Nematologica 34 (1988): 98-114, E. J. Brill, Leiden

EFFECT OF *HETERODERA CICERI* ON YIELD OF CHICKPEA AND LENTIL AND DEVELOPMENT OF THIS NEMATODE ON CHICKPEA IN SYRIA

BY

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Experiments were undertaken in 1984-1986 to assess losses caused by *Heterodera ciceri* to chickpea and lentil and to investigate the development of the nematode in Syria. Pots containing 5.5 dm³ of soil were sown to spring chickpea in 1985 and microplots containing 34 dm³ of soil sown to winter chickpea or lentil in 1985-1986. There were nine pots or ten microplots for each plant species and population density levels (0, 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64 and 128 eggs of *H. ciceri*/cm³ soil). Sixteen more microplots were sown to winter chickpea and 14 to spring chickpea, to investigate the development of the nematode. When plant size was considered, tolerance limits (*T*) to *H. ciceri* were 0.22 and 0.6 eggs/cm³ soil and minimum relative plant sizes 0.6 and 0.47 for winter sown chickpea and lentil, respectively. Tolerance limits of 1, 1.15, and 2.51 eggs/cm³ soil for spring and winter chickpea and lentil, respectively, and relative minimum yields of 0 for chickpea and 0.5 for lentil were instead estimated for grain and total plant weights. Seed protein content was also negatively affected by the nematode. Second stage juveniles of the nematode had invaded roots of both winter and spring chickpea by the time of emergence of the plants. Females appeared on 13 March and 10 April on the roots of winter and spring chickpea, and cysts 14 and 6 days later, respectively, when 212-227 day degrees had accumulated. Maximum reproduction rates of *H. ciceri* at very small initial population densities were large (249-297) and about the same on winter chickpea and lentil and 4.5 on spring chickpea.

Keywords: chickpea cyst nematode, development, chickpea, lentil, yield losses, host parasite relations, mathematical models.

The chickpea cyst nematode, *Heterodera ciceri* Vovlas, Greco & Di Vito, causes severe damage to chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medic.) in Syria (Greco *et al.*, 1984; Vovlas *et al.*, 1985). The nematode also affects pea (*Pisum sativum* L.) and can reproduce on a number of leguminous species (Greco *et al.*, 1986b). Under controlled conditions only one generation was completed (Kaloshian *et al.*, 1986). To investigate the development of *H. ciceri* under field conditions and its pathogenicity to the main crops affected, chickpea and lentil, experiments were done in Syria, in 1984 to 1986. Although chickpea is usually grown as a spring crop, winter sown chickpea was included in the experiments because recent studies by Hawtin and Singh (1984) have shown that its grain yields are considerably larger than of spring

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sown chickpea. Chickpea and lentil sown in December 1984 were heavily damaged by frost in early 1985, which left only an experiment with spring sown chickpea in that year. The experiments with winter chickpea and lentil were repeated in 1985-1986.

MATERIALS AND METHODS

Effect of population densities of H. ciceri *on lentil and chickpea.* Cysts were extracted in November 1984 from infested soil from a field in the Idleb area (North Syria), in which chickpea had been damaged severely by *H. ciceri*. Cysts and debris were then dried at room temperature, mixed with 40 kg of steam sterilized sand and used as inoculum. To estimate the nematode population of this inoculum ten subamples, 10 g each, were poured onto a 250 µm sieve and rinsed to remove fine soil particles. Cysts were then collected on a paper filter, counted and crushed according to Bijloo's modified method (Seinhorst & Den Ouden, 1966) to determine egg contents (standard error = 8.6% of the average). The correct amounts of the inoculum and 80 g of a fertilizer (18% N, 46% P_2O_5) were then added to and thoroughly mixed with lots of 148.5 dm^3 of soil per population level, in a concrete mixer, to establish the following range of population densities: 0, 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64 and 128 eggs of *H. ciceri*/cm^3 soil. The infested soil was divided between 27 plastic pots per nematode density (5.5 dm^3 per pot). The pots were sunk into the soil at ICARDA's principal research station at Tel Hadya (Aleppo, North Syria) to 5 cm below the edge and nine at each nematode density were sown to spring chickpea on 3 March 1985 (5 seeds of ILC 482 per pot, thinned to three per pot soon after emergence). The inoculum for the 1985-1986 experiments was collected from a similar field in the same way as the year before and the same range of nematode densities was prepared. Ten replicates at each population level and plant species were established, this time in microplots made of 55 cm long and 31 cm wide plastic tubes without bottom, sunk into the soil at the same location as the previous experiments. The bottom 5 cm layer of each microplot was filled with sterilized soil and then 34 dm^3 of the infested soil added to fill the microplots up to 5 cm below the edge. Because of the large volume of the microplots the soil of each was infested and fertilized (as in 1984) separately. Six seeds of chickpea (ILC 482) or 15 of lentil (ILL 4401 local small) were sown per microplot on 10 December and, after emergence of the plants, thinned to four and ten per microplot, respectively.

Pots and microplots were inoculated with the appropriate *Rhizobium* species soon after sowing.

