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Rotylenchus uniformis (Thorne) on carrots

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Abstract

Rotylenchus uniformis (Thorne) causes small orange lesions in the cortex of carrot roots and also orange discoloration of the stele in the vicinity of these lesions. The tolerance limit of carrots to *R. uniformis* was about 30 nematodes per 5 g soil in pot trials at about 17 °C and 2 nematodes per 5g soil at 5 ° to 10 °C. However, this temperature is too low for normal development of the plant. Field observations in the literature suggest that carrot yields are not reduced at densities of *R. uniformis* up to 20 nematodes per 5 g soil. No field data are available for higher densities. From the frequency distribution of different densities of *R. uniformis* in soil samples from carrot fields, and assuming a tolerance limit of 16 nematodes per 5 g soil, the area where losses occur is estimated to be between 10 and 15 % of the total area under carrots. The total reduction of yield by the nematode would then be less than 1 %. If the tolerance limit is 32 nematodes per 5 g soil, the damage would be negligible.

Carrot, cauliflower and *Phaseolus* beans are among the best hosts of *R. uniformis.*

Introduction

Rotylenchus uniformis (Thorne)[2] has been mentioned several times in relation to poor growth of carrots (Oostenbrink, 1954; Kuiper and Drijfhout, 1957; Seinhorst, 1958) but the evidence produced by these authors is not convincing. Kuiper and Drijfhout (1957), investigating the influence of nematicidal treatments and crop rotation, found a yield increase of 55 % of that on untreated plots after a DD treatment and of 36 % after a formalin treatment on a field with a density of *R. uniformis* of about 15 nematodes per 5 g soil. Their conclusions on the importance of this nematode are largely based on the assumption that DD treatment only promotes plant growth by killing nematodes.

Seinhorst (1958) described symptoms in carrot roots that had grown in soil from which the nematodes had been removed by elutriation and to which a nematode population consisting mainly of *Rotylenchus uniformis* had been added. The carrots in the inoculated soil were slightly stunted in comparison to those in soil which had not been re-inoculated. The roots showed some cortical necrosis but the most conspicuous symptom was orange discolouration of large parts of the stele of many roots, visible when these roots were placed in water and inspected at a magnification of 10 times or more (Fig. 1). In air and without magnification the roots appeared greyish whereas those of the healthy plants were white. As similar symptoms occurred in stunted

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[2] In the newer literature this nematode is also indicated by the name *Rotylenchus robustus* (de Man). The reasons for using the name *R. uniformis* (Thorne) are given by Goodey and Seinhorst (1960).

Fig. 1. Symptoms of attack by *Rotylenchus uniformis* in carrots. Left without and right with nematodes. The orange discolouration came out black in the photograph.

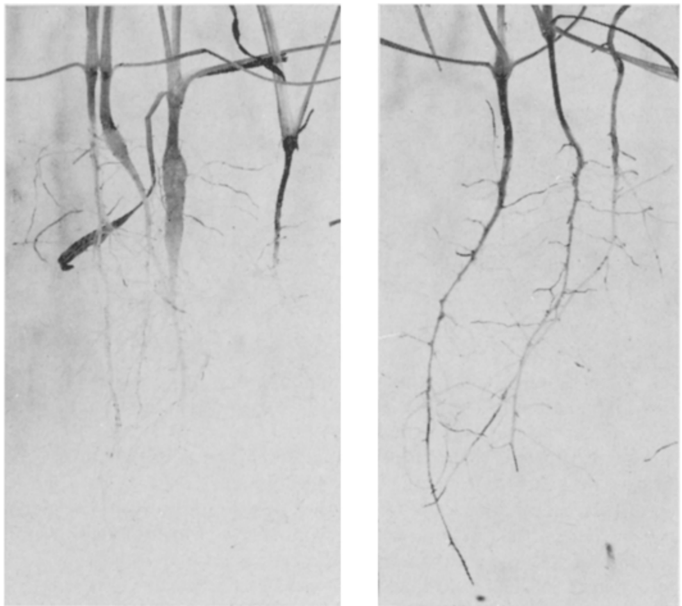

Fig. 1. Symptomen van aantasting door Rotylenchus uniformis bij peen. Links zonder en rechts met aaltjes. De oranje verkleuringen zijn zwart op de foto.

carrots grown in a field on sandy soil infested with *R. uniformis*, Seinhorst (1958) inferred that the stunting might be due to attack by this nematode. However, in this field the plants also suffered from "tailed carrot", a disease with unknown cause, which may also result in stunting (Seinhorst and Riezebos, 1959).

Small orange coloured lesions and orange discolouration of small stretches of the stele in their vicinity were also seen in the roots of carrot seedlings grown in silver sand inoculated with *R. uniformis*. Uninoculated controls were entirely free of these symptoms.

To investigate whether a plant parasitic nematode is of economic importance two aspects of the problem must be considered:

1. The relation between the density of the nematode and the yield of the crop(s) it attacks. In this relation the tolerance limit (Seinhorst, 1965) of these crops is especially important.
2. The densities occurring in the field and especially the frequency of those exceeding the tolerance limits of crops which are susceptible to damage.

The relation between the density of R. uniformis and carrot yield

Laboratory experiments

The influence of different densities of *R. uniformis* on the growth of carrots was investigated in three experiments. In the first the plants were grown in glass tubes with a mixture of silver sand and ground perlite (5% by weight) moistened with nutrient solution. Glass tubes 7 cm long and 1.5 cm wide were filled with 10 g silver sand-ground perlite mixture. A glass capillary was first placed in the tube to enable air to leave it when water was added from above. The artificial soil was introduced in small quantities at a time and gently packed with a thin stick so that the columns of soil in all tubes had the same height. Two ml of nutrient solution was added to the filled tubes.

The nematodes used for inoculation were from a glass-house culture on cauliflower in sterilized soil. They were collected from this soil by elutriation. The suspension obtained contained no other plant parasitic nematodes than *R. uniformis* and only a few rhabditids. The tubes were inoculated with 0, 5, 10, 20, 40, 80, 160, 320, 640, 1280 and 2560 nematodes per tube. There were seven tubes per density. Numbers of nematodes up to 80 per tube were picked by hand from a bulk suspension. To avoid selection of certain sizes or stages some milliliters of suspension were poured into a counting tray, with 2 × 2 mm squares marked on the bottom. All specimens from a number of squares large enough to yield the required number of nematodes were then picked out by hand and transferred to a drop of water on a siliconized watchglass. For 160 and more nematodes portions of the bulk suspension were transferred to siliconized watchglasses by pipette. The size of the drops of water containing the

Fig. 2. Relation in a pot experiment at 18°C between density of *R. uniformis* and length of the longest leaf of carrot plants growing in a mixture of silver sand and ground perlite at different times after sowing.

