certain areas of the C. elegans surface, that most sections viewed by TEM were from unlabelled areas. The hemocyanin labelling technique coupled with SEM has a marked advantage over TEM when it is desirable to localize receptor sites on the surfaces of small metazoa, since the bound hemocyanin molecules can easily be detected by a rapid scan of the whole organism.

LITERATURE CITED

Population Dynamics of Meloidogyne incognita on Corn Grown in Soil Infested with Arthrobotrys conoides

A. S. Al-Hazmi, D. P. Schmitt, and J. N. Sasser

Abstract: Microplot and greenhouse experiments were conducted to evaluate the effects of soil incorporation of the nematophagous fungus Arthrobotrys conoides and green alfalfa mulch on the population dynamics of Meloidogyne incognita on corn. Reproduction of M. incognita and the incidence of root galling were reduced by the addition of A. conoides and/or green alfalfa in all tests. Numbers of juveniles were reduced by as much as 84%, and eggs were fewest in early to mid-season soil samples from microplots. Yields increased in treatments with A. conoides and/or green alfalfa in greenhouse tests and in the microplot tests in 1979. No interaction was found between the fungus and green alfalfa in the reduction of the nematode population. Key words: biological control, population dynamics, ecology, green alfalfa, root-knot nematode, soil amendment, nematophagous fungus, nematode trapping fungus, organic mulch.


The role of nematophagous fungi as biological deterrents toward plant-parasitic nematodes is not clear (6,17). For instance, Meloidogyne population reductions in soil amended with pineapple shoots were attributed to the stimulation of nematophagous fungi (9,11). Of five such fungi tested, only Dactylella ellipsoidora Grove protected potted pineapple plants from root-knot nematode injury (10). Heterodera spp. were controlled in greenhouse tests but not in the field (7). Damage from M. incognita (Kofoid & White) Chitwood in other tests were not suppressed by the addition of several nematophagous fungi (16,17).

The introduction of organic amendments to soil has also been correlated with reduced population densities of Meloidogyne species (5,8,9,11,12,13,14,15,19,21,22,24,25,26). This reduction may be due to increased organic compounds or activity of other micro-organisms. For example, amendment of soil with margosa oil cake increased the concentration of phenolic substances (24) and fatty acids (25). More suppression of root-knot disease on tomato was obtained with 10 tons of oil cake per acre than with 5 tons and when the amendment was added 8 months before assaying than for shorter times (12,15).

The objective of this study was to determine the effect of Arthrobotrys conoides
Drechsl. alone and in soil amended with green alfalfa on *M. incognita* population dynamics on corn. These organisms were selected because both are common in North Carolina.

**MATERIALS AND METHODS**

**Inoculum:** *Meloidogyne incognita* was cultured on tomato (*Lycopersicon esculentum* Mill. 'Rutgers') in the greenhouse. A North Carolina isolate of *A. conoides* was cultured on cornmeal agar and allowed to grow for 3–5 days at 24°C, then transferred into a modified vermiculite medium (18). For the modified medium, a 600-cm³ nutrient suspension consisting of 35 g Czapek dox broth and 20 g cornmeal per liter of distilled water was mixed into 1500-cm³ grade 2 vermiculite. The mixture was autoclaved for 50 min at 121°C, cooled for 48 h, then autoclaved again for 50 min. When the medium had cooled, several 8-mm-d disks from the cornmeal agar culture were introduced. After 5-wk growth the contents of each container were wrapped in two layers of cheesecloth, soaked with tap water for approximately 10 sec, and squeezed by hand to remove excess water and nutrient solution. This inoculum then was spread thinly on a paper-covered bench and air dried until it was friable. The dried inoculum was placed in polyethylene bags and agitated to obtain a uniform mixture.

**Microplot experiments:** Microplots (78 cm d) (2) were established in a Norfolk loamy sand soil at the Central Crops Research Station near Clayton, North Carolina. All plots were fumigated with methyl bromide at the rate of 100 g/m² and aerated for 2 wk.

A factorial experiment with eight treatments was used in 1979. The treatments were *A. conoides*, green alfalfa, and *M. incognita*, alone and all possible combinations, and an untreated control. Green alfalfa (900 g/plot = 5,572 kg/ha) was chopped and then incorporated 15 cm deep into designated plots. Thirty days later the appropriate plots were infested with *M. incognita* (500 cm³ of sand containing ca. 150,000 eggs and juveniles in chopped tomato roots) and *A. conoides* (500 cm³ infested vermiculite medium). Plots were limed and fertilized according to soil test recommendations. Several corn seeds (*Zea mays* L., 'Pioneer 3368A') were planted in the plots, then thinned to three plants/plot 8 days later. A randomized complete block design with seven replicates per treatment was used.