Length and width of winter chickpea and lentil were measured on 5 May. At harvest (spring chickpea: 20 June 1985, lentil: 20 May 1986, winter chickpea: 5 June 1986), grain and straw plus grain were weighed. Chickpea and lentil seeds were tested for protein content (Nx6.25) using a NEOTEC food quality analyser Model 51A, which uses the principle of near-infrared reflectance spectroscopy (NIRS). Calibration was done by determining nitrogen by micro-kjeldhal procedure (AOAC, 1965). Soil samples of 1.5 kg, composed of 24 cores, 30 cm long and 1.5 cm wide, were then collected from each pot or microplot.

Development of H. ciceri *on chickpea.* Thirty microplots, as described above, were filled with soil infested with 20 eggs of *H. ciceri*/cm³ and sown to chickpea (ILC 482) on 10 December 1985 (16 microplots) and on 2 March 1986 (14 microplots). Roots of winter and spring sown chickpea were collected from one microplot each every two weeks from plant emergence until early March and then weekly until 5 June 1986. Roots were gently washed in water and cut in 0.5 cm long pieces. A 5 g sub-sample was processed by Coolen's method (1979) and the nematodes counted and classified according to different developmental stages. A 1 kg soil sample from the rhizosphere of each microplot was also collected at each sampling date (Table 3; Fig. 9). Soil moisture content was determined at each sampling date and referred to as per cent of dried soil weight (Fig. 10).

Processing of soil samples from all experiments. Soil samples were air dried, mixed and cysts were then extracted from a 200 g subsample (s.g. 1.2) in a Fenwick can, separated from debris with the Seinhorst apparatus (1974) substituting a magnesium sulfate solution (s.g. 1.25) for ethanol, and crushed to determine egg content.

In all experiments the soil used was composed of 20% sand, 33% silt, 46% clay, and <1% organic matter, with pH 8.2. Soil temperature at 10 and 20 cm depth was continuously recorded in the same field. During the experiment, pots were watered once or twice a week from March onwards and microplots only twice throughout the growing season, and the leaf miner (*Liriomyza cicerina* Rond.) was controlled.

RESULTS

Effect of population densities of H. ciceri *on lentil and chickpea.* Symptoms of *H. ciceri* attack (yellowing and stunting) on spring chickpea were evident by 18 April 1985 in the pots infested with 128 eggs/cm³ soil and on 5 May 1985 in those containing ≥8 eggs/cm soil. All plants in the pots infested with ≥64 eggs/cm³ soil were dead by 23 May. In 1986 nematode attack stunted the plants and, moreover, yellowing of winter sown chickpea appeared by 21 February at 128 eggs of the nematode/cm³ soil and by 21 March at ≥8 eggs/cm³ soil. Similar symptoms appeared in lentil two weeks later. No yellowing was observed at <8 eggs/cm³ soil. Times required for emergence, flowering and podding of both legumes were not noticeably affected by the

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SULTS

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nematodes. However, plants in heavily infested microplots flowered poorly and produced pods without seeds or with small and unmarketable seeds. Chickpea senesced earlier with larger numbers of nematodes than with smaller.

Lengths and widths of all winter sown chickpea and lentil plants were measured on 5 May 1986. Length to width ratios were constant up to 16 eggs/cm^3 soil in lentil and increased very slightly between 0.25 and 16 eggs/cm^3 soil in winter sown chickpea. They were strongly increased at >16 eggs/cm^3 soil. Variability was remarkably small (Fig. 1). This suggests that length times the square of the diameter of the plants could be used as a measure of their relative size or weight on 5 May. In Fig. 2 curves according to the equation $y = m + (1-m)z^{P-T}$ for $P > T$ and $y = 1$ for $P \leq T$ (1) (Seinhorst, 1965; 1986b), with $z^{-T} = 0.95$ are fitted to the relative sizes of the plants estimated by length times the square of the diameter (y) at the different nematode densities (P). Tolerance limits (T) were estimated to be 0.22 and 0.6 egg/cm^3 soil and minimum relative plant sizes (m) to be 0.6 and 0.47 for winter sown chickpea and lentil, respectively. Relative sizes of both plants at 64 and 128 eggs/cm^3 soil do not fit these curves, a phenomenon described by Seinhorst (1981a) from several other experiments. It more or less coincides here with increased length to width ratios of the chickpea and lentil plants.

Grain and total weights of the plants were strongly affected by *H. ciceri* attack. Tolerance limits (T) of 1 and 1.15 eggs/cm^3 soil and a minimum relative weight of 0 were derived for both grain and total plant weights of spring and winter sown chickpeas, respectively, from a curve according to eq. (1) fitted to the data (Fig. 3).

The productivity of lentil was reduced less than that of chickpea by *H. ciceri*. A tolerance limit of 2.5 eggs/cm^3 soil and a minimum relative yield of 0.5 were derived for both grain and total plant weight by fitting a curve according to eq. (1) to the data (Fig. 4).