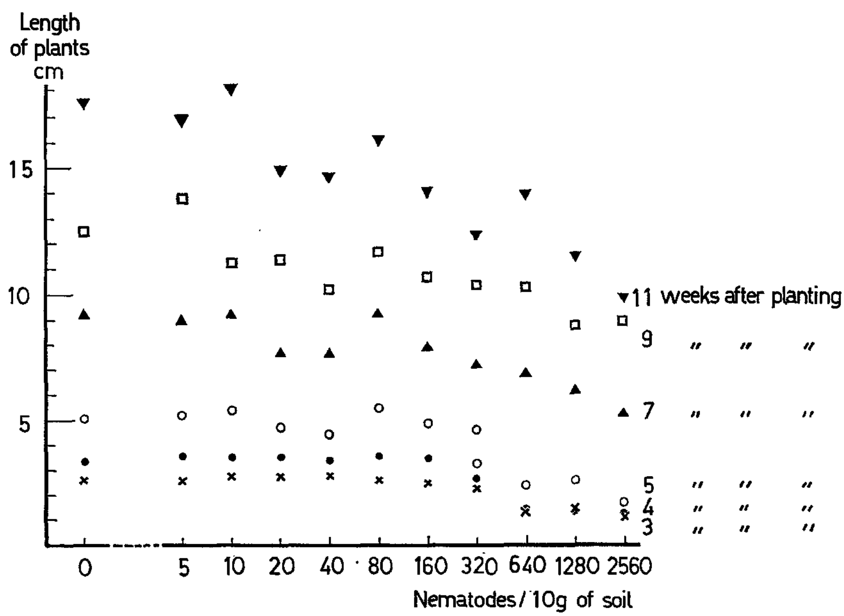

Fig. 2. De betrekking bij 18°C in een potproef tussen de dichtheid van R. uniformis en de lengte van het blad van peenplanten geteeld in een mengsel van glaszand en gemalen perliet verschillende tijden na het zaaien.

nematodes was reduced to about 1 mm diameter by sucking up the water with a fine pipette. These drops still moved easily on the siliconized surface together with the nematodes and could easily be transferred to the tubes. A day after this inoculation of a tube a germinated seed of carrot (var. 'Amsterdamse Bak') was placed on the sand and covered with enough moist silver sand so that the total weight of each tube became 14.5 g. This weight was maintained during the experiment by weighing the tubes and adding water if necessary. As soon as the plants had two or more normal leaves weighing and watering was done almost every day. Each week 1 ml of nutrient solution was added mostly divided over 2 or 3 days.

Fig. 3. Relation between initial density of *Rotylenchus uniformis* and final density of living and living + dead nematodes on carrots growing in a mixture of silver sand and ground perlite. P_i and P_f: initial and final densities in nematodes per 10 g growth medium.

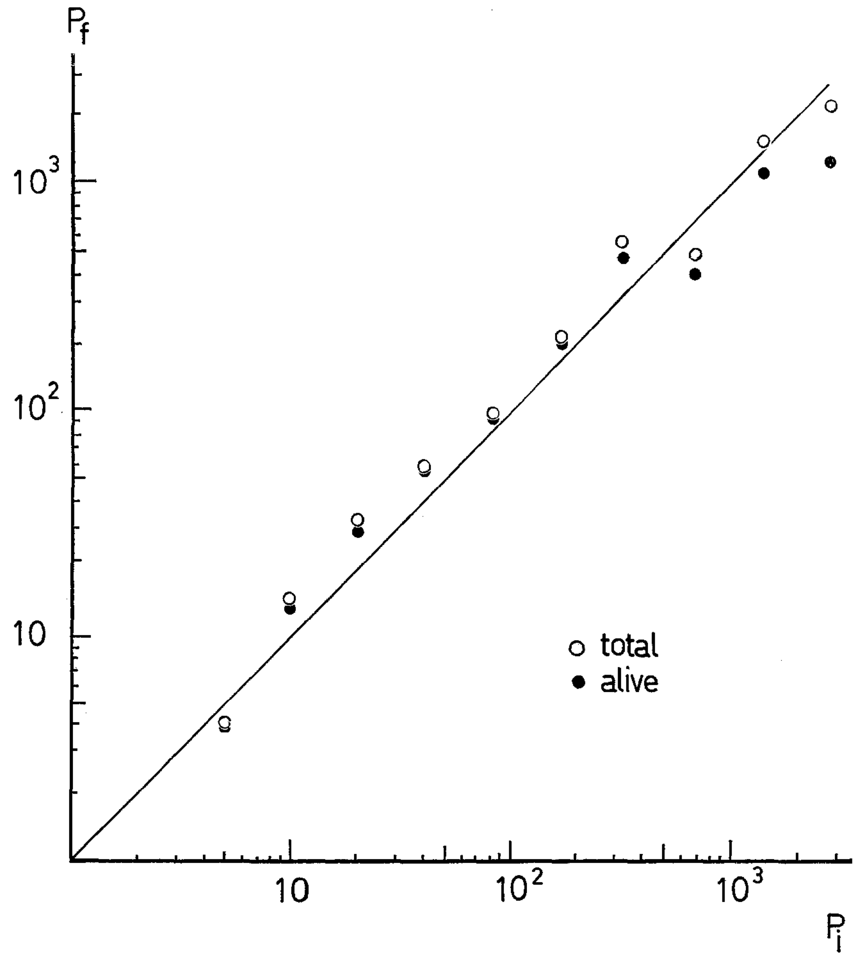

Fig. 3. De betrekking tussen de dichtheid van R. uniformis bij het begin en die van levende en levende + dode aaltjes bij het einde van een potproef met peen geteeld in een mengsel van glaszand en gemalen perliet. P_i en P_f: dichtheden bij het begin en eind van de proef in aaltjes per 10 g zand–perliet mengsel.

After the planting of the seed the tubes were kept in a glass house at about 18 °C and shaded by cheese cloth against direct sunlight.

The length of the longest leaf together with the distance from the soil to the leaf axil was measured every week from 2 weeks after the beginning of the experiment (further indicated as the length of the longest leaf). The results of the measurements are given in Fig. 2.

Eleven weeks after the beginning of the experiment the plants were taken from the tubes and weighed. The numbers of nematodes were counted. The contents of each tube were washed into a separate beaker and the carrot plant freed from sand. The nematodes were separated from the sand by repeated addition of water and decanting. The volume of the suspension was reduced by sieving it repeatedly through a 100 μ sieve, collecting the nematodes each time with a small quantity of water. The nematodes were then counted, distinguishing between living and dead specimens. A nematode was considered to be dead when it was immobile and its contents showed signs of deterioration. The results are given in Fig. 3.

The leaves, main root and fine roots of each plant were dried at about 70 °C and weighed separately. The results of these weighings are given in Fig. 4, 5, 6 and 7.

A second experiment was done in 2 liter pots as described by Seinhorst (1966). The

Fig. 4. Relation in a pot experiment at 18 °C between initial density of *R. uniformis* and dry weight of leaves of carrots grown in a mixture of silver sand and ground perlite.