A 5 × 3 factorial experiment with 15 treatments, five inoculum densities of *M. incognita*, and three of *A. conoides* was used in 1980. Either 0, 500 cm³, or 2,000 cm³ of *A. conoides*-infested vermiculite were introduced into each plot. Ten days later, 0, 7,100, 71,000, 355,000, or 710,000 *M. incognita* juveniles and eggs were added to the appropriate plots. The plots were hand weeded and sprayed with carbaryl to reduce insect populations as needed. A randomized complete block design with four replicates was used.

**Greenhouse experiments:** The treatments were the same as in the 1979 microplot experiment. A steam-sterilized mixture of equal parts sand and sandy loam soil were placed in 15-cm-d clay pots. Twenty grams of chopped alfalfa and 100 cm³ of *A. conoides*-infested vermiculite were added to the appropriate pots 2 wk before planting. Just before planting, 10,000 *M. incognita* eggs were mixed with the potting medium in selected pots. Corn was sown and pots watered regularly and fertilized as needed with a complete fertilizer.

At 50 days after planting, plants were harvested, root and shoot weights recorded, root gall index (0 = 0, 1 = 1–2, 2 = 3–10, 3 = 11–30, 4 = 31–100, and 5 = 101 + galls) determined, and 200-cm³ soil samples taken from each pot for nematode and fungus assay. The remaining soil was returned to the pot and 300 cm³ of fresh potting soil was added. The pots were then replanted with corn and returned to the greenhouse. Fifty days later plants were harvested and data were taken as before. A randomized complete block design with five replicates was used. Results in both experiments were similar, so the data were combined for analysis.

**Sampling and statistical analyses:** Soil samples for nematode and fungus assays were collected from the microplots three times during the growing season (at 50, 80, and 120 days in 1979: 40, 70, and 130 days in 1980). Each sample consisted of 6–8 cores/plot, taken with a 2.5-cm-d soil
sampling tube to a depth of 15–20 cm. A
200-cm³ subsample was processed from each
composite sample. In the greenhouse, soil
samples were collected when the tests were
terminated and a 200-cm³ aliquant proc-
essed. Juveniles and roots were extracted
from each sample by a combination of
elutriation and centrifugation (1). Egg
masses attached to roots or in soil were dis-
persed with 0.5% NaOCl (1).

Arthrobotrys conoides was reisolated from microplot and
greenhouse soils by a baited plates method
(3). Nematode population data were trans-
formed to \( \log_{10} (X + 1) \) or \( \log_{10} (X) \), for
statistical analysis.

RESULTS

Microplot experiments: In 1979 the
population density of Meloidogyne incog-
nita juveniles and eggs was suppressed in
plots containing A. conoides and green
alfalfa after 50 days, but at harvest (120
days after planting) only juveniles were
suppressed (Table 1). Similarly, M. incog-
nita juveniles and egg populations at 40
days, and juveniles at 70 days in 1980 were
suppressed in plots containing A. conoides
(Table 2).

Arthrobotrys conoides was recovered
from plots infested with the fungus or
amended with green alfalfa (Tables 1 and
2). Greatest recovery was at 40 or 50 days
after planting and then decreased with each
sampling time to harvest. M. incognita sup-
pressed yield in 1979 in plots without A.
conoides. Both the fungus and the alfalfa
mulch enhanced yields, but the effects were
independent of each other. There were
growth differences early in 1980, but yields
were not different (Table 2).

Greenhouse experiments: Results of the
two greenhouse experiments were similar, so
only the first experiment is discussed. The addition of A. conoides and/or alfalfa
mulch, both alone and in combination, re-
duced the numbers of M. incognita by
43–64% and the amount of root galling by
31–33% (Table 3).

Meloidogyne incognita alone suppressed
shoot and root fresh weights compared to
the untreated control (Table 3). The addi-
tion of A. conoides and/or green alfalfa
nematode-infested soil increased corn fresh
weight compared to the nematode alone
treatment. Plant weights in alfalfa-amended
soils were greater than in the untreated con-
tral, but were not different among the
alfalfa-amended treatments (Table 3).

