MANAGEMENT OF THE ROOT-KNOT NEMATODE, *MELOIDOGYNE INCOGNITA*, ON ARTICHOKE (*CYNARA CARDUNCULUS*) WITH SOIL SOLARIZATION AND LOW DOSES OF NEMATICIDES

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Summary. The effect of a seven week soil solarization period, alone or in combination with low doses of 1,3-D (50 l/ha), dazomet (125 kg/ha) or methyl bromide (200 kg/ha), on the yield of artichoke (*Cynara cardunculus*) and weed growth was compared for two consecutive seasons with the effect of standard rates of 1,3-D (150 l/ha), dazomet (500 kg/ha) and methyl bromide (600 kg/ha) in a field infested with the root-knot nematode *Meloidogyne incognita* host race 1. All treatments effectively controlled the nematode. The nematode soil population densities were reduced by 92 to 100% and by 81 to 99% in the first and second crops, respectively, resulting in low root gall indices and significant increase in marketable yield of artichoke. Complete control of weeds was observed only in the plots treated with solarization or methyl bromide.

Globe artichoke (*Cynara cardunculus* L.) is a perennial plant whose immature flower heads (capitula) are used as food. Locally, it is an important crop in many parts of the world, being cultivated on nearly 121,500 ha which gives an annual production of about 1,177,000 t (FAO, 2004). Italy ranks first for growing area (50,000 ha) and production (389,000 t/year), 33% of world production. Apulia, Sardinia and Sicily are the most important Italian regions in which the crop is cultivated (Bianco, 2000).

Several soil-borne pathogens are known to cause severe damage to artichoke. *Meloidogyne incognita* (Kofoid *et* White) Chitw., *M. javanica* (Treub) Chitw., *M. arenaria* (Neal) Chitw. and *M. hapla* Chitw. are the most important species of root-knot nematodes globally. Among them, *M. incognita* appears to be the most damaging to artichoke (Di Vito and Botta, 1976). The tolerance threshold of artichoke to this nematode is 1.1 eggs and second stage juveniles/cm^3 soil at transplanting and yield losses of 40 and 80% can be expected in fields infested with 8 and 32 eggs and second stage juveniles of the nematode/cm^3 soil, respectively (Di Vito and Zaccheo, 1991). The control of these nematodes is necessary to maintain crop yield and quality at economic levels. Soil solarization has shown promise in the control of soil borne pathogens (Katan and De Vay, 1991), including nematodes (Greco *et al.*, 1985; Gaur and Perry, 1991; Lamberti and Greco, 1991; Cartia *et al.*, 1998), but it is effective only in the top parts of the soil profile. This may not be sufficient when cultivating long cycle and deep rooted crop plants, such as artichoke. To improve nematode control in deeper soil profile, the combination of soil solarization with reduced rates of nematicides can be useful. Therefore, a trial was undertaken to evaluate the effect of soil solarization, alone or in combination with low rates of some fumigant nematicides, on *M. incognita* host race 1, weeds and yield of artichoke. The work was done to find an alternative to the use of methyl bromide and thereby reduce the amount of nematicides used on the crop.

MATERIALS AND METHODS

The experiment was established in a field of sandy soil that was evenly infested with about 1.6 eggs and second stage juveniles/cm^3 soil of the root-knot nematode *M. incognita* host race 1 (Taylor and Sasser, 1978; Di Vito and Cianciotta, 1991) at Cerveteri (Province of Rome) in 1998. The field was irrigated to disrupt dormancy of nematode and weed seeds, and three days later, was rotavated and divided into 32 plots each of 31.2 m^2 (6 x 5.2 m). The plots were spaced 30 cm apart and arranged in a randomized block design with four replications. Treatments (Tables I-III) were soil solarization for seven weeks alone or combined with 50 l of 1,3-D/ha, 125 kg of dazomet/ha and 200 kg of methyl bromide/ha. These treatments were compared with the standard rates of 150 l of 1,3-D/ha, 500 kg of dazomet/ha and 600 kg of methyl bromide/ha. Non-treated plots served as controls. 1,3-D was applied with a hand injector at 20 cm depth while dazomet was broadcast on the plots and then incorporated into the top 20 cm of soil by rotavation on 6 July 1998. All plots were then rolled, lightly irrigated by sprinkler, and those to be solarized were covered with 50 µm thick transparent polyethylene film one day later. The methyl bromide was applied after the start of the solarization period.

Soil temperature was recorded continuously at 15 and 30 cm depth in a solarized and in a non-solarized plot during the solarization period. Seven weeks later, on 25 August, solarized plots were uncovered and

weeds were harvested from the centre of each plot and weighed. Plots were then rotavated to disperse any residues of soil fumigants and to incorporate 200 kg/ha of NPK fertilizer (10% N, 20% P_2O_5 and 20% K_2O).

Twenty-five seedlings of artichoke cv. Romanesco, a very common cultivar used in the area and obtained from *in vitro* culture, were transplanted one week later in each plot. There were five rows of artichoke per plot spaced 1.2 m apart and each having five plants spaced 1 m from each other.