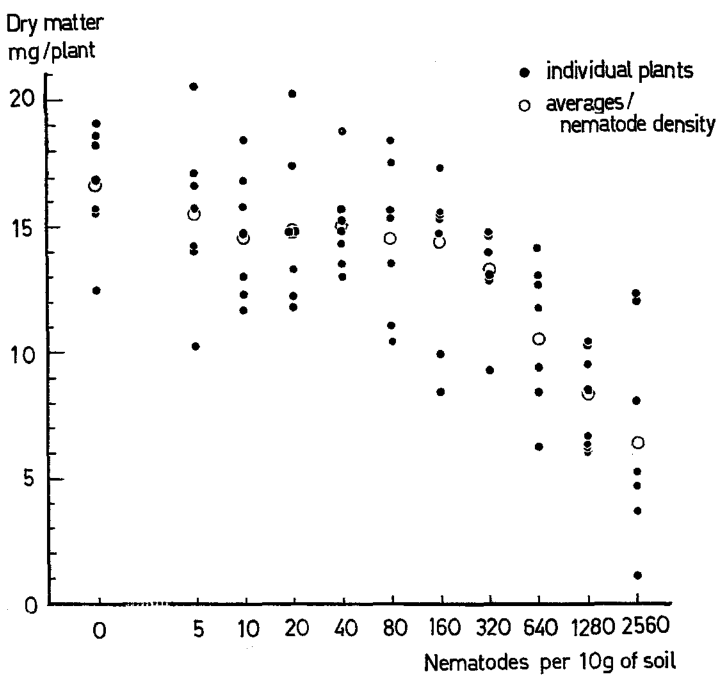

Fig. 4. De betrekking in een potproef bij 18 °C tussen de dichtheid van R. uniformis en het drooggewicht van het blad van peen groeiend in een mengsel van glaszand en gemalen perliet.

Fig. 5. Relation in a pot experiment at 18 °C between initial density of *R. uniformis* and dry weight of main roots of carrots grown in a mixture of silver sand and perlite.

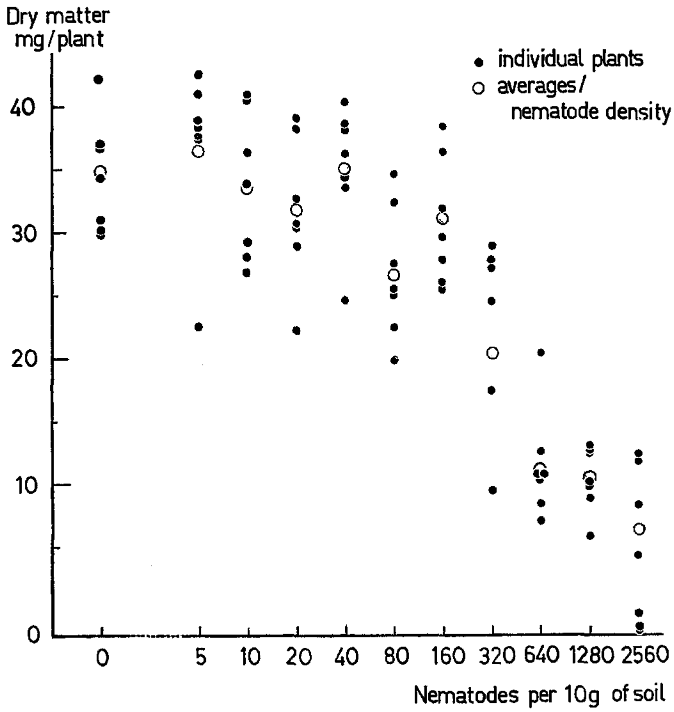

Fig. 5. De betrekking in een potproef bij 18 °C tussen de dichtheid van R. uniformis en het drooggewicht van de penwortel van peen groeiend in een mengsel van glaszand en perliet.

sandy soil used came from a previous pot experiment in which carrots and white clover had been grown at different densities of *R. uniformis*. It had been treated with DD and inoculated with different numbers of *R. uniformis* by adding nematode suspensions before the carrots and white clover were sown. Neither the carrots nor the clover showed any difference in yield at the different nematode densities. The experiment had therefore not introduced changes in the soil associated with the initial nematode densities. To obtain a suitable range of nematode densities, soil from the clover experiment containing a certain number of *R. uniformis* was mixed with the same quantity of soil from the carrot experiment containing a certain number of nematodes. The densities of *R. uniformis* in the mixtures were determined (500 g soil investigated per density) and six pots filled with soil of each density. Carrots were sown in five of these and one was left without plants. The pots were placed in a well ventilated glasshouse in which the temperature did not differ much from that outdoors, where the daily maxima varied from 14° to 30 °C and the average temperatures per 10 days from 15° to 19 °C. Three weeks after sowing the number of plants per pot was reduced to 15.

The experiment was finished 10 weeks after the carrots were sown. The tops, tap

Fig. 6. Relation in a pot experiment at 18 °C between initial density of *R. uniformis* and dry weight of fine roots of carrots grown in a mixture of silver sand and perlite.

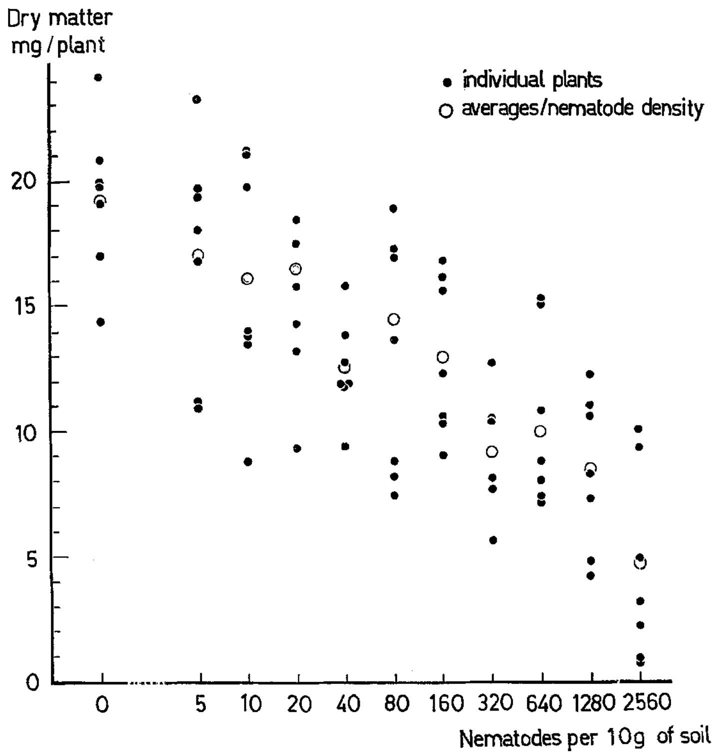

Fig. 6. De betrekking in een potproef bij 18 °C tussen de dichtheden van R. uniformis en het drooggewicht van fijne wortels van peen geteeld in een mengsel van glaszand en gemalen perliet.