DISCUSSION

Suppression of Meloidogyne incognita
populations and subsequent retardation of
root-knot disease of corn was obtained with
the use of A. conoides and/or green alfalfa
in both microplot and greenhouse tests.
Similar suppressions of Meloidogyne popu-
lations and disease severity with organic
amendments have been reported on pine-
apple (9,11), tomato (19,25,26), okra (8),
and tobacco (21). Two mechanisms (4,23)
might be involved: i) the decomposition
products released from soil amendments
into soil by soil micro-organisms are di-
rectly toxic to plant nematodes; ii) the ad-
dition of soil amendments initiates a suc-
cession of events favoring the build-up of
bacteria, microbivorous nematodes, nema-
tode-trapping fungi, and other soil orga-
nisms that are antagonistic to nematodes.

The consistent recovery of A. conoides
from alfalfa-amended soil, even though it
was not added, is suggestive of contamina-
tion or a favorable environment for its es-
establishment. The latter is the most probable
explanation because A. conoides was also
recovered in tests utilizing autoclaved al-
alfa (Al-Hazmi, unpublished data).

The successful establishment of A.
conoides and subsequent control of M. in-
cognita in these experiments may be related
to several factors. The soil was fumigated
which reduced the populations of compet-
ing organisms. A vigorous culture of the
fungus was incorporated into the fumigated
soil to which a large population of M. in-
cognita was subsequently added. Edaphic
and other ecological factors not determined
may also have been favorable during this
experiment. The ecological relationships of
nematode-trapping fungi are variable and
complex, and very little is known about
how effective the fungi are in suppressing
specific nematode populations (17).

Although corn supports high popula-
tions of M. incognita in the field, chemical
control of this nematode has rarely resulted
Table 1. Numbers† of *Meloidogyne incognita* juveniles and eggs/200 cm³ soil, and the percentage recovery of *Arthrobotrys conoides* at 50, 80, and 120 days after planting corn (*Zea mays* 'Pioneer 3368A') in microplots amended with alfalfa and/or infested with *A. conoides* and/or *M. incognita*. Grain yield at 120 days after planting is also shown. 1979.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>50</th>
<th></th>
<th>80</th>
<th></th>
<th>120</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Yield† (g/micro-plot) §</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Juveniles</td>
<td>Eggs</td>
<td>% Ac recovery</td>
<td>Juveniles</td>
<td>Eggs</td>
<td>% Ac recovery</td>
<td>Juveniles</td>
<td>Eggs</td>
<td>% Ac recovery</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>650</td>
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<td>384</td>
<td>27058</td>
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<td>652</td>
<td>3908</td>
<td>100</td>
<td>2514</td>
<td>2252</td>
<td>0</td>
<td>484</td>
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<td>--</td>
<td>--</td>
<td>100</td>
<td>--</td>
<td>--</td>
<td>86</td>
<td>--</td>
<td>--</td>
<td>71</td>
<td>640</td>
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<td>--</td>
<td>--</td>
<td>100</td>
<td>--</td>
<td>--</td>
<td>100</td>
<td>--</td>
<td>--</td>
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<td>100</td>
<td>497</td>
<td>2092</td>
<td>100</td>
<td>1586</td>
<td>2525</td>
<td>43</td>
<td>609</td>
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<tr>
<td>N + OM</td>
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<td>591</td>
<td>2097</td>
<td>57</td>
<td>1538</td>
<td>3188</td>
<td>43</td>
<td>467</td>
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<tr>
<td>Ac + OM</td>
<td>--</td>
<td>--</td>
<td>86</td>
<td>--</td>
<td>--</td>
<td>86</td>
<td>--</td>
<td>--</td>
<td>57</td>
<td>679</td>
</tr>
<tr>
<td>N + Ac + OM</td>
<td>58</td>
<td>280</td>
<td>100</td>
<td>480</td>
<td>1857</td>
<td>86</td>
<td>732</td>
<td>3363</td>
<td>57</td>
<td>815</td>
</tr>
</tbody>
</table>

F Values:

- *A. conoides* 7.28* 6.27* 2.24 0.67 28.07** 0.81 4.60*
- *M. incognita*...
- Organic matter 1.38 7.80* 0.24 3.37 34.80*** 0.68 10.98**
- Ac × OM 1.38 7.80* 0.24 3.37 34.80*** 0.68 10.98**

