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Control of *Heterodera carotae, Ditylenchus dipsaci,* and *Meloidogyne javanica* with Fumigant and Nonfumigant Nematicides

N. Greco, F. Elia, and A. Brandonisio[1]

Abstract: Five field trials were conducted in Italy in 1983 and 1984 to test the efficacy of isazofos and benfuracarb in controlling *Heterodera carotae* on carrot, *Ditylenchus dipsaci* on onion, and *Meloidogyne javanica* on tomato. Methyl isothiocyanate (MIT) was tested against *H. carotae* and *M. javanica.* Single (10 kg a.i./ha) and split (5 + 5 kg a.i./ha) applications of isazofos gave yield increases of carrot and onion similar to those obtained with DD (300 liters/ha) and aldicarb (10 kg a.i./ha). Population densities of *H. carotae* in carrot roots at harvest and of *M. javanica* in tomato roots 2 months after transplanting were also suppressed by isazofos. Benfuracarb (10 kg a.i./ha increased onion yields in a field infested with *D. dipsaci,* but it was not effective against *H. carotae* or *M. javanica.* The efficacy of MIT at 400 and 600 liters/ha was similar to that of MIT + DD (Di-Trapex) at 300 liters/ha. Both nematicides inhibited hatch of *H. carotae* eggs and decreased the soil population density of *M. javanica.*

Key words: Aldicarb, *Allium cepa,* onion, benfuracarb, chemical control, *Daucus carotae,* carrot, DD, *Ditylenchus dipsaci,* stem and bulb nematode, fenamiphos, *Heterodera carotae,* carrot cyst nematode, *Lycopersicon esculentum,* tomato, *Meloidogyne javanica,* root-knot nematode, methyl isothiocyanate.

Heterodera carotae Jones, *Ditylenchus dipsaci* (Kühn) Filipjev, and *Meloidogyne javanica* (Treub) Chitwood have been reported to cause severe yield suppression, respectively, of carrot (*Daucus carota* L.), onion (*Allium cepa* L.), and tomato (*Lycopersicon esculentum* Mill.) in Italy (5,6,9,11). Considerable effort has been expended to control plant parasitic nematodes without using nematicides. Crop rotation is ineffective because *D. dipsaci* and *M. javanica* have very wide host ranges, and resistant cultivars are not available or are not suited to Italy's environment or commercial processors. Chemical control therefore is still one of the most reliable ways to limit yield suppression caused by these nematodes. Although good control of *H. carotae* (8) and *D. dipsaci* (7) has been achieved with nematicides, information is lacking on their efficacy against *M. javanica* in Italy. Five field trials were conducted in 1983 and 1984 to determine the efficacy of several nematicides against these nematodes.

Materials and Methods

Control of H. carotae: A field of sandy soil (98% sand, 1.5% O.M., pH 7.8) at Margherita di Savoia (Province of Foggia) infested with an average of 40 eggs of *H. carotae*/g soil was selected for study. The field was divided into 54 plots, 2 × 2 m each spaced 30 cm apart. Plots were arranged in a randomized block design with six replicates per treatment. Efficacy of single (5 and 10 kg a.i./ha) and split (5 + 5 kg a.i./ha) applications of isazofos (O-5-chloro-1-isopropyl-1H-1,2,4-triazol-3-yl-O,O-diethyl phosphorothioate) and benfuracarb (2,3-dihydro-2,2-dimethyl-7-benzofuranyl-N-(N-2 ethoxy carbonyl-ethyl) N-iso-

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[1] Istituto di Nematologia Agraria del C.N.R., Via G. Amendola 165/A, 70126 Bari, Italy.
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propylamino-sulphenil N-methyl carbamate) was compared with that of 300 liters/ha of DD (1,3 dichloropropene-1,2-dichloropropane mixture) and 10 kg a.i./ha of aldicarb (2-methyl-2-(methylthio) propionaldehyde O-methylcarbamoyloxime). The soil was tilled, and DD was injected 20 cm deep in holes 30 cm apart with a hand injector on 23 July 1983. Soil temperature was 20–25 C at 20 cm deep. Fumigated plots were lightly irrigated to limit nematicide loss. Twenty days later plots were tilled to release any remaining fumigant and the nonvolatile nematicides were applied broadcast and incorporated into the top 10 cm of soil. Selezione 92 carrot was sown on 17 August 1984. The second half of split applications was applied broadcast on 5 October, and all plots were irrigated the same day to enhance distribution of the chemicals through the soil profile.