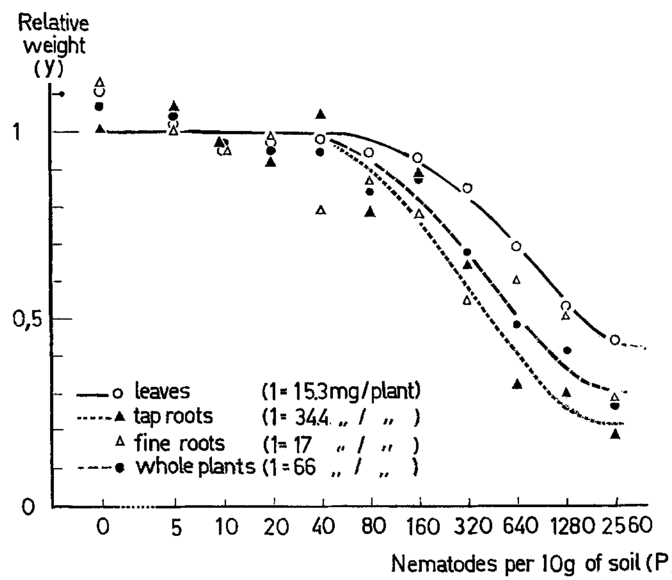

Fig. 7. Comparison of the relations at 18 °C between density of *R. uniformis* and dry weight of leaves, tap roots, fine roots and whole plants of carrot grown in a mixture of silver sand and ground perlite.

Fig. 7. Vergelijking van de betrekking bij 18 °C tussen de dichtheid van R. uniformis en het drooggewicht van bladeren, penwortels, fijne wortels en hele planten van peen geteeld in een mengsel van zilver zand en gemalen perliet.

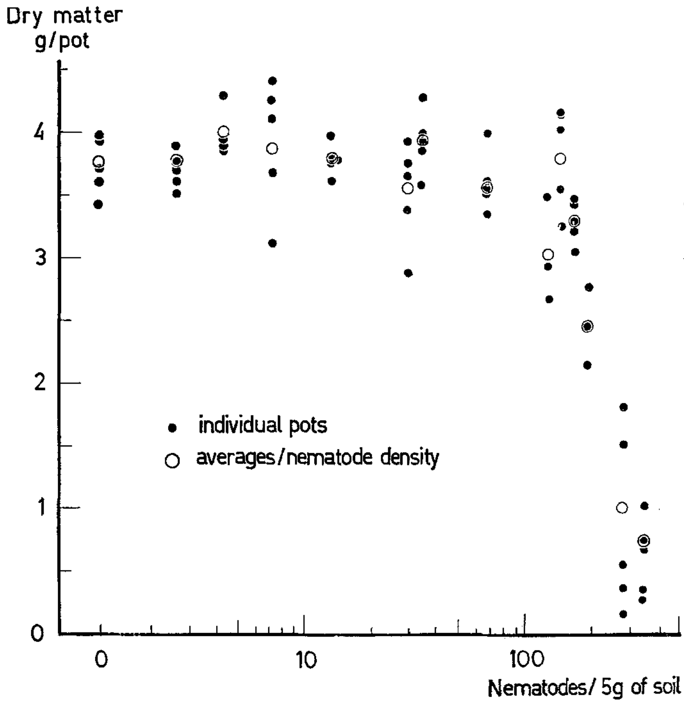

Fig. 8. Relation at about 17 °C between the initial density of *R. uniformis* in pots with sandy soil and the dry weight of leaves of carrots.

Fig. 8. De betrekking bij ongeveer 17 °C tussen de begindichtheid van R. uniformis in potten met zandgrond en het drooggewicht van het blad van peen.

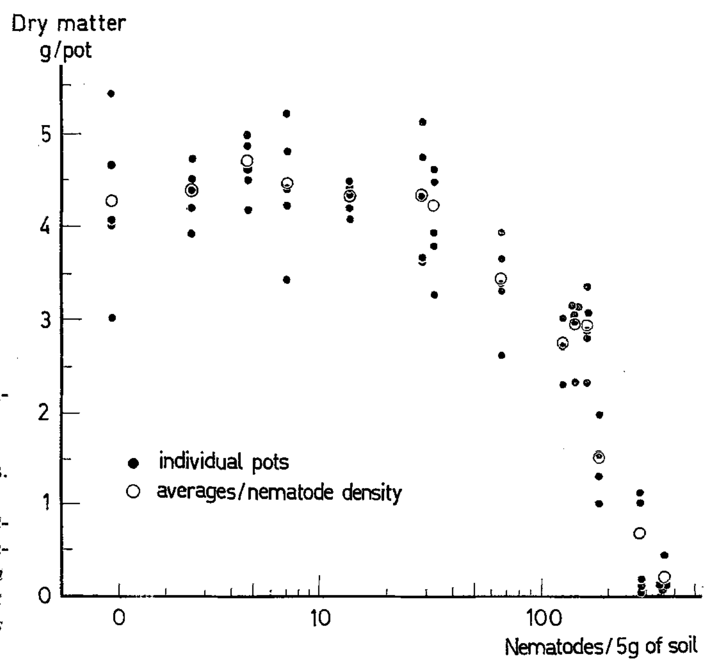

Fig. 9. Relation at about 17 °C between the initial density of *R. uniformis* in pots with sandy soil and the dry weight of tap roots of carrots.

Fig. 9. De betrekking bij ongeveer 17 °C tussen de begindichtheid van R. uniformis in potten met zandgrond en het drooggewicht van penwortels van peen.

Fig. 10. Relation at about 17 °C between the initial density of *R.uniformis* in pots with sandy soil and the dry weight of whole carrot plants.

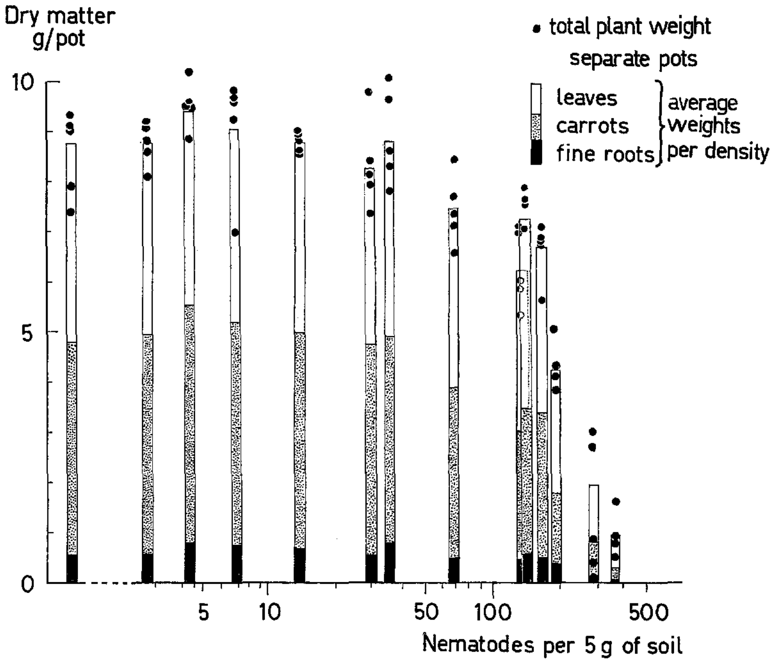

Fig. 10. De betrekking bij ongeveer 17 °C tussen de begindichtheid van R.uniformis in potten met zandgrond en het totale drooggewicht van wortelen.