*Significant at P = 0.05. **Significant at P = 0.01.*
†Original data were transformed to log₁₀ (X + 1) in samples collected early season and to log₁₀ (X) in samples collected mid-season and at harvest.
*Weight adjusted to 15.5% moisture.
°Microplots were 78 cm d.
Table 2. Numbers† of *Meloidogyne incognita* juveniles and eggs/200 cm³ soil, and the percentage recovery of *Arthrobotrys conoides* at 40, 70, and 130 days after planting corn (*Zea mays* 'Pioneer 3368A') in microplots amended with alfalfa and/or infested with *A. conoides* and/or *M. incognita*. Grain yield at 130 days after planting is also shown. 1980.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Days after planting</th>
<th>% Ac recovery</th>
<th>Juveniles</th>
<th>Eggs</th>
<th>% Ac recovery</th>
<th>Juveniles</th>
<th>Eggs</th>
<th>% Ac recovery</th>
<th>Juveniles</th>
<th>Eggs</th>
<th>% Ac recovery</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>40</td>
<td></td>
<td>70</td>
<td></td>
<td>130</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td><em>A. conoides</em> (<em>Ac₁)</em></td>
<td></td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>100</td>
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<tr>
<td><em>M. incognita</em> (<em>N₁</em>)</td>
<td></td>
<td>12</td>
<td>70</td>
<td>0</td>
<td>35</td>
<td>15</td>
<td>180</td>
<td>75</td>
<td>1185</td>
<td>3560</td>
<td>0</td>
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<tr>
<td><em>Ac₁ + N₁</em></td>
<td></td>
<td>10</td>
<td>30</td>
<td>100</td>
<td>15</td>
<td>140</td>
<td>100</td>
<td>75</td>
<td>792</td>
<td>3150</td>
<td>100</td>
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<td><em>Ac₂ + N₁</em></td>
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<td>40</td>
<td>100</td>
<td>15</td>
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<td>75</td>
<td>642</td>
<td>3420</td>
<td>75</td>
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<tr>
<td><em>M. incognita</em> (<em>N₂</em>)</td>
<td></td>
<td>22</td>
<td>80</td>
<td>0</td>
<td>290</td>
<td>740</td>
<td>100</td>
<td>75</td>
<td>1440</td>
<td>3250</td>
<td>75</td>
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<tr>
<td><em>Ac₁ + N₂</em></td>
<td></td>
<td>12</td>
<td>50</td>
<td>100</td>
<td>145</td>
<td>740</td>
<td>100</td>
<td>75</td>
<td>1030</td>
<td>2720</td>
<td>50</td>
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<td><em>Ac₂ + N₂</em></td>
<td></td>
<td>12</td>
<td>40</td>
<td>100</td>
<td>92</td>
<td>560</td>
<td>100</td>
<td>75</td>
<td>857</td>
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<td>75</td>
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<td><em>M. incognita</em> (<em>N₃</em>)</td>
<td></td>
<td>40</td>
<td>330</td>
<td>0</td>
<td>597</td>
<td>2810</td>
<td>100</td>
<td>75</td>
<td>1370</td>
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<tr>
<td><em>Ac₁ + N₃</em></td>
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<td>487</td>
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<td>75</td>
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<td>795</td>
<td>1340</td>
<td>0</td>
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<td>100</td>
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<td>1050</td>
<td>75</td>
<td>75</td>
<td>920</td>
<td>1960</td>
<td>50</td>
</tr>
<tr>
<td><em>Ac₂ + N₄</em></td>
<td></td>
<td>5</td>
<td>150</td>
<td>100</td>
<td>305</td>
<td>880</td>
<td>100</td>
<td>75</td>
<td>810</td>
<td>3000</td>
<td>100</td>
</tr>
</tbody>
</table>

**F-Values:**

- *A. conoides* (*Ac*) 6.83** 5.88** 12.46** 5.40** 13.88** 0.88 NS
- *M. incognita* (*N*) 6.19** 14.24** 21.26** 7.45** 1.02 0.24 NS
- *Ac X N* 1.26 1.43 1.95 1.98 0.38 0.05 NS

**Significant at P = 0.01.

†Original data were transformed to log₁₀ (X + 1) when zeroes occurred in counts and log₁₀ (X) otherwise.

‡Seed weight adjusted to 15.5% moisture.

