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CONTROL OF THE POTATO CYST NEMATODE, *GLOBODERA ROSTOCHIENSIS*, WITH SOIL SOLARIZATION AND NEMATICIDES

by
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Summary. A trial was undertaken in Italy in 1997/98 to assess the effectiveness of different soil treatments for the control of the potato cyst nematode, *Globodera rostochiensis*, on potato. Soil solarization periods were four, six and eight weeks. The fumigant nematicides were applied seven months before planting at the rate of 150 l/ha 1,3-D and 500 kg/ha dazomet. The non-fumigant nematicides were applied at the rate of 10 kg/ha aldicarb and fenamiphos and 12 kg/ha ethoprophos, as a single application before planting or split between planting and one month after potato germination. Maximum soil temperature 43-44 °C in solarized soil occurred at 10 cm depth. Nematode egg survival was 6.8-17, 27.8 and 6.1% in plots treated with soil solarization, dazomet and 1,3-D, respectively. These treatments and the non-volatile nematicides aldicarb, fenamiphos and ethoprophos significantly suppressed nematode reproduction with a split application of aldicarb giving the least (0.82) reproduction rate. All treatments greatly reduced the numbers of nematodes in potato roots. Marketable potato tuber yield increased significantly in all plots (20-43.4%) except in those treated with split applications of fenamiphos and ethoprophos.

Production of early potatoes is of considerable economic importance in southern Italy. Crops are usually planted from November to late winter and harvested from early to late spring, when winter stored potatoes have been consumed. Therefore, early potatoes are commonly sold on the Italian market as well as in European countries, when the price is generally higher than in later periods. Potato cyst nematodes, *Globodera rostochiensis* and *G. pallida*, are severe crop constraints in the major potato growing area of south Italy. Crop rotations can satisfactorily control these nematodes, but in southern Italy farmers often grow potatoes on the same land every year or every other year thus increasing nematode severity. However, other control measures are available, among them soil solarization which has proved effective against several nematode species including the cyst forming ones (Greco *et al.*, 1985; 1992; Cartia *et al.*, 1989; 1997; Greco and Brandonisio, 1990; Di Vito *et al.*, 1991; Gaur and Perry, 1991; Lamberti and Greco, 1991). Nevertheless, the effectiveness of soil solarization for the control of *G. rostochiensis* on potato has received little attention despite the world wide importance of the crop and of the nematode (LaMondia and Brodie, 1984, LaMondia *et al.*, 1986; Gaur and Perry, 1991). Therefore, a trial was undertaken in 1997/1998 to assess the efficacy of different soil solarization periods, for the control of *G. rostochiensis*, in comparison with that of chemical nematicides which are available for use on potato in Italy.

Materials and methods

A field on which potato had been severely damaged by *Globodera rostochiensis* Woll. in spring 1997 was selected for the trial. Treatments (Tabs. I-II) were soil solarization for four, six and eight weeks, the fumigant nematicides 1.3-D 150 l/ha and dazomet 500 kg/ha and the non-fumigant nematicides aldicard and fenamiphos at 10 kg a.i./ha and ethoprophos at 12 kg a.i./ha.

In early July 1997 the field was rotary cultivated, divided in 60 plots of 21 m^2 (m 3.5 x m 6) which were separated 70 cm apart and distributed according to a randomised block design. The field was then irrigated to wet the top 40-50 cm soil. On 17 July, fifteen plots selected for solarization were covered with transparent polyethylene sheets 50 µm thick with the edge buried all in the soil. The plastic film was removed from five plots each time, after four, six and eight weeks. During the solarization period soil temperatures were recorded at 10, 20 and 30 cm deep in a solarized plot. The nematicide 1,3-D was also applied on 17 July 1997, at a depth of 20 cm, by a hand injector. The same day dazomet was broadcast on the plot surface and quickly incorporated in the top 20 cm soil by a rotavator. At this time the soil temperature at 20 cm deep was 25-26 °C. All fumigated plots were lightly surface irrigated to reduce the escape of the nematicidal gases. The field was rotary cultivated on 12 September and planted to chicory which was harvested in January, 1998. Then the soil was again rotary cultivated and the previous plots re-identified. The non-fumigant nematicides were broadcast on the soil surface on 12 February, 1998 and immediately incorporated into the top 10-15 cm soil. Potato, *Solanum tuberosum* L. ssp. *tuberosum*, cv. Spunta was planted the same day. There were five rows of potato per plot and 24 seed tubers per row spaced at 25 cm. Emergence of potatoes was almost complete by mid March. On 14 April the second portion of the split application of the non-fumigant nematicides was broadcast on the soil surface prior to cultivation (hilling) to concentrate the nematicide granules along the plant rows.