Fig. 11. Comparison of the relations at about 17 °C between density of *R.uniformis* and dry weights of leaves, tap roots and fine roots of carrots in pots with sandy soil.

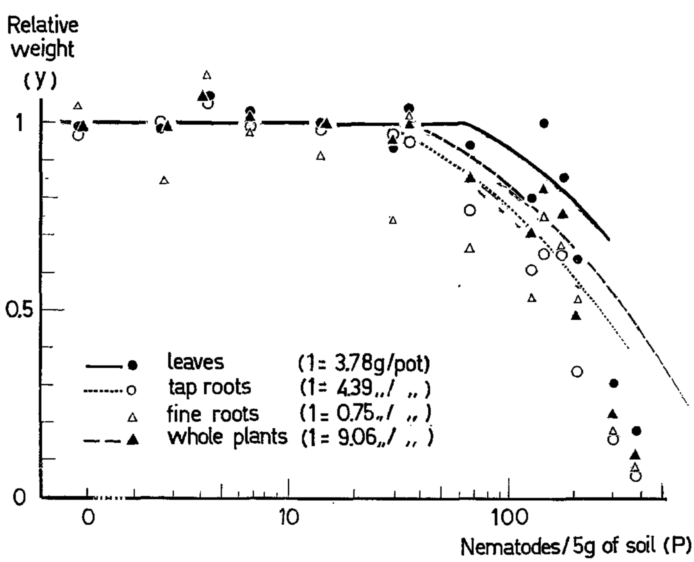

Fig. 11. Vergelijking van de betrekkingen bij ca. 17 °C tussen de dichtheid van R.uniformis en de drooggewichten van blad, penwortels, en fijne wortels van peen in potten met zandgrond.

Fig. 12. The relation at about 17 °C between initial and final densities (P_i and P_f) of *R. uniformis* in pots with sandy soil with and without carrots. P_i and P_f in numbers of nematodes per 5 g soil.

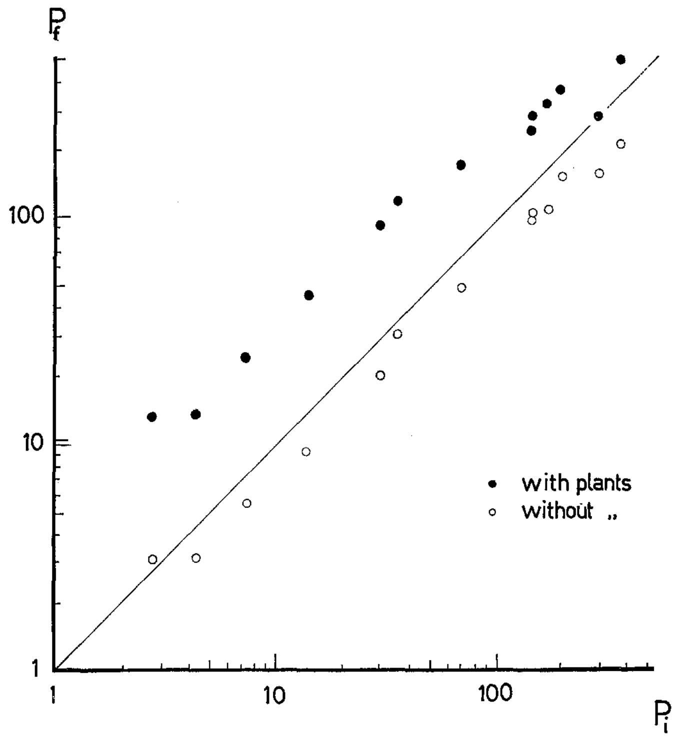

Fig. 12. De betrekking bij ongeveer 17 °C tussen de dichtheden van P_i en P_f van R. uniformis bij het begin en het eind van een proef met zandgrond in potten met en zonder peenplanten. P_i en P_f in aantallen aaltjes per 5 g grond.

roots and fine roots from each pot were dried separately at about 75 °C and weighed. The results are given in Fig. 8, 9, 10 and 11. Nematode densities were also determined in 500 g soil per pot. The results are to be found in Fig. 12.

The soil of the six pots with each initial nematode density was mixed and some sterilized sandy soil was added to make up for the soil used for determination of nematode densities. Samples of 500 g were taken from the mixtures to determine nematode densities and with the remaining soil six pots were filled per nematode density. In these pots carrots were sown in the beginning of November. The pots were kept at about 5° to 10 °C in the glass house. This temperature only allowed very slow growth of the plants. The first composite leaf appeared about 3 weeks after sowing. When the experiment was finished in the end of February the plants still had no thickened tap root. Total plant weights at the different nematode densities are given in Fig. 13. The relation between nematode densities at the beginning and at the end of the experiment are given in Fig. 14. At the highest initial densities the roots of the plants had not reached the lower part of the pots. To investigate whether this had

Fig. 13. The relation at about 8 °C between the density of *R. uniformis* in pots with sandy soil and the dry weight of whole carrot plants.

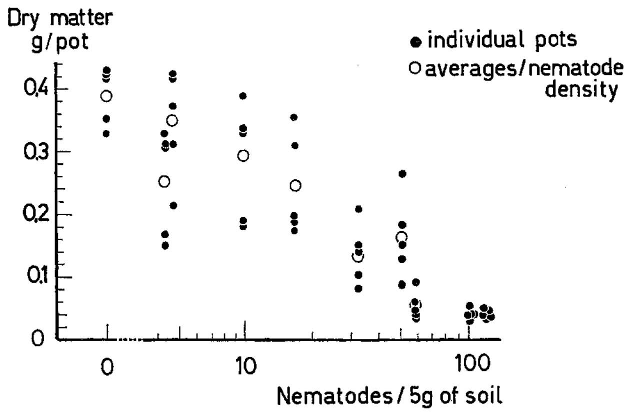

Fig. 13. De betrekking bij ongeveer 8 °C tussen de dichtheid van R. uniformis in potten met zandgrond en het drooggewicht van gehele peenplanten.

Fig. 14. The relation at about 8 °C between initial and final densities P_i and P_f of *R. uniformis* in pots with sandy soil with and without carrots. P_i and P_f in numbers of nematodes per 5 g soil.