§*Ac₁* and *Ac₂* = 500 cm³ and 2,000 cm³ media containing *A. conoides*, respectively. *N₁*, *N₂*, *N₃* and *N₄* = 0.1, 1.0, 5.0 and 10.0 eggs and juveniles/cm³ soil, respectively.
Table 3. Numbers of *Meloidogyne incognita* juveniles and eggs/200-cm² soil, fresh corn shoot and root weight, galling index, and the percentage recovery of *Arthrobotrys conoides* in greenhouse experiments in which the soil was amended with green alfalfa and/or infested with *A. conoides* and/or *M. incognita*.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Juveniles</th>
<th>Eggs</th>
<th>Shoot (g)</th>
<th>Root (g)</th>
<th>Gall index↑</th>
<th>% Ac recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>—</td>
<td>—</td>
<td>101</td>
<td>44</td>
<td>—</td>
<td>20</td>
</tr>
<tr>
<td><em>M. incognita</em> (N)</td>
<td>633</td>
<td>4344</td>
<td>73</td>
<td>27</td>
<td>3.6</td>
<td>20</td>
</tr>
<tr>
<td><em>A. conoides</em> (Ac)</td>
<td>—</td>
<td>—</td>
<td>121</td>
<td>51</td>
<td>—</td>
<td>100</td>
</tr>
<tr>
<td>Alfalfa mulch (OM)</td>
<td>—</td>
<td>—</td>
<td>175</td>
<td>72</td>
<td>—</td>
<td>60</td>
</tr>
<tr>
<td>N + Ac</td>
<td>362</td>
<td>2496</td>
<td>107</td>
<td>40</td>
<td>2.5</td>
<td>100</td>
</tr>
<tr>
<td>N + OM</td>
<td>284</td>
<td>1912</td>
<td>159</td>
<td>66</td>
<td>2.5</td>
<td>60</td>
</tr>
<tr>
<td>Ac + OM</td>
<td>—</td>
<td>—</td>
<td>164</td>
<td>67</td>
<td>—</td>
<td>100</td>
</tr>
<tr>
<td>N + Ac + OM</td>
<td>230</td>
<td>1672</td>
<td>162</td>
<td>70</td>
<td>2.4</td>
<td>100</td>
</tr>
</tbody>
</table>

LSD (0.05) 155  1676  21  11  0.7
LSD (0.01) 213 — 28  15 —

↑Gall index represents degree of infection based on number of galls on roots: 0 = none, 1 = 1-2, 2 = 3-10, 3 = 11-50, 4 = 51-100, and 5 = greater than 100 galls per root system.

in a yield increase of corn (H. E. Duncan, personal communication). Corn growth and yield in our tests were reduced by *M. incognita* if *A. conoides* was not present. Since *A. conoides* is widespread in corn fields in North Carolina (20), *A. conoides* might be effective in limiting the damage caused by *M. incognita*. However, a better understanding of the ecological requirements of the fungus is needed before *A. conoides* can be used in the suppression of *M. incognita* in the field.

**LITERATURE CITED**

Relationship between Meloidogyne hapla Density and Damage to Carrots in Organic Soils

T. C. VRAIN

Abstract: Field and growth chamber experiments were conducted to determine the effect of five initial densities (Pi - 20-240/100 cm³ soil) of Meloidogyne hapla on carrot development and yield of storage roots at maturity. Carrots growing in infested and noninfested organic soil were harvested after 15, 29, 44, 59, and 106 days of growth in controlled environment chambers and after 110 days in field plots. Nematodes affected weight of roots and foliage, weight and length of the storage portion of tap roots, and induced malformations (forking), galling, and hairiness of tap roots. In most cases the data could not be represented satisfactorily by the exponential model of Seinhorst: y = m + (1-m) P⁻¹. In growth chambers the weight of mature storage roots was not correlated to initial nematode density, but there was a significant negative correlation between weight of storage roots and initial nematode density in field plots. Tolerance levels were calculated as points where the regression lines reached the growth level on noninoculated plants. The tolerance levels of foliage were higher than those of roots, and increased with age of plants. The tolerance level of marketable weight in field plots, average crop value, and a hypothetical control cost function are used to discuss the possibility of optimizing chemical control of root-knot nematode in organic soils. Key words: root-knot nematode, population dynamics, tolerance levels, damage function.

Carrot (Daucus carota sativa L.) is a very susceptible host of Meloidogyne hapla Chitwood in temperate climates (2,3,14,16,21). High densities of the nematode at planting (several hundreds/100 cm³ soil) induced loss of weight of foliage and of roots, severe galling of roots, extreme malformations (forking) of storage roots, and a total loss of the crop (3,18,21). Quality requirements for carrot production are long and smooth tap (storage) roots, but even with low densities of root-knot nematodes (less than 40/100 cm³ soil), storage roots can be malformed and unmarketable, although their weight is not affected. Because of this low tolerance level, i.e., nematode density beyond which the crop in infested soil becomes quickly unprofitable, carrot growers rely heavily on chemical control measures when root-knot nematode is detected. Soils rich in organic matter bind organic pesticides, and high dosages of fumigant are required to reduce the initial nematode density before planting. The recommended treatment of infested carrot fields in Quebec organic soils is to apply 292 liter/ha broadcast of 1,3-dichloropropene nematicide. This standard practice is costly and lacks flexibility, but no information is available from

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1Agriculture Canada Research Station, 6660 N. W. Marine Drive, Vancouver, B.C. V6T 1X2.

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