The growth period of the artichoke was from August to the following May. Appropriate procedures were followed for irrigation, fertilizers and disease, pest and weed control.

Heads of artichoke from 12 plants in the centre of each plot were harvested and measured as they reached commercial size, during the first and second year of cultivation. Soil samples of 1.5 kg, each a composite of 40 cores, were collected with an auger of 1.5 cm diameter and 30 cm long, in the centre of each plot before transplanting and along the plant rows. Samples were taken before application of treatments, before transplanting and after the last harvest of the first and second years. The eggs and second stage juveniles of the nematode were extracted from 500-cm^3 sub-samples using the Coolen's modified method (Coolen, 1979; Di Vito *et al.*, 1985). Root samples, each consisting of 25 g of rootlets, were collected from the centre of each plot, only at the end of the second year, and nematodes were extracted by Coolen's method (Coolen, 1979). In addition, at the end of the second year, artichokes from the central areas were uprooted and the degree of galling of the roots was rated according to a 0-5 scale (Di Vito *et al.*, 1979).

Data were analysed by ANOVA and the means compared with LSD.

RESULTS AND DISCUSSION

Weather conditions during the first seven weeks were favourable for soil solarization. Daily mean maximum temperature at 15 and 30 cm depth of the solarized plots were in the range 41-44 °C and 34-39 °C, respectively, much higher than in non-solarized plots (Fig. 1).

After treating, the nematode population densities declined significantly in all treated plots and especially in the plots treated with methyl bromide and those in which soil solarization had been combined with the fumigants (Table I). At the first harvest (1999), the nematode population had increased slightly in the treated plots but was still significantly less than in the control plots, which showed a 20-fold increase. At the end of the experiment (in 2000), the nematode population densities in the treated plots, although slightly greater than 1999, remained at levels significantly less than in the control plots, with methyl bromide alone or combined with solarization showing the best control (Table I). In the control plots the nematode population increased by nearly 100-fold over that before transplanting and 5-fold over that at the first harvest, respectively.

At the end of the experiment, the root gall index was as low as 1 in the plots treated with methyl bromide alone or in combination with solarization (Table II), in the range 2.5-3.5 in plots treated with 1,3-D or dazomet

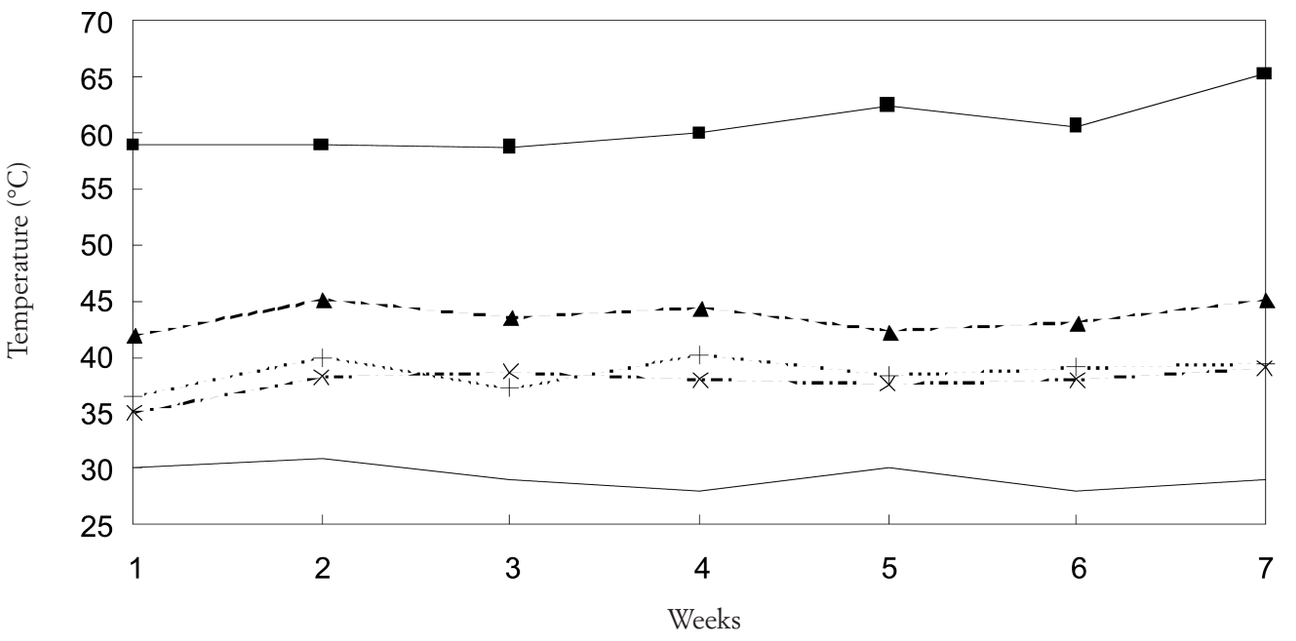

Fig. 1. Temperature registered during the solarization period: soil surface (–■–); air (···+···); 15 cm deep solarized (– –▲– –); 30 cm deep solarized (– · –×– · –); and 15 cm deep non-solarized (—).

