	200 ef	179 f	169 e	4.4 de
1,3 D 250 l/ha	34 b	65 ab	174 def	151 def	141 cde	3.8 bcd
Control	49 ab	29 b	59 a	43 a	35 a	0.7 a

[1] Number of plants per plot = 289.
Figures are means of six replicates. Numbers in the same column followed by the same letter are not significantly different for P = 0.05, according to Duncan's multiple range test.

Results

After the second week of solarization, soil temperatures in the solarized plots were in the ranges 41-44.4, 36.4-38 and 32.4-33.6 °C at 10, 20, and 30 cm depth, respectively (Fig. 1). In non-solarized plots temperatures at the same depths were 6, 4 and 3 °C less, respectively.

H. carotae

There was a sudden drop of temperature at the end of November and early December 1990, which may have limited the potential yields of carrots in all plots.

Experiment 1. About 57% of the eggs within cysts were not viable in control plots (Table I). The hatching test demonstrated that significantly more eggs were killed by all treatments, except 25 l 1,3 D/ha alone. Control of *H. carotae* with soil solarization was satisfactory, especially when it lasted eight weeks, and was further improved, although not significantly, when this technique was combined with reduced rates of the 1.3 D. This combination was as effective as treatments with 100 or 250 l/ha of the fumigant, resulting in nearly the eradication of the nematode from the top 30 cm soil.

At harvest significantly fewer nematode eggs were on carrot rootlets from plots fumigated with 100 and 250 l 1,3 D/ha and in those in which soil solarization was combined with the reduced rates of the fumigant compared with the control. Numbers of females and cysts on carrot feeder roots were significantly suppressed in all fumigated plots and in those in which soil fumigation was combined with soil solarization, except in the treatments of 50 l/ha 1,3 D followed by four week solarization. Other stages of the nematode on the roots generally were suppressed by fumigation with 100 or 250 l 1,3 D/ha or when the reduced rates of the fumigant were combined with soil solarization (Table I).

Eggs and juveniles of the nematode in the soil declined in all plots and no significant differences were observed among treatments (Table I).

Although the population density of the nematode before the treatments was not large (Table I) and despite the adverse growing conditions, carrot yield increased in nearly all plots. Significant yield increases were obtained in plots that were solarized in combination with low rates of the fumigant, or in plots treated with 100 l 1,3 D/ha injected 35 cm deep but not in plots that were solarized only (Table I).

Experiment 2. In this trial more than 95% of the *H. caro-*

tae eggs were not viable before treating in three replicates, therefore only the results of the remaining three replicates are considered. These showed, however, only 40% of the eggs viable (Table II). Egg mortality was significantly higher in all treatments, with the exception of the four week solarization period alone or combined with the lowest rate of dazomet. For both solarization periods the kill of the nematode increased when in combination with 100 or 50 kg dazomet/ha. Application of 100 kg/ha of this chemical followed by solarization was as effective as fumigation with 250 l 1,3 D/ha, which eradicated the nematode in the top 30 cm soil.

Also in this experiment the soil population density of *H. carotae* declined, although not always significantly, in all plots (Table II). None of the treatments significantly reduced nematode infestation of carrot rootlets by harvest time, although different nematode life stages and eggs were fewer in the roots from plots treated with 250 l 1,3 D/ha, 500 kg dazomet/ha or both solarization periods combined with 100 kg dazomet/ha. No significant effect of the treatments was observed on the yield of carrot.

Experiment 3. Because of the high percentage of dead eggs, it was not possible to estimate the effect of the treatments on the mortality of the nematode.

There were no substantial differences in root infestation among the different treatments (Table III). However, the soil population density of *H. carotae* after harvest was larger in the control than in any of other plots and less than before sowing. Carrot yields increased in all plots, but significant yield increases (62%) were obtained only in those in which incorporation of 10 t straw/ha was followed by the eight week solarization period.

D. dipsaci

Experiment 1. The nematode was very destructive and nearly all onions had died long before harvest in half of the first trial. Therefore only the results of three replicates are presented.