A 1.5–2-kg soil sample (composite of 80 cores) was collected from the center square meter of each plot with a 1.0-cm-d soil sampler to 30 cm deep before treatment and again at harvest. The soil was air dried and thoroughly mixed, a 200-g subsample was processed by the Fenwick can method, and cysts were recovered by the Seinhorst method (12).

Since new cysts of *H. carotae* may not float in the ethanol used in the Seinhorst method, 1.25 sp. gr. magnesium sulphate solution (2) was substituted. Cysts were counted and crushed according to Bijloo's modified method (13), and eggs were counted.

To obtain information on viability of eggs within cysts in fumigated soil, soil samples were also collected from DD-treated and nontreated plots 20 days after fumigation. Cysts separated from fresh soil were incubated for 8 weeks at 20 C in carrot root leachate (10). Numbers of second-stage juveniles emerging from cysts recovered from fumigated plots were referred to as percentage of those from nontreated plots.

Carrots from the center square meter of each plot were harvested on 6 December 1983 and weighed. Five grams of rootlets were collected from these carrots and processed by Coolen's method (2); nematodes in different developmental stages were then counted.

Control of D. dipsaci: Nematicides tested in the carrot study were also tested against *D. dipsaci* on onion. A field infested with fourth-stage juveniles (578/500 cm^3 soil) was selected in the same area as the carrot tests. DD was applied on 11 October 1983; the soil temperature was 18–22 C at 20 cm deep. Nonvolatile nematicides were broadcast on 3 November 1983, and all plots were tilled to incorporate the chemicals. Fumigated plots were also tilled on 3 November to ensure escape of the fumigant. Two-month-old onion Bianca di Maggio seedlings were transplanted on 13 November. The second half of the split application of isazofos and benfuracarb was applied on 7 February 1984.

Onions were harvested from the center square meter of each plot on 15 May 1984, and bulbs were weighed.

To obtain information on pretreatment and posttreatment population densities of *D. dipsaci,* soil samples were collected from all plots on 11 October 1983 and 16 May 1984. On 3 November 1983 additional soil samples were collected from fumigated and nonfumigated plots. The samples were processed by Coolen's method (2), and the nematodes were counted.

Control of M. javanica: The nematicides tested in the carrot study were also tested against *M. javanica* on tomato; however, single (10 kg a.i./ha) and split (5 + 5 kg a.i./ha) applications of fenamiphos (ethyl 4-methylthio-m-tolyl isopropylphosphoramidate) were used instead of aldicarb. A field at Torchiarolo (Province of Brindisi) infested with *M. javanica* second-stage juveniles and eggs (1,547/500 cm^3 soil) was divided into 60 2.6 × 3.6 m plots. Plots were randomized in six blocks and separated along rows 0.5 m apart. Soil samples (composites of 40 cores) were collected with a 1.8-cm-d soil sampler from each plot on 26 April, 6 August, and 26 September 1984. To assess the efficacy of DD, control samples were collected on 24 May from fumigated plots. Soil samples were processed by Coolen's method (2) to estimate numbers of eggs and juveniles.

DD was applied on 26 April 1984 followed by light irrigation. Nonvolatile nematicides were applied on 24 May 1984. Tomatoes were transplanted on 6 June 1984. Each plot was planted with 24 two-month-old Ventura tomato seedlings in two rows 80 cm apart. The remainder of the

TABLE 1. Effect of soil nematicide application on carrot yield and on population densities of *Heterodera carotae* in carrot rootlets and soil.