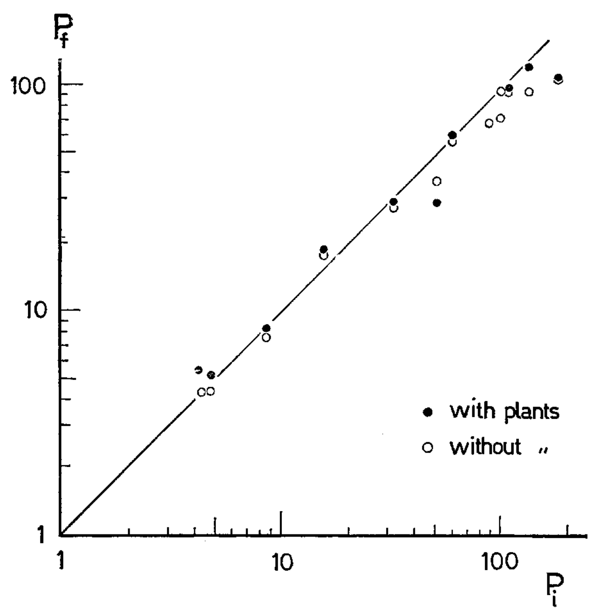

Fig. 14. De betrekking bij ongeveer 8 °C tussen de dichtheden P_i en P_f van R. uniformis bij het begin en het eind van een proef in potten met zandgrond met en zonder peenplanten. P_i en P_f in aantallen aaltjes per 5 g grond.

Table 1. Densities of *R. uniformis* in upper and lower halves of pots at four initial densities. Numbers are those found in five lots of 500 g soil devided by 500.

		Initial densities			
		5	20	59	133
Final densities	upper half	5	23	60	130
	lower half	6	24	58	132

Tabel 1. Dichtheden van R. uniformis in de boven- en onderhelft van potten bij vier begindichtheden. De getallen zijn aantallen aaltjes gevonden in 5 maal 500 g grond gedeeld door 500.

influenced the distribution of the nematodes their densities in 500 g of soil from the upper and lower halves of the pots were determined at four initial densities. The results are given in Table 1.

Discussion of the results of the laboratory experiments

The plants developed slowly in the tubes with 10 g sand-perlite mixture, probably because of the small amount of nutrient available. They produced 6.6 mg of dry matter per g sand–perlite mixture in the tubes with 0, 5, 10, 20 and 40 nematodes (Fig. 7). This is a little more than in the pot experiment with sandy soil (5 mg per g soil, Fig. 11) where, however, individual plants (15 per pot) were about 10 times as large. The ratio between the lengths of the longest leaves at the highest and the lowest nematode densities (derived from curves fitted through the points in Fig. 2) increased with time, indicating that growth reduction was severest in the early stages of growth. The ratio between leaf weights at the highest density and the lower five densities (Fig. 7) at the end of the experiment (0.4) is about the third power of that between the lengths of the longest leaves at the same densities (about 0.7 according to a smooth curve fitted to the points in Fig. 2). This is in accordance with the observation that the nematode attack kept size, thickness and number of leaves smaller than in healthy plants by retarding the growth of the plant. As the youngest leaves are very light in comparison to the older ones total leaf weight depends largely on the size of the larger leaves.

The relation between nematode density and dry weight of leaves is well in accordance with the equation $y = a + (1–a)cz^P$ $(a \leqslant y \leqslant 1)$, (solid line in Fig. 7) in which y = the ratio between this weight at nematode density P and that in the absence of nematodes (the maximum yield estimated to be 15.3 mg per plant), a = the ratio between the yield at very high nematode densities (the minimum yield) and the maximum yield, z = a constant < 1 and c = a constant >1 (Seinhorst, 1965). If c is considered to be 1.05 (as in Fig. 7), the tolerance limit (value of P for $y = 1$) is 60 nematodes per tube. The average weights per nematode density of the tap roots show a less distinct pattern than that of the weights of the leaves. A curve $y = a + (1–a)cz^P$ $(a \leqslant y \leqslant 1)$ can be fitted to the observations assuming that the maximum yield was 34.4 mg per plant, $a = 0.20$ and $c = 1.05$ (stippled line in Fig. 7). The resulting tolerance limit is 40 nematodes per tube. It is not practicable to describe the relation between nematode density and weight of fine roots in a similar way.

The experiment is of course not accurate enough to determine exact values of c. Changing the value of c from 1.05 tot 1.1 doubles the tolerance limit. The difference between the yield at the tolerance limit and at a density twice as large is 5% of (1–a) times the yield in the absence of nematodes when $c = 1.05$ and 10% of (1–a) times this yield when $c = 1.1$.

According to Fig. 4 and 5 the ratio of weight of leaves to weight of tap roots is increased by the nematode attack. This means that the roots were affected at smaller nematode densities than the tops.

At the low initial densities the nematodes multiplied to about 1.3 times the initial number and the equilibrium density can be estimated to be about 600 nematodes per tube (300 nematodes per 5 mg) (Fig. 3). The proportion of the recovered nematodes that was dead increases considerably with increase of initial density from the equilibrium density on. Apparently death because of starvation was an important cause of population reduction at densities larger than the equilibrium density. If mortality had been entirely due to age and other causes unrelated to food supply the percentage that died would be the same at all initial densities.

In the second experiment the nematodes multiplied to 3.5 times the initial number at the lower densities. At higher initial densities the rate of multiplication was smaller and the equilibrium density in this experiment is estimated at about 500 nematodes per 5 g of soil. In pots without plants the populations decreased during the experiment to about 75% of the initial density (Fig. 8). Seinhorst (1967) estimated the maximum rate of multiplication of *R. uniformis* on carrots in a field experiment to have been 10 times between October and mid June. The carrots were grown under Dutch windows between October and May. A maximum rate of multiplication of 16 × can be derived from data by Seinhorst and Knoppien (1960) for *R. uniformis* on carrots (March till August) followed by endive (August till November). As the pot experiment was of much shorter duration than the growing period of the carrots in the filed there probably was little difference in the activity of the nematodes at small densities. Equilibrium densities in the field were between 7 and 20 nematodes per 5 g soil. The nematodes were therefore more active in the pots than in the field at the higher initial densities.

According to Fig. 11 the tolerance limits in the pot experiment were about 30 nematodes per 5 g soil for total plant weight and weight of tap roots and about 60 nematodes per 5 g soil for above ground parts. Nematode attack, therefore, increased the ratio between the weights of leaves and those of tap roots also in this experiment. Fig. 7 and 11 show that at low nematode densities this ratio probably varies less than the actual weights of the different parts of the plants. Therefore the relation between nematode density and shoot–tap root ratio also provides a good indication of the tolerance limit: damage occurred at the densities at which the relative weights of leaves and tap roots differ markedly (Fig. 7 and 11).

At the higher nematode densities yields were considerably lower than is in accordance with the equation $y = a + (1\text{–}a)cz^P$ (lines in Fig. 11). A possible cause is that the nematode attack increased the shoot-root ratio. Although the average weights of fine roots varied considerably in both experiments discussed above and also at low nematode densities, Fig. 7 and 11 suggest that from a certain density on nematode attack increased the ratio between weight of leaves and that of fine roots. A similar phenomenon was reported by Seinhorst (1965) for *Fragaria vesca* attacked by *Longi-*

dorus elongatus. If the relation between nematode density P and root weight and that between nematode density and shoot weight can both be expressed by the equation $y = a + (1\text{–}a)cz^P$ shoot–root ratios would increase with nematode density. There obviously is a limit to this increase. It is not very likely that at high nematode densities the plant could maintain a balance between root and shoot weight by producing more roots than is in accordance with the above mentioned equation. Therefore if from a certain nematode density on, the shoot–root ratio remained the same the shoot weight would decrease more strongly than is in accordance with the above mentioned equation. The deviation will be more obvious the smaller the value of a (i.e. when minimum yields are small).