To obtain information on nematode population dynamics, soil samples were collected from each plot on 11 February 1998, before treating with non-fumigant nematicides, and on 17 July 1998 after harvest of potatoes. Each sample was a composite of 60 cores collected with a soil sampler 30 cm long and 1.5 cm diameter. To assess the effect of the treatments on nematode infestation of the plants, four potato roots were collected from the middle row of each plot on 22 May 1998. The soil from around the rhizosphere of these roots was also collected.

All plots were periodically irrigated with an overhead sprinkler and normal maintenance was given throughout the potato growing period.

Potatoes were harvested from the second and fourth rows of each plot on 15 July and marketable tubers weighed. Because nematode population densities generally are not very uniform among plots, for a better understanding of the effect of the treatments on potato yield, per cent yield increases were determined by comparing the actual yield per plot with that expected in the same but non-treated plot. These expected yields per plot were estimated considering: 1) the percentage of viable eggs in control plots (22.6% as estimated from the hatching test described below); 2) the expected yield in control plots in the absence of the nematode (495.4 q/ha); 3) a tolerance limit of potato to *G. rostochiensis* of 1.9 eggs/g soil and a minimum relative yield of 0.1 (Greco *et al.*, 1982) and 4) the tables of nemato-pathogenicity (Sasanelli, 1994).

Nematode cysts from soil samples collected before planting and after harvest were extracted combining the Fenwick can with the Seinhorst ethanol method (Seinhorst, 1974). Cyst were then counted, crushed according to the Bijloo's modified method (Seinhorst and Ouden, 1966) and their egg content determined.

Males and second stage juveniles were extracted with the Coolen (1979) method from the soil samples collected on 22 May and counted. Potato roots were gently washed in water, excess water eliminated, weighed, cut in 0.5 cm long pieces and all nematodes extracted by the Coolen (1979) method, counted and classified according to developmental stages.

To assess the effect of the treatments on egg survival, cysts from soil samples collected before planting in plots that were solarized, treated with 1,3-D or dazomet and those left as untreated controls were extracted from 200 cm^3 wet soil with the Fenwick can, separated from soil debris and incubated at 21 °C, for five weeks in a 0.6 mM sodium metavanadate solution and for a further two week period in a 0.3 mM picrolonic acid solution. Hatched juveniles were counted weekly and the hatching solution renewed at the same time. At the end of the test, the cysts were crushed by the Bijloo's modified method (Seinhorst and Ouden, 1966), unhatched eggs were counted and the sums of these and of juveniles emerged per samples were considered as total numbers of eggs per samples at the beginning of the test. Second stage juveniles emerged from cysts of the treated plots were expressed as per cent of those emerged from untreated plots and these considered as per cent of survived eggs. Because the non fumigant nematicides are known to not kill eggs inside cysts, no hatching test was conducted with cysts from plots treated with these nematicides.

All data were statistically analysed and averages compared with the Student's *t* test or Duncan's Multiple Range test.

Results

During the solarization period the daily maximum soil temperature at 10 cm deep was 41-44 °C for five weeks, 37-40 °C during one week and 40-42 °C during the last two weeks. The same temperatures at 20 and 30 cm deep were 5-6 °C and 8-11 °C less, respectively (Fig. 1). Thereafter