Table I. Effect of treatments on soil population densities of *Meloidogyne incognita* during the two artichoke growing seasons.

Treatment	Eggs and second stage juveniles/cm^3 soil			
	Before treatment	Before transplanting	At harvest	
			First year (1999)	Second year (2000)
Dazomet 500 kg/ha	1.8	0.4	1.7	15.4
Dazomet 125 kg/ha + soil solarization	1.5	0.1	0.7	10
1,3-D 150 l/ha	1.3	0.6	1.3	12
1,3-D 50 l/ha + soil solarization	1.2	0.1	0.1	7
Methyl bromide 600 kg/ha	2.1	0	0	1.6
Methyl bromide 200 kg/ha + solarization	2.0	0	0	1.5
Solarization	1.5	0.5	0.9	19.2
Control (non-treated)	1.2	1.1	21.6	102.1
LSD: P=0.01	1.89 NS	0.39	4.68	20.76
P=0.05	1.40 NS	0.29	3.45	15.31

Table II. Effect of nematicidal treatments on gall index and number of specimens of *Meloidogyne incognita* in the roots of artichoke at the end of the experiment.

Treatment	Gall index (0 - 5)	Nematodes in the roots (specimens/g)
Dazomet 500 kg/ha	3.5	31.2
Dazomet 125 kg/ha + solarization	2.5	52.2
1,3-D 150 l/ha	3.2	66.2
1,3-D 50 l/ha + solarization	2.7	45.7
Methyl bromide 600 kg/ha	1.2	14.0
Methyl bromide 200 kg/ha + solarization	1.0	8.5
Soil solarization	3.5	60.5
Control (non-treated)	4.7	191.2
LSD: P=0.01	0.98	55.89
P=0.05	0.72	41.24

alone or combined with soil solarization and significantly larger (4.7) in the non-treated plots. The effectiveness of the treatments was confirmed by the numbers of nematodes in the roots, which were very low in the plots treated with methyl bromide alone or in combination with solarization and significantly less than in the control (Table II).

Good weed control was obtained in the plots treated with a combination of soil solarization and fumigants, and in those treated with solarization, methyl bromide and dazomet alone. The plots fumigated with 1,3-D alone and the non-treated plots were heavily covered by weeds (Table III).

The control of the nematodes resulted also in significant increases in numbers of artichoke heads, head size and yield at both harvests. Increase in numbers of heads over that in the non-treated plots was, however, greater in the plots treated with methyl bromide (146 and 171%, in the first and second growing season, respectively) than in all other treatments (average of 129 and 138%). The average yield in plots fumigated with methyl bromide was 3.5-3.6-fold that in the control plots, and in the other treatment plots was 1.7-1.8-fold that in the control plots, in the two growing seasons. The size of heads was also very much improved; the average head weight was 308-317 g in the control plots, 672-802 g in the plots fumigated with methyl bromide and 387-471 g in all other treated plots.

Our results indicate that seven week soil solarization period is effective in controlling weeds and root-knot nematodes. The nematode control improved further when soil solarization was combined with low rates of the three soil fumigants and was similar to that of standard rate (600 kg/ha) of methyl bromide. However, the

Table III. Effect of nematicidal treatments on biomass of fresh weeds, number of heads, head weight and total yield of artichoke, in a field infested with *M. incognita*.

Treatment	Biomass of fresh weeds (g/m^2)	First year (1999)			Second Year (2000)		
		Heads/12 plants (N°)	Average weight/head (g)	Yield/12 plants (kg)	Heads/12 plants (N°)	Average weight/head (g)	Yield/12 plants (kg)
Dazomet 500 kg/ha	75	60.2	423.2	25.5	55.2	385.2	21.2
Dazomet 125 kg/ha + solarization	0	59.7	410.2	24.5	57.2	373.0	21.2
1,3-D 150 l/ha	9,650	53.2	428.7	22.7	47	458.0	21.5
1,3-D 50 l/ha + solarization	0	62.5	387.5	24.2	49.2	474.2	23.2
Methyl bromide 600 kg/ha	0	64.2	801.2	51.5	63.5	698.5	44.2
Methyl bromide 200 kg/ha + solarization	0	68.7	692.0	47.5	64.0	671.5	43.0
Soil solarization	0	57.7	437.2	25.2	57.7	414.7	23.7
Control (non-treated)	7,450	45.5	308.5	14	38.5	318.7	12.2
LSD: P=0.01	2285.4	5.54	81.24	4.31	7.34	105.49	5.06
P=0.05	1686.4	4.09	59.95	3.18	5.41	77.84	3.73

largest increase in yield, and number and size of artichoke heads occurred in the plots treated with methyl bromide, probably because this fumigant, alone or combined, with soil solarization was more effective against other soil pathogens or penetrated more deeply into the soil profile than we sampled. The results also indicate that soil solarization, alone or combined with low rates of fumigants is nearly as effective as the standard rate (600 kg/ha) of methyl bromide. Thus, it will be possible to reduce the use of methyl bromide in developing countries, where this fumigant will be available until 2014, by combining soil solarization with reduced application rates of it.

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