Treatment	Yield (kg/m²)	Juveniles and adults/g roots	Eggs and juveniles/g soil	
			Before sowing	After harvest
Aldicarb, 10 kg a.i./ha	0.9 bc	3,631 cd	32 a	10* a
DD, 300 liters/ha	1.4 a	141 a	30 a	17* a
Benfuracarb, 5 kg a.i./ha	0.2 ef	5,754 d	42 a	14** a
Benfuracarb, 10 kg a.i./ha	0.3 def	2,291 c	23 a	8* a
Benfuracarb, 5 + 5 kg a.i./ha	0.6 cd	3,548 cd	30 a	11* a
Isazofos, 5 kg a.i./ha	0.5 de	5,248 d	29 a	9* a
Isazofos, 10 kg a.i./ha	0.7 c	3,548 cd	28 a	11* a
Isazofos, 5 + 5 kg a.i./ha	1.1 ab	407 b	23 a	12* a
Nontreated	0.06 f	6,607 d	28 a	13* a

Means in columns followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.
Means significantly different from those observed before sowing when compared with the Student's *t*-test: *$P = 0.05$, **$P = 0.01$.

split application of novolatile nematicides was broadcast on 5 July 1984.

Four tomato plants were uprooted on 6 August 1984. The roots were washed free of soil, chopped finely, and thoroughly mixed. A 10-g sample was then processed by Coolen's method (2) to collect developmental stages of *M. javanica.* Root galling index on a 0–5 scale (3) was estimated for all plants at the end of the experiment and also for plants uprooted on 6 August. Tomato fruits were harvested and weighed on 6 and 24 September.

Effect of MIT on H. carotae and M. javanica: Methyl isothiocyanate is generally mixed at a rate of 20% with DD in commercial formulation. A fumigant of 40.4% MIT is now available. Its efficacy against *H. carotae* and *M. javanica* was tested in the following treatments: 1) 400 liters/ha MIT 40.4%, 2) 600 liters/ha MIT 40.4%, and 3) Di-Trapex (20% MIT + 80% DD) 300 liters/ha. Nontreated plots served as control.

Twenty-four plots, each 2 × 2 m, distributed in six randomized blocks, were prepared in a field infested with *H. carotae* (115 eggs/g soil) at Margherita di Savoia. The plots were tilled, fumigated with a hand injector on 26 June 1984, and irrigated. Soil sampling and extraction and incubation of cysts were as in the first experiment.

Similar plots at Torchiarolo infested with *M. javanica* at two juveniles/cm³ soil were established. The plots were fumigated on 10 July 1984 and irrigated lightly. Soil samples were collected before fumigation and again on 1 August, as described previously, and processed by Coolen's method (2).

No crops were planted in the plots of this experiment.

All data were subjected to ANOVA, and means were compared by Duncan's multiple-range test.

RESULTS

Control of H. carotae: Results of hatching studies indicated that only 1% of the eggs within *H. carotae* cysts survived in DD-treated plots. Plants grew poorly in many plots and were completely destroyed in most of the nontreated plots.

DD and isazofos (5 + 5 kg a.i./ha) applications resulted in the greatest carrot yields (Table 1). Except for the single preplant treatments of benfuracarb, all nematicide treatments resulted in significant increases in carrot yield.

Invasion of carrot roots by *H. carotae* was greatly limited by DD and isazofos (5 + 5 kg a.i./ha). Benfuracarb at 10 kg a.i./ha also limited invasion, but more than 2,000 adults and juveniles/5 g of roots were observed at harvest.