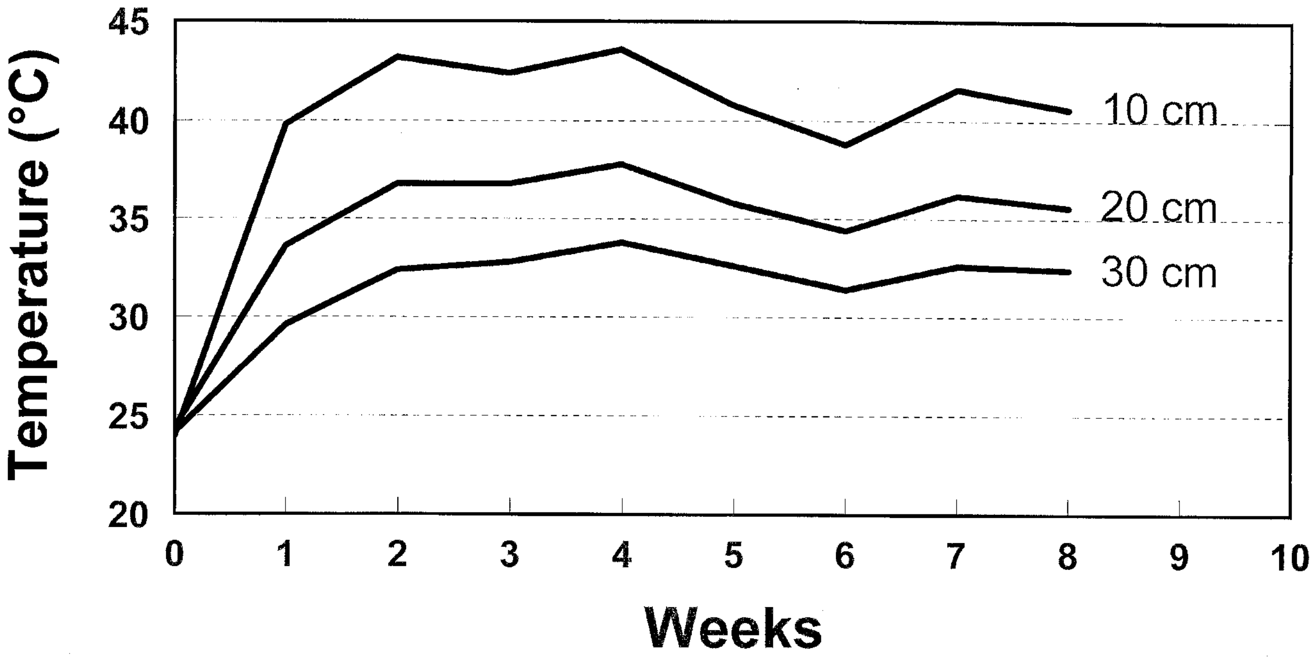

Fig. 1 - Weekly maximum soil temperatures recorded at three depths in the solarized plots.

environmental conditions, except for a drop of temperature in early March which did not damage potato plants, were favourable for potato growth and nematode development. Nearly all potatoes had germinated by mid March.

The hatching test demonstrated that the three soil solarization periods, 1.3-D and dazomet all greatly reduced egg survival. However, dazomet was significantly less efficient than the other treatments since 27.8% of the eggs had survived, while soil solarization was as effective as fumigation with 150 l/ha of 1.3-D (Table I).

Examination of soil samples collected on 22 May (Table II) revealed that in the plots with both single or split application of aldicarb, numbers of second stage juveniles were significantly larger than in plots of all other treatments. Also, in the plots treated with ethoprophos at planting second stage juveniles were significantly greater than in plots that were solarized, fumigated with 1.3-D or dazomet or left untreated. Numbers of males were suppressed by all treatments except ethoprophos in which plots had more males than the control ones (Table II). At the same date all treatments, except ethoprophos, significantly suppressed root invasion by second stage juveniles and development of third stage juveniles of the nematode (Table II), with soil solarization for eight weeks, fenamiphos, aldicarb, dazomet and 1,3-D giving better root protection than the remaining treatments. All treatments significantly suppressed the numbers of fourth stage juveniles, females and cysts of the nematode in the roots (Table II). Again, the fewest nematodes were observed in the roots from plots treated with aldicarb and fenamiphos.

TABLE I - *Per cent eggs of* Globodera rostochiensis *surviving in the soil treated with different solarization periods or fumigant nematicides, in comparison with non treated control.*

Treatment	% Eggs surviving	
Soil solarization 4 wk	8.0 cd	C
Soil solarization 6 wk	17.0 c	BC
Soil solarization 8 wk	6.8 cd	C
Dazomet 500 kg/ha	27.8 b	B
1,3-D 150 l/ha	6.0 d	C
Control	100.0 a	A

Figures in each column followed by the same letter are not significantly different according to Duncan's multiple range test. Small letters for $P = 0.05$ and capital letters for $P = 0.01$.

The nematode soil population density before planting (Table III) showed a certain degree of variability. However, only the plots treated with a single application of fenamiphos had more eggs than the control plots. After potato harvest, the nematode soil population density, with the exception of that in plots treated with dazomet, was significantly smaller than in the control. Moreover, comparing the nematode soil population after harvest with that before planting shows a significant increase in the untreated plots and in those treated with soil solarization, ethoprophos, split applications of fenamiphos or of the two fumigant nematicides. No significant population increase was observed in plots treated with aldicarb or single application of fenamiphos. Split application of aldicarb was the only treatment that reduced, but no significantly, the nematode population after harvest. The reproduction rate of the nematode was significantly ($P = 0.01$) suppressed by all of the treatments. However, the greatest suppression was observed in plots treated with aldicarb, both as a single or split application, or single application of fenamiphos. In the plots treated with split application of aldicarb a decline of the nematode population to 0.82 of that before planting was observed at harvest of potato.