However, there seems to be a discrepancy between Fig. 2 and Figs 3 and 4, tolerance limits being considerably larger in the latter than in the former, whereas the curves according to eq. (1) also fit to relative weights of chickpea and lentil at 64 and 128 eggs/cm^3 soil in the latter but not in the former. To investigate the nature of this discrepancy the data were introduced in growth models as described by Seinhorst (1986b). Plants without nematode were supposed to increase in weight by a constant amount per unit of time after they had reached about a fourth of their final weights, about 17 weeks after planting, whereas they doubled their weight every two weeks before that date. Growth curves for plants with nematodes were then constructed assuming that the ratio between the time t_p, needed by these plants to reach a certain weight and the t_o, needed by plants without nematodes to reach this weight was the same from the beginning of nematode attack (here assumed to coincide with the planting date). Relative plant weights on 5 May were supposed to be equal

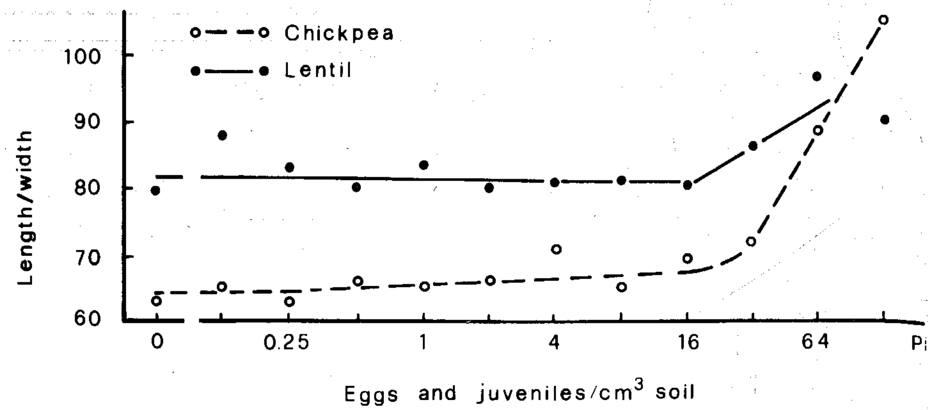


Fig. 1. Length to width ratios of winter sown chickpea and lentil, grown in microplots infested with increasing numbers of *Heterodera ciceri*, on 5 May 1986.

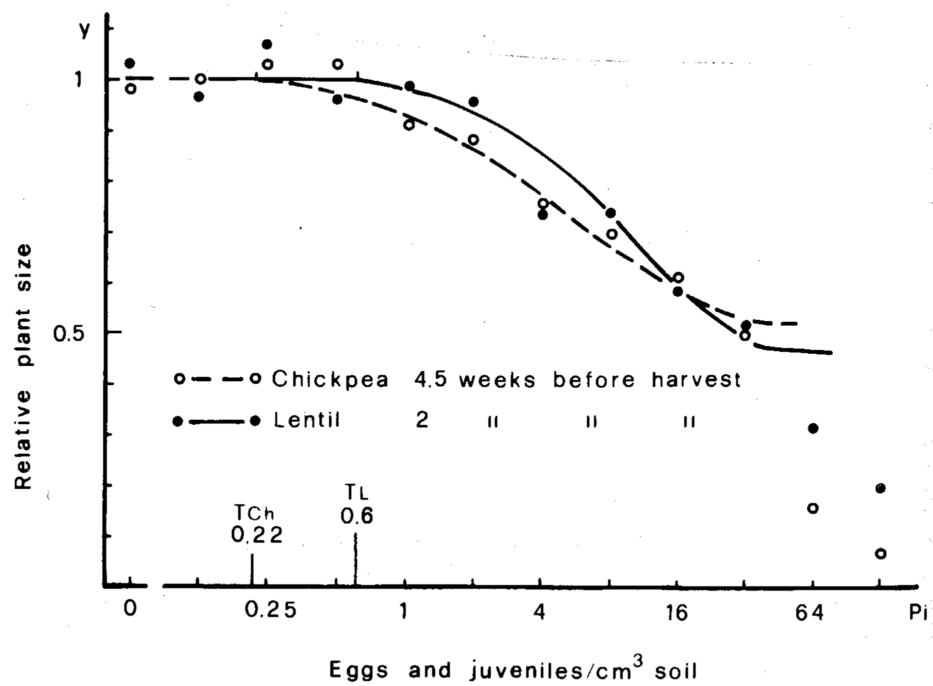
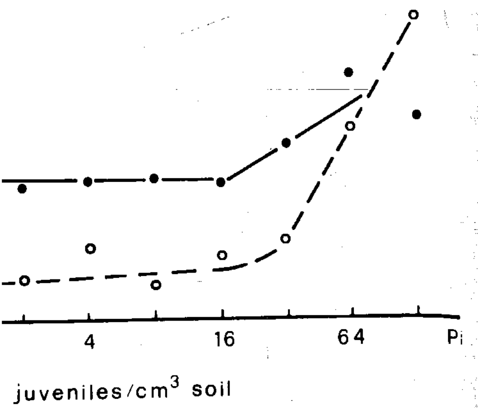


Fig. 2. Relationship between numbers of *Heterodera ciceri* and relative (y) plant size (assumed = to plant length × square of plant diameter) of winter sown chickpea and lentil grown in microplots in 1986 (TCh = tolerance limit of chickpea; TL = tolerance limit of lentil).