Unfortunately, the effects of the chemicals on the soil population density of *H. carotae* at harvest could not be determined. The nematode life cycle was not complete and no mature cysts were observed on carrot roots. Moreover, many eggs occurring within cysts before treating the soil may have been killed by nematicides or hatched by harvest. Therefore, even though at harvest less than half of the soil population density at sowing occurred in all treatments, the observed decline was independent of treatment (Table 1).

Control of D. dipsaci: All treatments ex-

TABLE 2. Effects of soil nematicide application on plant survival, onion yield, and soil population densities of *Ditylenchus dipsaci*.

Treatment	Plants surviving to harvest (%)	Marketable bulbs (kg/m²)	Nematodes/500 cm³ soil at harvest
Aldicarb, 10 kg a.i./ha	49.9 a	2.1 a	97 b
DD, 300 liters/ha	24.8 cd	1.4 ab	466 a
Benfuracarb, 5 kg a.i./ha	19.7 d	0.8 bc	159 b
Benfuracarb, 10 kg a.i./ha	28.5 cd	1.5 ab	221 ab
Benfuracarb, 5 + 5 kg a.i./ha	24.3 cd	1.1 ab	91 b
Isazofos, 5 kg a.i./ha	29.8 cd	1.6 ab	145 b
Isazofos, 10 kg a.i./ha	42.7 ab	2.0 a	97 b
Isazofos, 5 + 5 kg a.i./ha	36.7 bc	2.0 a	72 b
Nontreated	2.9 e	0.1 c	178 b

Means in columns followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

cept benfuracarb at 5 kg a.i./ha significantly enhanced onion growth (Table 2). Aldicarb and isazofos treatments at 10 kg a.i./ha resulted in greatest yield increases. Except for the increase observed in the DD-treated plots, soil population densities of *D. dipsaci* at harvest were not different in treated and nontreated plots.

Control of M. javanica: DD effectively controlled *M. javanica* with only 1% of the juveniles recovered from the treated, compared with nontreated, plots 3 weeks after fumigation. A marked increase in the soil population densities of *M. javanica* eggs and juveniles was observed 2 months after transplanting tomato, but none of the treatments was significantly different from the control (Table 3). Reproduction of *M. javanica* was suppressed except in plots treated with benfuracarb at 5 + 5 kg a.i./ha. DD, fenamiphos at 10 kg a.i./ha, and isazofos at 10 kg a.i./ha gave the best suppression of *M. javanica* in roots and the lowest galling indices of tomato roots.

Tomato yields in plots treated with DD were 2.6 times the yields from nontreated plots (Table 4). All treatments except benfuracarb at 5 + 5 kg a.i./ha increased tomato yields, but only DD and fenamiphos gave significant increases.

Effect of MIT and Di-Trapex on H. carotae and M. javanica: Hatching of *H. carotae* eggs was inhibited and the soil population densities of *M. javanica* eggs and juveniles suppressed by all treatments with MIT and Di-Trapex (Table 5).

DISCUSSION

Environmental conditions following sowing were very good for crop growth and nematode development in the first and third experiments. In the experiment on the control of *D. dipsaci*, soil conditions after fumigation with DD were favorable for

TABLE 3. Effects of soil nematicide application on the numbers of *Meloidogyne javanica* recovered from tomato roots and soil and root gall indices 2 months after transplanting.

Treatment	Eggs and juveniles/ 500 cm³ soil	Nematodes/10 g roots		Gall index
		Eggs	Juveniles and adults	
Fenamiphos, 10 kg a.i./ha	6,635 c	6,282 de	982 ab	1.8 ef
Fenamiphos, 5 + 5 kg a.i./ha	10,909 bc	9,464 cde	2,027 ab	2.2 de
DD, 300 liters/ha	2,630 c	1,654 e	431 a	1.2 f
Benfuracarb, 5 kg a.i./ha	10,730 abc	11,121 cde	4,538 abc	2.6 cd
Benfuracarb, 10 kg a.i./ha	19,540 ab	14,357 cd	4,948 bc	3.0 bcd
Benfuracarb, 5 + 5 kg a.i./ha	22,035 a	27,610 ab	9,324 d	3.5 ab
Isazofos, 5 kg a.i./ha	19,795 ab	19,982 bc	6,986 cd	3.2 abc
Isazofos, 10 kg a.i./ha	12,075 abc	9,191 cde	2,550 bc	2.7 cd
Isazofos, 5 + 5 kg a.i./ha	13,320 abc	16,391 cd	2,027 ab	3.0 bcd
Nontreated	11,660 abc	31,403 a	7,385 cd	3.8 a