Another possible cause of the deviation or part of it is the difference in average moisture content between pots with large and with small plants. As all pots were watered at the same time those with small plants were wetter on the average than those with large plants. This may have influenced the activity of the nematodes and favoured root rot following the destruction of cortical cells by nematodes in the pots with small plants.

The tolerance limit of whole plants, roots and leaves of carrot to *R. uniformis* attack in the third pot experiment (at 5 °–10 °C, average about 8 °C) is estimated to have been about 3 nematodes per 5 g soil (1/32 of the density at which the yields approach the minimum yield) (Fig. 13).

During the experiment the nematodes did not change materially in density in either the fallow pots or in those with plants (Figs. 14) and they did not migrate towards the roots in the pots with poor growth (Table 1). Apparently *R. uniformis* is much more damaging to carrots at low temperatures than at higher ones. This could be of importance for early carrots, which grow at low temperatures for a comparatively long time. However, in all cases carrots reach their final size at fairly high temperatures. The damage done by a period of growth at low temperatures then depends on the degree of recovery the plants can attain at the higher temperatures. For a proper evaluation of the effect of low temperatures on the tolerance limit of carrots to *R. uniformis* it must be taken into account that the experiment was done from November till the end of February, thus the amount of light the plants received was much smaller than at the same temperatures outdoors in spring. This possibly reduced the vigour of the plants and their tolerance limit in comparison to those growing in the field at the same temperatures.

Field observations

Seinhorst and Riezebos (1959) found that nematicidal treatments of fields with 3 to 20 *R. uniformis* per 5 g soil (densities determined in 500 g samples) did not improve the stand and marketing quality of carrots sown in October and harvested mid June except in one case (with 7 nematodes per 5 g untreated soil). Here a better stand on DD treated plots became apparent after March. However, in this field there was also a heavy attack by "tailed carrot", a disease which can also be controlled by DD treatment of the soil. In two experiments (with 10 to about 20 nematodes per 5 g soil in the untreated plots) the stand of the carrots was better on the untreated than on the treated plots. Seinhorst and Knoppien (1960) reduced *R. uniformis* densities of 5 to 10 nematodes per 5 g soil to 0.1 to 5 nematodes per 5 g soil by means of soil treatments with different dosages of N.N.'-dimethyl thiuramdisulfide (Tridipam). Yields of carrots grown after these treatments between March and August were the same at all densities. The field observations therefore suggest that carrot yields are not reduced by *R. uniformis* in densities of probably up to 20 nematodes per 5 g soil.

If the differences in yield between untreated and DD treated plots found by Kuiper and Drijfhout (1957) were due entirely to *R. uniformis* attack then about 15 nematodes per 5 g soil would have caused a yield reduction of 35%. According to the equation $y = a + (1-a)cz^P$ and assuming $a = 0$ and $c = 1.1$ this would mean a tolerance limit of 2 nematodes per 5 g soil. The yields they obtained after potato (1.6 kg at 20 nematodes per 5 g soil) and after beet (0.9 kg at 35 nematodes per 5 g soil) interpreted in the same way would lead to a tolerance limit of <4 nematode per 5 g soil. As such values are not supported by any evidence from other experiments, we must conclude that these differences in yields were due to other causes than *R. uniformis* attack.

Densities of R. uniformis occurring in the field and estimates of total damage to carrots in different areas

In The Netherlands *R. uniformis* is found in appreciable numbers only in sandy soils. All carrots for direct consumption and canning are grown on sandy soils, especially along the coast. Table 2 gives the frequencies of different densities of *R. uniformis* in the coastal sand area (compilation of observations during several years), in Friesland (according to Kuiper and Drijfhout, 1957; C. Kaai, personal communication) and in carrot fields in the whole country (according to Kaai, personal communication). In all cases samples were from areas of at most a few square metres and therefore give a good picture of true densities found in the field. From these data an estimate can be made of yield losses caused by *R. uniformis* attack to be expected in the different carrot growing areas. If 16 nematodes per 5 g soil is taken to be the limit of safe carrot growing then according to Table 2 about 10% of the dune sand area would be subject to an average loss of about 5% assuming that yield loss in % is 100 $(1-cz^P)$ (see Fig. 11) For $P \leqslant 16$ nematodes per 5 g soil. This would mean a loss

Table 2. Frequencies of different densities of *R. uniformis* on sandy soils in The Netherlands.

R. uniformis per 5 g soil	Dune sand area	Friesland (Kuiper and Drijfhout, 1957; Kaai, pers. comm.)	In carrots whole country (Kaai, pers. comm.)
0– 1	27	5	9
1– 2	12	1	11
2– 4	20	1	8
4– 8	30	1	3
8–16	20	6	18
16–32	11	9	16
32–70	1	8	9
Total	121	31	74

Tabel 2. Frequenties van verschillende dichtheden van R. uniformis op zandgronden in Nederland.

of 0.5% of the yield of the whole area. If carrots were grown continuously then according to Kaai's (personal communication) data (Table 2, fourth column) about 30% of the area of carrots in The Netherlands would be subject to yield reductions. On 2% of the area the average yield reduction would be 5% and on 12% of the area about 17%. This would make a total of about 3% of the carrot yield of the whole country. In Friesland yield reductions would be caused by *R. uniformis* in about 55% of the area under carrots. An average loss of 5% would occur in about 30% and one of about 17% in about 25% of the area. This makes a total for the whole area of 0,3 × 5% + 0.25 × 17% = 5.7%. In the latter two cases most or all of the samples were taken in carrot fields in summer. As carrot is among the best hosts of *R. uniformis*, densities found in these samples are higher than average in the sampled fields and the estimated losses would only occur if carrots or equally good hosts were grown continuously. Generally some time will elapse between harvesting one carrot crop and sowing the next if no other crop plant is grown in between. In this period nematode densities will decrease. Estimates of losses based on the third and fourth column of Table 2 are therefore too high. Moreover the tolerance limit may be higher. If it is assumed to be 32 nematodes per 5 g soil (as in the pot experiments in summer) losses derived from the three columns of Table 2 become 0.0%, 1.3% and 0.6%, respectively, and 0% if there is a 50% reduction of nematode densities between carrot crops (Table 3).

Influence of different crops on densities of R. uniformis in the field

Growing a host of a nematode species increases the density of this nematode up to a limit which depends on the host and the conditions in the field (Seinhorst, 1967). This limit may be constant for many years in a field or change with time (Seinhorst,

Table 3. Estimates of yield losses of carrots caused by *R. uniformis* derived from Table 2.