All treatments, except fenamiphos and a split application of ethoprophos, significantly increased the yield of marketable potato tubers, with 1,3-D giving the largest yield (Table III). Yield increases, over the expected yield in the absence of treatments, ranged from 16.5% in plot with split application of ethoprophos to

TABLE II - *Effect of soil solarization and nematicides on* G. rostochiensis *in the soil and in potato roots.*

Treatment	In 50 cm³ soil		In 15 g roots			
	J2	Males	J2+J3	J4	Females+ cysts	Totals
Soil solarization 4 wk	3 d C	10 c D	623 bc ABCD	596 de CDE	152 bc BCDE	1371 cd CD
Soil solarization 6 wk	2 d C	7 c D	425 bcd BCDE	383 de DE	59 cd CDE	867 de DE
Soil solarization 8 wk	2 d C	4 c D	274 de DE	356 de DE	50 cd DE	680 de DE
Fenamiphos 10 kg/ha	58 bc BC	2 c D	136 de E	202 e DE	18 d E	356 e DE
Aldicarb 10 kg/ha	177 a A	20 c CD	357 cde BCDE	340 de DE	47 cd DE	745 de DE
Ethoprophos 12 kg/ha	68 b B	89 a A	733 ab ABC	1201 bc BC	202 b BC	2137 bc BC
Fenamiphos 5+5 kg/ha	51 bc BC	6 c D	84 e E	102 e E	34 d E	220 e E
Aldicarb 5+5 kg/ha	150 a A	11 c D	83 e E	88 e E	9 d E	180 e E
Ethoprophos 8+4 kg/ha	58 bc BC	84 a AB	735 ab AB	1619 b B	214 b B	2569 b B
Dazomet 500 kg/ha	20 cd BC	17 c CD	318 cde CDE	863 cd CD	194 b BCD	1376 cd CD
1,3-D 150 l/ha	2 d C	12 c D	145 de E	369 de DE	82 cd BCDE	595 de DE
Control	22 cd BC	50 b BC	920 a A	2768 a A	645 a A	4334 a A

Figures in each column followed by the same letter are not significantly different according to Duncan's multiple range test. Small letters for P = 0.05 and capital letters for P = 0.01.
J3, J3, J4 = second, third and fourth stage juveniles, respectively.

TABLE III - *Effect of soil solarization and nematicides on the dynamics of* G. rostochiensis *and the yield of potato tubers in field plots.*

Treatment	Nematode eggs/200 g soil		Nematode reproduction rate (Pf/Pi)	Marketable tubers (kg/8.4 m²)	% Yield increase
	Before planting (Pi)	After harvest (Pf)			
Soil solarization 4 wk	7068 bc B	24297** d DEF	3.50 bc CD	46.3 abc ABC	32.3 bc A
Soil solarization 6 wk	7724 bc AB	22563** de DEF	3.15 bcd BCD	44.6 abcd	29.7 bc A
Soil solarization 8 wk	6096 c B	28543** cd CDE	4.83 b B	46.8 abc ABC	28.8 bc A
Fenamiphos 10 kg/ha	12743 a A	19856 de EFG	1.53 cde CD	42.3 bcde ABCD	38.0 bc A
Aldicarb 10 kg/ha	8900 abc AB	10020 ef FG	1.26 de D	47.4 ab AB	42.0 c A
Ethoprophos 12 kg/ha	9603 abc AB	40237** b ABC	4.31 b BC	43.7 abcd ABCD	24.0 bc A
Fenamiphos 5+5 kg/ha	8213 bc AB	27240** cd CDE	3.53 bc BCD	40.8 cde BCD	20.0 abc A
Aldicarb 5+5 kg/ha	9370 abc AB	5930 f G	0.82 e D	46.9 ab AB	43.4 c A
Ethoprophos 8+4 kg/ha	9037 abc AB	37610** bc BCD	4.56 b B	39.1 de CD	16.5 ab A
Dazomet 500 kg/ha	10274 ab AB	46107** ab AB	4.57 b B	44.8 abcd ABC	37.5 bc A
1,3-D 150 l/ha	7666 bc AB	25570** d CDEF	3.40 bcd BCD	48.4 a A	38.1 bc A
Control	6757 bc B	54887** a A	8.83 a A	36.1 e D	0.0 a A

Figures in each column followed by the same letter are not significantly different according to Duncan's multiple range test. Small letters for P = 0.05 and capital letters for P = 0.01. Comparison between Pi and Pf made according to Student t test. ** Significantly different at P = 0.01.