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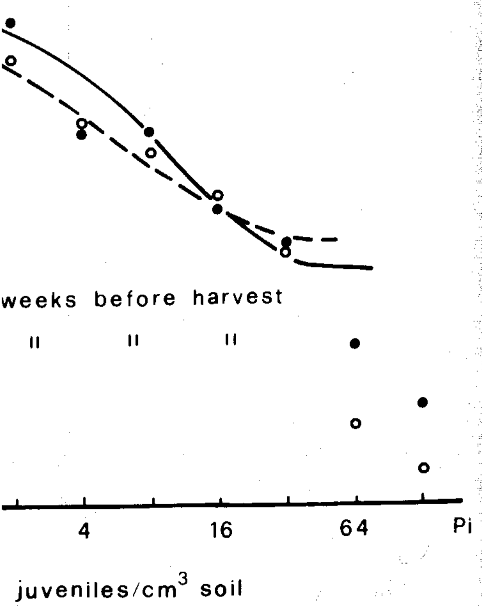

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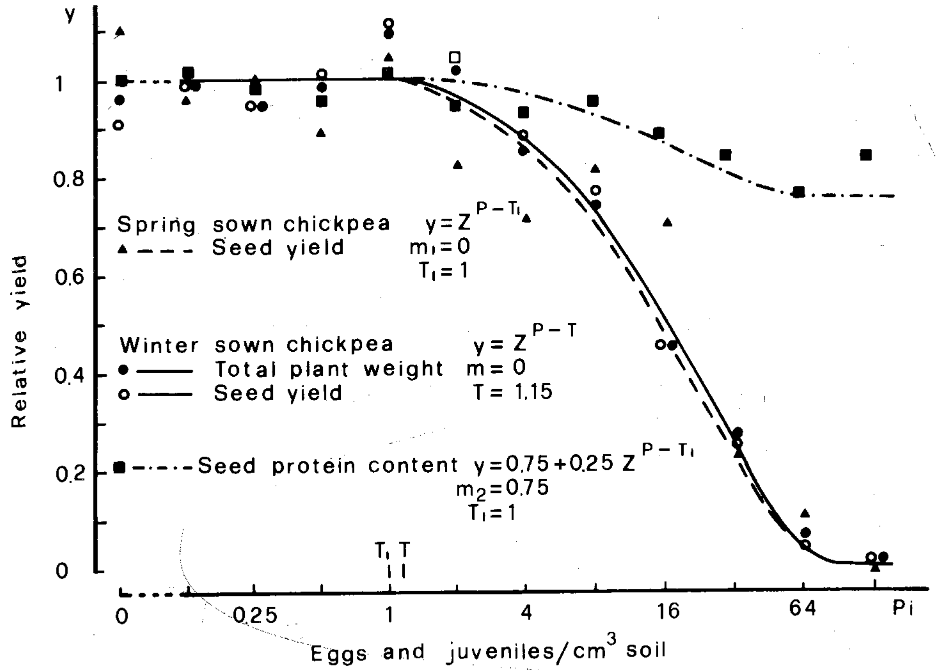

Fig. 3. Relationship between numbers of *Heterodera ciceri* at sowing (Pi) and relative yields (y) of spring and winter chickpeas grown in pots in 1985 or microplots in 1986, respectively; and protein content of winter chickpea.

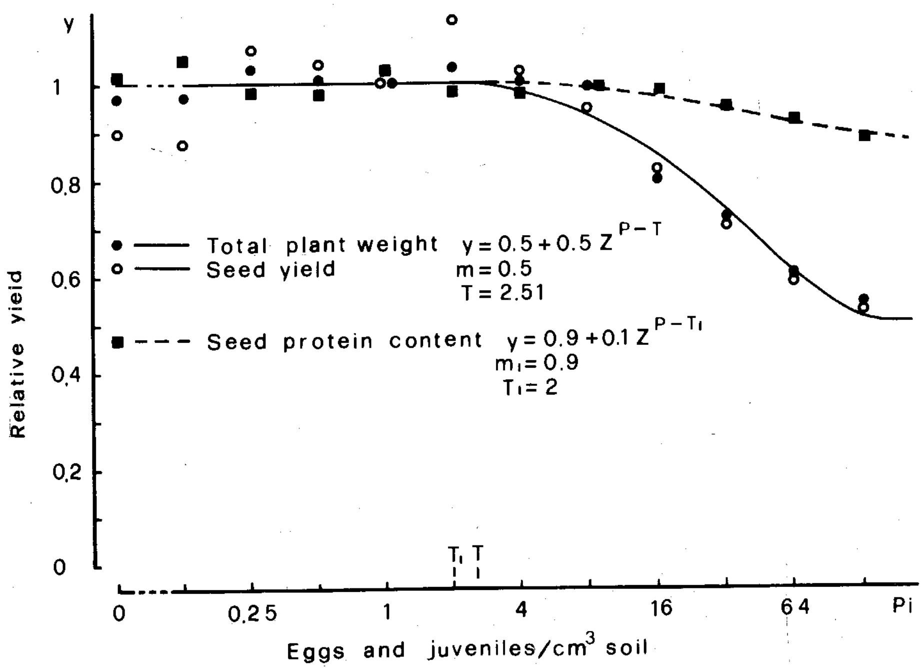

Fig. 4. Relationship between numbers of *Heterodera ciceri* at sowing (Pi) and relative yields (y) and protein content of lentils grown in microplots in 1986.