Nematode soil population densities significantly declined after treatment, but with no differences between treatments (Table IV), and increased thereafter. Severe infestation of the onions was apparent one month after transplanting. However, significantly more onion plants survived nematode infestation in plots treated with 25 and 50 l 1,3 D/ha followed by eight week solarization or with 25 l 1,3 D/ha followed by four week solarization, since 8 March 1991 until harvest (Table IV). There were significant differences between these treatments and those in which the same rates of the fumigant or the same solarization periods were applied alone. At harvest significantly more plants were also present in plots fumigated with 250 1 1,3 D/ha.

Except in plots fumigated with 25 1 1,3 D/ha, onion yields increased in all other treatments (Table IV), although significantly only in those fumigated with 250 1 1,3 D/ha or 25 l/ha followed by soil solarization. Soil solarization, alone or in combination with 25-50 1 1,3 D/ha, increased yields 2-4 times, but because of large variability the observed differences were significant only when solarization was combined with the smallest rate of fumigant (Table IV).

Experiment 2. Nematode attack was less severe in the trial with dazomet. The soil population density after treatment and at harvest was similar to that observed in the previous trial and no important differences were observed (Table V).

TABLE VI - *Effect of soil solarization and wheat straw, alone or in combinaton, on the population of* Ditylenchus dipsaci, *number of onion plants that survived the nematode infestation and marketable onion bulbs*

Treatment	Nematodes/100 cc soil		Surviving onion plants/4 m² [1]			Marketable bulbs (kg/m²)
	before sowing	after harvest	8/3/91	8/4/91	13/5/91	
Sol. 8 weeks	20 bc	85 ab	127 c	103 c	95 c	2.3 bc
Sol. 8 weeks + straw 5 t/ha	13 c	67 ab	168 d	104 c	95 c	3.2 c
Sol. 8 weeks + straw 10 t/ha	16 c	51 ab	55 b	39 b	34 b	1.1 ab
Straw 10 t/ha	43 ab	52 ab	41 ab	22 ab	17 ab	0.5 a
Straw 5 t/ha	16 c	107 a	116 c	102 c	96 c	2.7 c
Control	56 a	43 b	27 a	9 a	8 a	0.2 a

[1] Number of plants per plot = 289.
Figures are means of three replicates. Numbers in the same column followed by the same letter are not significantly different for P = 0.05, according to Duncan's multiple range test.