Tolerance limit	16 nematodes per 5 g soil			32 nematodes per 5 g soil		
	% area		loss % of total yield	% area		loss % of total yield
	av. loss 5%	av. loss 17%		av. loss 5%	av. loss 17%	
Dune sand area	10	0	0.5	0	0	0
Friesland	30	25	5.7	25	0	1.3
Whole country	21	12	3.2	12	0	0.6
Assuming a 50% decrease of nematode densities between carrot crops						
Friesland	25	0	1.5	0	0	0
Whole country	12	0	0.6	0	0	0

Tabel 3. Schattingen van opbrengstverliezen van wortelen veroorzaakt door R. uniformis afgeleid van Tabel 2.

Table 4. Frequencies of different densities of *R. uniformis* after different crops in Kennemerland.

R. uniformis per 5 g soil	Carrots	Cauliflower and *Phaseolus* beans	Strawberry	Other crops
0– 1	1	1	4	9
1– 2	2	2	1	2
2– 4	1	2	7	1
4– 8	4	1	6	5
8–16	1	3	0	1
16–32	1	2	0	1
32–64	0	0	0	0
Totals	10	11	18	19

Tabel 4. Frequenties van verschillende dichtheden van R. uniformis na verschillende gewassen in Kennemerland.

1967). To obtain an insight into the importance of a plant parasitic nematode species it is therefore necessary to know not only the actual frequency distribution of densities, but also the maximum densities that could be reached in different places by growing good hosts. Table 4 gives the frequencies of different densities of *R. uniformis* after different crops in Kennemerland. Of the crops mentioned carrots, cauliflower and *Phaseolus* beans are known to be among the best hosts. Table 3 suggests a decreae of the frequency of densities <1 nematode per 5 g soil and an increase of that of densities >16 nematodes per 5 g soil when good hosts are grown but the frequency of the latter densities remains small. We may therefore assume that in the carrot growing areas densities of more than 16 nematodes per 5 g soil would not be much more frequent than in Tables 2 and 3 when good hosts were grown much oftener.

Conclusions

Densities of *R. uniformis* in the carrot growing areas do not often exceed the tolerance limit of carrots grown in pots at about 16 °C: 30 nematodes per 5 g soil. Field observations also suggest a tolerance limit of summer and winter grown carrots of over 20 nematodes per 5 g soil. This means that *R. uniformis* could only damage carrots noticeably in a small proportion of the fields. The available evidence suggests that here losses do not exceed 30% by weight. They will in most cases be obscured by yield fluctuations caused in other ways the more so as attack by this nematode does not produce diagnostic symptoms. At temperatures below 10 °C the tolerance limit may be less than 10 nematodes per 5 g soil. It remains to be investigated whether initial damage to carrots sown in autumn and kept under Dutch windows during winter or sown in early spring is still expressed in yields at harvest time in June. These investigations require climate rooms preferably with a certain degree of climate simulation. Limited field observations have not disclosed damage by small *R. uniformis* densities in winter and early spring with certainty.

Although *R. uniformis* possibly causes yield reductions in a limited number of carrot fields, the density of this nematode will only seldom be a reason to give a nematicidal treatment. Treatment of the soil with DD often results in increased yields and improved quality of carrots, but the increase in vigor of the plants must be ascribed to the removal of other growth inhibiting factors e.g. tailed carrot, *Meloidogyne* and possibly others.

Where high densities of the nematode occur one may avoid growing carrots after carrots, cauliflower, *Phaseolus*-beans and beets (Kuiper and Drijfhout, 1957) if this has no disadvantages. Otherwise the losses caused by this cultural measure may exceed those caused by the nematode.

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Samenvatting

Rotylenchus uniformis (Thorne) op peen

Rotylenchus uniformis veroorzaakt kleine vaak enigszins oranje gekleurde lesies in de schors van de wortels van peen. In de nabijheid van deze lesies is ook vaak de stele oranje gekleurd. Bij grote dichtheden van het aaltje wordt de ontwikkeling van de wortels geremd. De tolerantiegrens van peen voor *R. uniformis* was ongeveer 30 aaltjes per 5 g grond in potproeven bij ongeveer 17 °C in de zomer en 2 aaltjes per 5 g grond bij 5° tot 10 °C in de winter. Uit veldwaarnemingen vermeld in de literatuur kan worden afgeleid dat de opbrengst van peen niet wordt verlaagd door dichtheden van *R. uniformis* beneden 20 aaltjes per 5 g grond, zowel bij zaaien in de herfst als in het voorjaar. Er zijn geen veldwaarnemingen over hogere dichtheden. Het is mogelijk, dat bij de hogere temperatuur in de laatste maanden voor de oogst de peen zich herstelt van de schade, die bij lagere temperatuur vroeger in het seizoen werd aangericht en ook dat door de gunstiger temperatuur–licht verhouding dan bij de kasproef in de winter de tolerantiegrens van peen in de volle grond bij lage temperatuur hoger is dan in de kasproef.

Door Kaai (persoonlijke mededeling) werden in 10% van de onderzochte grondmonsters (genomen van oppervlakten niet groter dan enkele m^2) van met peen beteelde velden op zandgrond dichtheden van *R. uniformis* van meer dan 32 aaltjes per 5 g grond gevonden en in ruim 20% van deze monsters dichtheden van 16 tot 32 aaltjes per 5 g grond. Als wordt aangenomen, dat de tolerantiegrens van peen 16 aaltjes per 5 g grond is, dan zou bij het telen van peen na peen en zaaien van het nieuwe gewas onmiddellijk na de oogst van het voorgaande de schade ruim 3% van de totale opbrengst zijn. Wordt aangenomen, dat tussen het oogsten van de peen en het zaaien van het volgende gewas peen enige tijd verloopt, waarin de aaltjesdichtheid tot de helft daalt, dan kan de schade geschat worden op ruim 0,5% van de totale opbrengst. Bij een tolerantiegrens van 32 aaltjes per 5 g grond worden deze schattingen respectievelijk 0,6% en 0% (Tabel 3).

Peen hoort met bloemkool en *Phaseolus*-bonen tot de beste waardplanten van *R. uniformis*. De frequentie van dichtheden boven 16 aaltjes per 5 g grond is na teelt van

deze laatste gewassen niet hoger dan na teelt van peen (Tabel 4). De dichtheden, die in de zomer in peenvelden werden gevonden geven dus niet een te gunstig beeld van die, waarbij peen op zandgrond wordt geteeld.

Hoewel *R. uniformis* waarschijnlijk op enkele plaatsen enige schade in peen veroorzaakt, zal de bevolkingsdichtheid van dit aaltje toch zelden aanleiding tot het toepassen van een nematicide behandeling zijn, temeer daar hieraan bij gebruik van DD enige kans op smaakbederf en fytotoxische nawerking kleeft. Waar geregeld hoge dichtheden van *R. uniformis* voorkomen zou het telen van peen na peen, bloemkool, *Phaseolus*-bonen en bieten vermeden kunnen worden als dit geen bezwaren meebrengt. Anders zou de vermindering van de netto opbrengst de schade door deze maatregel die door aaltjesschade gemakkelijk kunnen gaan overtreffen.

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