TABLE I

Effect of population densities of Heterodera ciceri *on length and width of winter chickpea and lentil on 5 May 1986*

Eggs/	Length (cm)		Width (cm)	
cm³ soil	Chickpea	Lentil	Chickpea	Lentil
0.00	39	29	62	36
0.125	40	30	62	34
0.25	40	30	63	36
0.50	41	28	62	35
1	39	29	60	35
2	39	28	59	35
4	39	26	55	32
8	36	26	55	32
16	36	24	52	30
32	34	24	48	28
64	28	22	30	23
128	23	18	22	20

to relative plant sizes on that date, derived from lengths and widths. Ratios tp/t_0 for the different nematode densities were supposed to be those with $tp = 145$ days (on 5 May). Growth rates were probably smaller during the first months of growth than later on, due to lower temperature, but this (requiring an assumption that the start of growth and attack were later than the planting date) appeared not to affect the resulting growth curves materially. A good fit of relative weights of winter sown chickpea at the end of the experiment to the growth curves was obtained if weight increase from 17 weeks after planting was supposed to be 10% of the final weight per week (Fig. 5), if the relatively large final weights at 1 and 2 eggs/cm³ soil could be considered to be due to variability. A somewhat smaller or larger rate of weight increase would have resulted in an equally good fit. The rate of 10% was chosen as the estimated weights with 32 to 128 eggs/cm³ soil were about the same on 5 May and 5 June. The plants were then thought to have ceased growth on or before 5 May, suggesting a phenomenon similar to "early senescense" in potatoes caused by *Globodera pallida* (Seinhorst, 1986b). At 16 eggs/cm³ soil cessation of growth is thought to have occurred in the third week of May.

Growth curves in accordance with relative plant sizes and weights of lentil on 5 and 20 May, respectively, were not so easily constructed. A reasonable fit for 0 to 64 eggs/cm³ soil was obtained by assuming that the plants at 0 to 0.5 eggs/cm³ soil ceased to increase in weight a week before harvest and those at 1 and 2 eggs/cm³ soil between 13 and 20 May (Fig. 6). However, relative size on 5 May and relative weight on 20 May of the plants at 128 eggs/cm³ soil could not be made to match at all. No reason for the discrepancy could be found.

E I

iceri *on length and width of winter chickpea*
May 1986

l	Width (cm) Chickpea	Lentil
	62	36
	62	34
	63	36
	62	35
	60	35
	59	35
	55	32
	55	32
	52	30
	48	28
	30	23
	22	20

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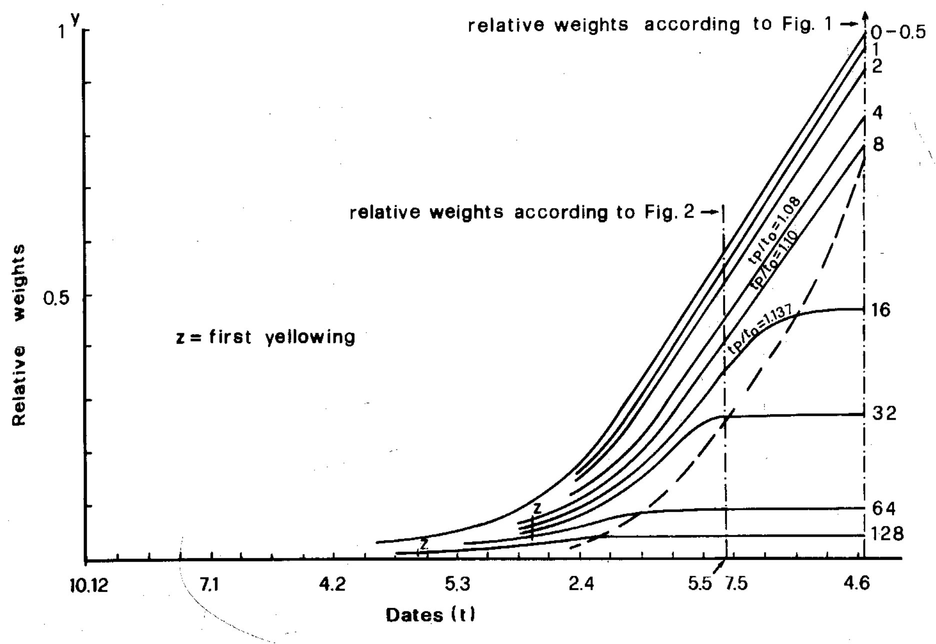


Fig. 5. Growth curves (according to Seinhorst, 1986a) of winter sown chickpea grown in microplots infested with increasing numbers of *Heterodera ciceri*, derived considering plant size on 5 May and plant weight on 5 June.