43.4% in those with split applications of aldicarb. Only in plots that received split applications of fenamiphos or ethoprophos was there no significant yield increase. The largest yield increases were in plots treated with both single and split applications of aldicarb.

Discussion

All treatments increased potato tuber yield and suppressed potato root invasion by *G. rostochiensis*. By harvest of the potato crop, there was a general increase of the nematode soil population density except in plots that had been treated with split application of aldicarb. In general the three soil solarization periods tested were satisfactory. They reduced nematode egg survival of the same magnitude of that of 1,3-D, which is considered one of the most effective nematicide available, suppressed invasion of potato roots by the nematode, reduced its reproduction rate and increased yield of potato tubers. In the plots treated with dazomet although suppression of egg survival was not as great as that of soil solarization and 1,3-D, yield nevertheless increased and nematode suppression were not significantly different from these treatments. Although damage caused by other potato parasites was not obvious, it must be considered that most of the treatments may have had an effect on other soil borne pathogens. Therefore, the reported yield increases must be considered as the result of all effects of the treatments.

The presence of large numbers of the second stage juveniles of the nematode in the soil of the plots treated with the non-fumigant nematicides is an indirect confirmation that these chemicals have little effect on egg survival. The few nematodes within the potato roots indicates, instead, that these nematicides do affect root invasion by second stage juveniles. The lack of significant difference in potato tuber yield between the plots that received a single application of fenamiphos and those of the untreated control, rather than to lack of efficacy of the chemical, should be attributed to the larger nematode ppulation density in the plots treated with this nematicide. In the same plots yield increases, determined as explained, were instead highly significant. However, fenamiphos was more effective as single rather than as split application, while aldicarb was equally effective with both applications, with split applications giving a little better root protection and less nematode reproduction. It is noteworthy that only in plots treated with a split application of aldicarb the soil population density of the nematode after harvest of potato was less than that before planting. This would mean that the soil water concentration of aldicarb required to suppress root invasion by *G. rostochiensis* is less, or that soil degradation of fenamiphos was faster than that of aldicarb.

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Literature cited

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

CARTIA G., GRECO N. and DI PRIMO P., 1997. Soil solarization for the control of *Fusarium oxysporum* f. sp. *radicis lycopersici* and *Meloidogyne incognita* on tomato grown in plastichouse. *Tecnica Agricola, 46* (3): 13-18.

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

DI VITO M., GRECO N. and SAXENA M. C., 1991. Effectiveness of soil solarization for control of *Heterodera ciceri* and *Pratylenchus thornei* on chickpea in Syria. *Nematol. medit., 19*: 109-111.

GAUR H. S. and PERRY R. N., 1991. The use of soil solarization for control of plant parasitic nematodes. *Nematological Abstracts, 60* (4): 153-167.

GRECO N. and BRANDONISIO A., 1990. Effect of soil solarization and SIP 5561 on *Heterodera carotae* and *Ditylenchus dipsaci* and on yield of carrot and onion. *Nematol. medit., 18*: 189-193.

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., Stea V. and Brandonisio A., 1992. The synergism of soil solarization with fumigant nematicides and straw for the control of *Heterodera carotae* and *Ditylenchus dipsaci*. *Nematol. medit.*, *20*: 25-32.

Greco N., Di Vito M., Brandonisio A., Giordano I. and De Marinis G., 1982. The effect of *Globodera pallida* and *G. rostochiensis* on potato yield. *Nematologica*, *28*: 379-386.

Lamberti F. and Greco N., 1991. Effectiveness of soil solarization for control of plant parasitic nematodes, pp. 167-172. In: *Soil Solarization* (J.E. DeVay, J.J. Stapleton and C.L. Elmore eds.). FAO Plant Production and Protection Paper 190. FAO, Rome, Italy.

LaMondia J. A. and Brodie B. B., 1984. Control of *Globodera rostochiensis* by solar heat. *Plant Disease*, *68*: 474-476.

LaMondia J. A., Brodie B. B. and Brucato M. L., 1986. Management of *Globodera rostochiensis* as influenced by nematode population densities and soil type. *J. Nematol.*, *18*: 74-78.

Sasanelli N., 1994. Tables of nematode-pathogenicity. *Nematol. medit.*, *22*: 153-157.

Seinhorst J. W., 1974. Separation of *Heterodera cysts* from 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.

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