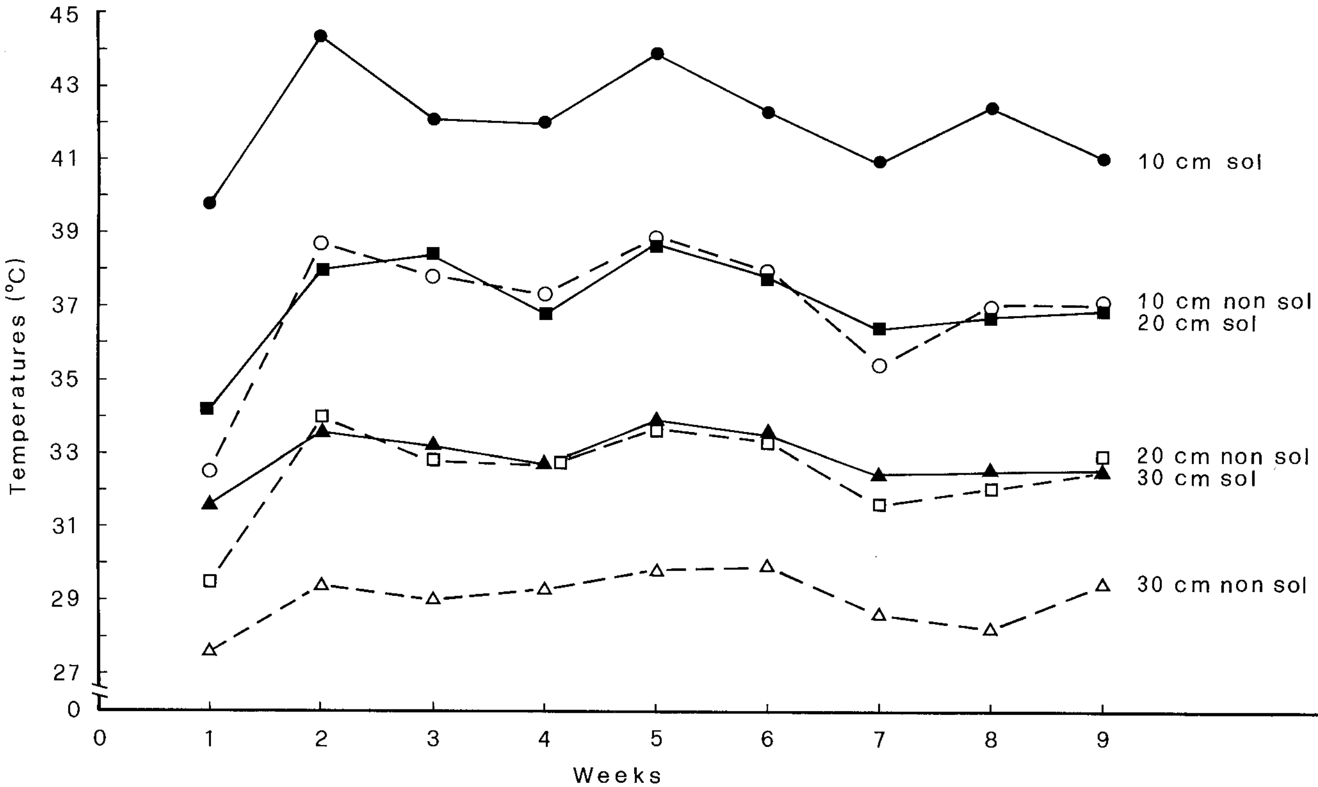

Fig. 1. Soil temperature recorded at 10, 20, and 30 cm depth in solarized (sol) and non solarized (non sol) plots, during the solarization period.

Compared with the untreated control, the numbers of onion plants which survived nematode attacks were larger in all plots, except those treated with 50 kg dazomet/ha followed by eight week solarization (Table V). Again the severity of the nematode infestation increased as harvest approached.

Every treatment, except soil solarization for eight weeks combined with 50 kg dazomet/ha, increased onion yield (Table V), with the best yield with dazomet at 500 kg/ha, followed by fenamiphos.

Experiment 3. Nematode populations were suppressed by all treatments, except incorporation of 10 t/ha of straw, at sowing but not at harvest. More onion plants survived *D. dipsaci* infestations in all solarized plots. However, soil incorporation of 5 t straw/ha combined with eight weeks solarization prevented nematode infestation even better than soil solarization alone. This resulted in satisfactory yield increases in all solarized plots especially if solarization was combined with soil incorporation of straw (Table VI).

Discussion and conclusion

Stapleton and De Vay (1983) obtained satisfactory control of several plant parasitic nematodes in California using soil solarization and they found that control was further enhanced, in most of their trials, by combining this technique with the injection of 122 or 140 1 1,3 D/ha. Frank *et al.* (1986) reported that in Israel soil solarization combined with the application of metham sodium gave greater control of shell spot disease of peanut pods than either treatment alone. Greco *et al.* (1990) also obtained good control of *H. carotae* with an application of 100 l 1,3 D/ha followed one week later by 4-8 weeks solarization periods. The rate of application of the chemical is, however, rather large and therefore would provide little benefit in reducing environmental pollution. Stapleton *et al.* (1987) found no synergism of soil solarization with 44 l/ha of 1,3 D or 64 l/ha metham sodium.

Our investigations, especially those with *H. carotae*, indicate that soil application of reduced rates of 1,3 D (25-50 l/ha) or dazomet (50-100 kg/ha), when combined with soil solarization, provided better control than soil solarization or chemical treatment alone. Most probably the deeper injection of 1,3 D, irrigation and the polyethylene mulch may have reduced the escape of these fumigants and thus improved their nematicidal activity. Moreover, weakening of the nematode by one type of treatment may have rendered it more sensitive to another. Also, the increased soil temperature under mulches could have enabled the fumigants to diffuse in a deeper soil profile, but this was not investigated.