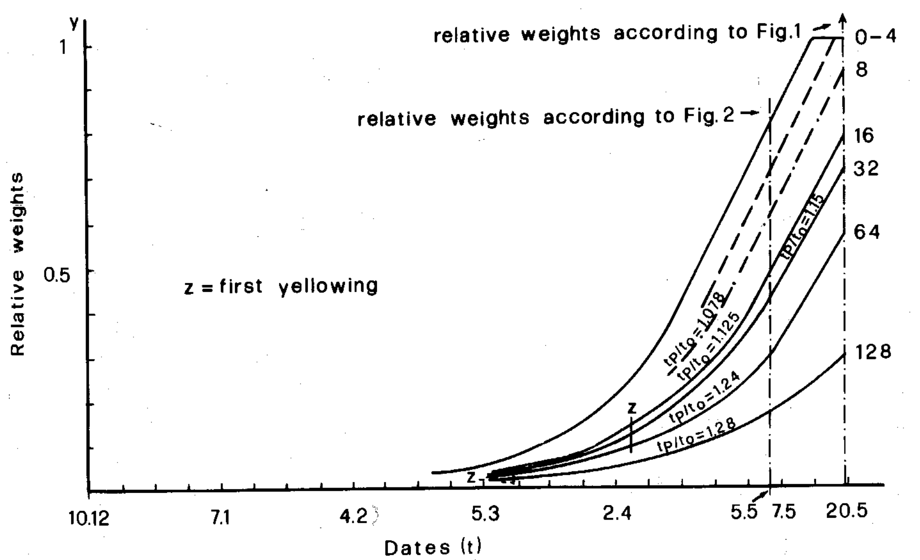


Fig. 6. Growth curves (according to Seinhorst, 1986a) of lentil grown in microplots infested with increasing numbers of *Heterodera ciceri*, derived considering plant size on 5 May and plant weight on 20 May.

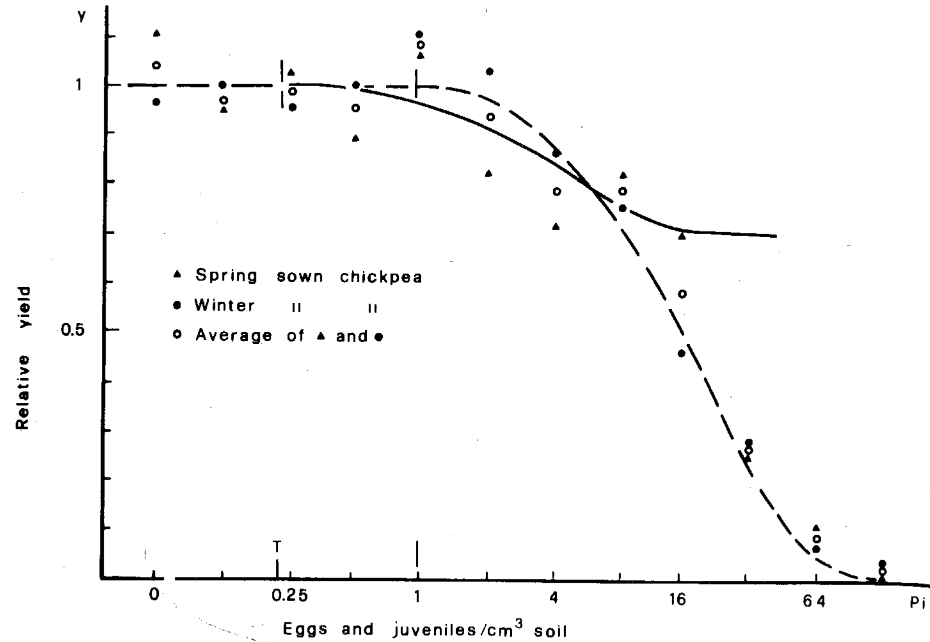
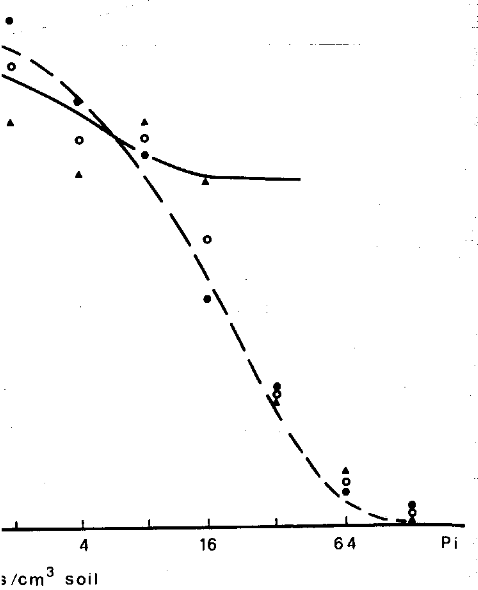


Fig. 7. Relationship between numbers of *Heterodera ciceri* and average of relative plant weights of winter sown chickpea and relative seed weights of spring sown chickpea.