Means in columns followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

TABLE 4. Effects of soil nematicide application on yield of tomato, root gall index, and soil population densities of *Meloidogyne javanica* at harvest.

Treatment	Yield (kg/9 m²)	Gall index	Eggs and juveniles/ 500 cm³ soil
Fenamiphos, 10 kg a.i./ha	11.2 bc	4.9 a	16,745 a
Fenamiphos, 5 + 5 kg a.i./ha	12.0 b	4.2 a	9,575 a
DD, 300 liters/ha	20.5 a	2.6 b	4,560 a
Benfuracarb, 5 kg a.i./ha	11.3 bc	4.4 a	13,380 a
Benfuracarb, 10 kg a.i./ha	11.7 bc	4.6 a	13,885 a
Benfuracarb, 5 + 5 kg a.i./ha	7.7 c	4.6 a	13,900 a
Isazofos, 5 kg a.i./ha	8.9 bc	4.8 a	11,925 a
Isazofos, 10 kg a.i./ha	9.5 bc	4.2 a	13,735 a
Isazofos, 5 + 5 kg a.i./ha	10.4 bc	4.2 a	12,050 a
Nontreated	7.8 c	4.9 a	12,560 a

Means in columns followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

maximum efficacy; however, heavy rains before nematode sampling 4 weeks later may have caused downward soil movement of *D. dipsaci.* More apparently dead nematodes were recovered from the top 30 cm of soil from DD-treated plots than from nontreated plots. The soil maintained good moisture content until the end of December 1983 but thereafter was wet through early March 1984.

Isazofos effectively controlled *Radopholus similis* (Cobb) Thorne on bananas (14) and *Helicotylenchus multicinctus* (Cobb) Thorne and *M. javanica* on plantain (1). More recently isazofos has shown good control of *Belonolaimus longicaudatus* Rau, *H. dihystera* Cobb, and *Paratrichodorus christiei* Allen on Ormond bermudagrass (15). Our trials have confirmed the nematicidal efficacy of isazofos reported in these studies. Against *H. carotae* and *D. dipsaci* it was as effective as DD or aldicarb.

Isazofos also suppressed invasion of tomato roots by *M. javanica* until 2 months after transplanting, but this did not result in increased yields. Environmental conditions during the tomato growing season were favorable for reproduction of *M. javanica,* resulting in more completed generations of the nematode than in normal years. Therefore, late invasion of tomato roots resulted in heavy root infestation even in most of the plots where root infestation was low through July.

Satisfactory control of root-knot nematodes on tomato and melon have been obtained by soil applications of benfuracarb (4). In our experiments this chemical gave good control of *D. dipsaci* but had little effect on *Heterodera carotae* or *M. javanica.*

MIT reduced *H. carotae* and *M. javanica* soil population densities and should be considered a good soil fumigant because of its efficacy against fungi, insects, and weed seeds as well as nematodes.

TABLE 5. Effect of methyl isothiocyanate soil application on the control of *Heterodera carotae* and *Meloidogyne javanica* in the field.

Treatments	*H. carotae* hatch (%)	Eggs and juveniles of *M. javanica*/ 500 cm³ soil
MIT, 400 liters/ha	2.04 b	180 b
MIT, 600 liters/ha	0.04 c	107 b
Di-Trapex, 300 liters/ha	0.11 c	60 b
Nontreated	100.00 a	724 a

Means in columns followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

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