Differences in the yields obtained in the various treatments against *H. carotae* and *D. dipsaci* were most probably due to differences in nematode soil population densities. In the *H. carotae* experiments the plots had medium to low nematode densities. *D. dipsaci* was very destructive, because of its high population densities and the favorable environmental conditions, thus causing severe loss of onion bulbs even in plots where normal rates of chemicals were applied.

In Japan (Horiuchi, 1991) soil incorporation of rice straw and other organic materials followed by soil solarization has been successful in controlling several soil-borne diseases. Our investigations also demonstrated that incorporation of wheat straw into the soil followed by eight week solarization, prevented infestation of onions by *D. dipsaci* until harvest, thus improving yield performance. However, the use of more than 5 t straw/ha was not practicable.

Although the data need confirmation, it appears that combining soil fumigation or soil incorporation of straw with soil solarization may help to achieve better nematode control and reduce the undesirable impact of chemicals used in agriculture on the environment.

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Literature cited

CARTIA G., GRECO N. and CIPRIANO T., 1989. Effect of soil solarization and fumigants on soil-borne pathogens of pepper in greenhouse. *Acta Horticulturae, 255*: 111-116.

COOLEN W. A., 1979. Methods for the extraction of *Meloidogyne* spp. and other nematodes from roots and soil. In: Root-knot nematodes (*Meloidogyne* species) Systematics, Biology and Control (Lamberti F. and Taylor C. E. eds.), Academic Press, London, pp. 317-329.

DE VAY J. E., 1991. Historical review and principles of soil solarization. In: Soil solarization (De Vay J. E., Stapleton J. J. and Elmore C. L. eds), FAO, Rome, pp. 1-15.

FRANK Z. R., BEN-YEPHET Y. and KATAN J., 1986. Synergetic effect of metham and solarization in controlling shell pots of peanut pods. *Crop Protection, 5*: 199-202.

GRECO N. and BRANDONISIO A., 1986. The biology of *Heterodera carotae*. *Nematologica, 12*: 447-460.

GRECO N., BRANDONISIO A. and DE MARINIS G., 1982. Investigation on the biology of *Heterodera schachtii* in Italy. *Nematol. medit.*, 10: 201-214.

GRECO N., BRANDONISIO A. and ELIA F., 1985. Control of *Ditylenchus dipsaci, Heterodera carotae* and *Meloidogyne javanica* by solarization. *Nematol. medit., 13*: 191-197.

GRECO N., D'ADDABBO T., BRANDONISIO A. and ZWEEP A., 1990. Combined effect of soil solarization and 1,3 dichloropropene for control of *Heterodera carotae*. *Nematol. medit., 18*: 261-264.

GRINSTEIN A., ORION D., GREENBERGER A. and KATAN J., 1979. Solar heating of the soil for the control of *Verticillium dahliae* and *Pratylenchus thornei* in potatoes. In: Soil-borne Plant Pathogens (Schippers B. and Gams W. eds), Academic Press, London, pp. 431-439.

HORIUCHI S., 1991. Solarization for greenhouse crops in Japan. In: Soil Solarization (De Vay J. E., Stapleton J. J. and Elmore C. L. eds), FAO, Rome, pp. 16-27.

KATAN J., 1987. Soil solarization. In: Innovative Approaches to Plant Disease Control (Ilan Chet ed.), Wiley and Sons, New York, pp. 77-105.

PORTER I. J. and MERRIMAN P. R., 1983. Effect of solarization of soil on nematode and fungal pathogens at two sites in Victoria. *Soil Biol. Biochemistry, 15*: 39-44.

SEINHORST J. W., 1974. Separation of *Heterodera* cysts from dry organic debris using ethanol. *Nematologica, 20*: 367-369.

SEINHORST J. W. and OUDEN H. DEN, 1966. An improvement of Bijloo's method for determining the egg content of *Heterodera* cysts. *Nematologica, 12*: 170-171.

STAPLETON J. J. and DE VAY J. E., 1983. Response of phtytoparasitc and free-living nematodes to soil solarization and 1,3-dichloropropene in California. *Phytopatology, 73*: 1429-1436.

STAPLETON J. J., LEAR B. and DE VAY J. E., 1987. Effect of combining soil solarization with certain nematicides on target and nontarget organisms and plant growth. *Ann. app. Nematol., 1*: 107-112.

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