Final seed weights of spring sown chickpea (Fig. 7) suggest a relation between nematode numbers and relative plant weight as in Fig. 2 for relative plant sizes of winter sown chickpea, but the observations are too variable to draw definite conclusions. The death of plants at 64 and 128 eggs/cm^3 soil four weeks before harvest indicates that spring sown chickpea also suffered "early senescence" with large nematode numbers. If winter and spring sown chickpeas can be considered to react in the same way to attack by *H. ciceri* and also relative plant weights of the latter can be considered to be about the same as relative seed weights, relative plant weights of winter sown chickpeas and relative seed weights of spring sown chickpeas can be averaged at different levels of nematode numbers to obtain a more general impression of the relation between *H. ciceri* numbers and relative yield of chickpea. These averages at 0 to 8 eggs/cm^3 soil appeared to fit reasonably well to a curve according to eq. (1) with $T = 0.22$ and $m = 0.7$ (Fig. 7), suggesting that deviations from this curve are due to experimental error. However, as weights of the spring sown chickpeas seem to vary more than those of the winter sown ones, this conclusion must be considered with caution.

Protein contents of seeds were reduced significantly ($P \leq 0.05$) at ≥ 2 eggs/cm^3 in winter sown chickpea and at ≥ 32 eggs/cm^3 soil in lentil. Relative protein contents also fitted eq. (1) with the same tolerance limits as derived for



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grain and total plant weights as in Figs 3 and 4. Minimum relative protein contents were larger, 0.75 and 0.9 for chickpea and lentil, respectively.

The relation between initial and final egg densities, *Pi* and *Pf*, of a cyst nematode species producing one new generation per year, on a plant species that is damaged by the nematode, can be described by the equation: $Pf = rfa(-^e \log q)^{-1}\,(1\text{-}q^{Pi}) + rb(1\text{-}y)Pi + b\,(1\text{-}r)Pi$ (eq. 2) (Seinhorst, 1970; 1986a) in which a = the maximum rate of multiplication, r = the proportion of the egg population (*Pi*) that is induced to hatch when plant size is not reduced by nematode attack (small population densities), f = the relative size of the food source, b = the proportion of the nematode eggs that do not hatch spontaneously in the absence of host roots and y = the relative size of the root system according to eq. (1). No good fit of a curve according to eq. (2) to the relation in Fig. 7, between *Pi* and *Pf* for spring sown chickpea, could be obtained by assuming $r = 1$, $a = 4.5$ (average ratio $PfPi^{-1}$ at $Pi = 0.25$, 0.5, 1 and 2 eggs/cm³ soil. That at $Pi = 0.125$ is clearly aberrant), for $f = y = y$ as in Fig. 3 for relative widths of winter or spring sown chickpeas, and $b = 0.65$ (as in fallow pots), and $M\,[= a\,(1\text{-}q^{Pi})\,(-^e \log q)^{-1}]$ for $P\infty = a\,(-^e \log q)^{-1} > 500$ eggs/cm³ soil. However, an acceptable fit was obtained, assuming $f = y = y$ as in Fig. 2 for relative sizes of winter sown chickpeas ($T = 0.22$ eggs/cm³ soil, $m = 0.6$ and y at 32, 64 and 128 eggs/cm³ soil as for the observed plant sizes in Fig. 2). This would mean that, as could be expected, juveniles penetrating roots during the last weeks of the experiment did not develop further into adult females and cysts.

According to Fig. 8 and Table II reproduction rates of *H. ciceri* of winter sown chickpea and lentil were about the same at small *Pi* and large: at $Pi = 0.125$, 0.25, and 0.5 eggs/cm³ soil on the average 249 times and at 0.125 and 0.25 eggs/cm³ soil even 297 times. At 0.25-0.5 eggs/cm³ soil 1 new cyst was formed per egg in the inoculum and at the two lowest initial egg numbers 1.6 cysts per egg. On lentil 2.5 cysts were formed per egg at the two lowest initial numbers. As *H. ciceri* most probably is an amphimictic species (there are many males; Table III), the ratio of numbers of juveniles that penetrated into roots to those which became cysts must have been much larger than 2. If initial numbers were not strongly underestimated the only explanation of the large rates of reproduction can be that a second generation developed on winter sown chickpea and on lentil, possibly produced by a few of the offspring of the parent generation. There is little if any evidence of a second generation in Table III. However, as the initial number in that experiment was 20 eggs/cm³ soil, the plants had, according to Fig. 5, ceased to grow by the beginning of May, after which the roots may have been unsuitable for the development of nematodes (see also Table III, 8 to 22 May). Maximum final numbers on lentil were about four times those on winter sown chickpea.

As eq. (2) has no provisions to account for activities of a second generation, fitting curves according to this equation to the data on the reproduction of *H. ciceri* on winter sown chickpea and lentil (Fig. 8) is meaningless. At large initial

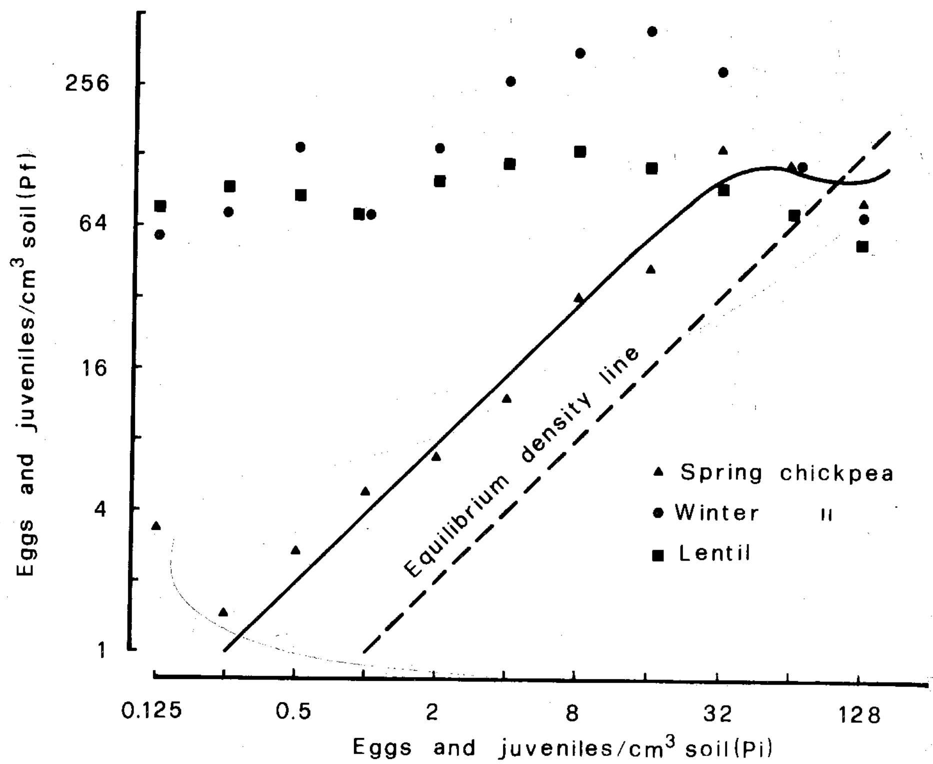
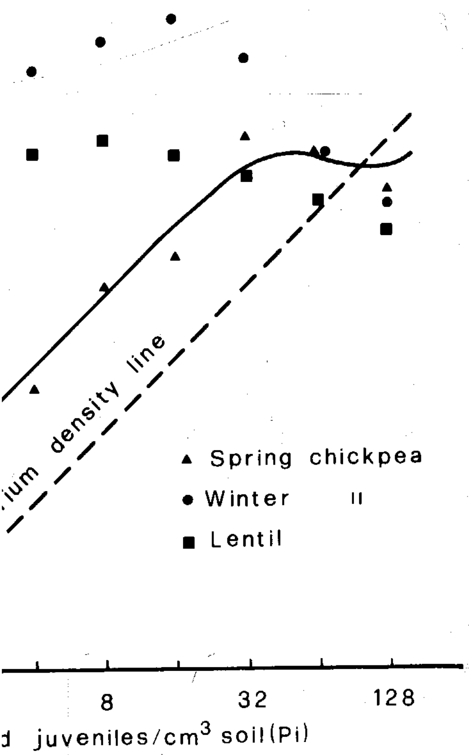


Fig. 8. Relationship between numbers of *Heterodera ciceri* at sowing (*Pi*) and at harvest (*Pf*) on spring chickpea in pots (1985) and on winter chickpea and lentil in microplots (1986).

TABLE II

Effect of population densities of Heterodera ciceri *at sowing on the numbers of cysts, per cent of new cysts, and eggs/cyst, in pots sown to spring chickpea (SC) in 1985 and in microplots sown to winter chickpea (WC) and lentil (L) in 1985-1986*

Eggs/ cm^3 soil at sowing	At harvest								
	Cysts/200 cm^3 soil			% new cysts			Eggs/cyst		
	WC	SC	L	WC	SC	L	WC	SC	L
0.125	40	8	63	99	97	99	289	106	234
0.25	46	5	84	99	90	99	312	65	226
0.5	89	6	77	99	83	99	307	105	223
1	61	9	83	97	78	97	240	126	179
2	116	12	116	96	67	96	238	140	177
4	197	27	127	96	74	94	275	110	186
8	330	47	182	95	68	92	211	165	148
16	429	83	162	93	64	81	212	123	138
32	476	258	192	87	77	69	122	134	100
64	374	252	265	68	52	54	55	97	54
128	286	430	380	15	44	36	49	46	28



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: sown to spring chickpea (SC) in 1985 and
ι (WC) and lentil (L) in 1985-1986

h a r v e s t				
% new cysts		Eggs/cyst		
SC	L	WC	SC	L
97	99	289	106	234
90	99	312	65	226
83	99	307	105	223
78	97	240	126	179
67	96	238	140	177
74	94	275	110	186
68	92	211	165	148
64	81	212	123	138
77	69	122	134	100
52	54	55	97	54
44	36	49	46	28

TABLE III

Specimens of Heterodera ciceri *found in 5 g of roots*

Stage	15/1/86	29/1	13/2	26/2	6/3	13/3	20/3	27/3	4/4	10/4	16/4	25/4	2/5	8/5	15/5	22/5	5/6
	Winter chickpea (sown 10/12/85)																
J_2	64	95	815	2429	1092	1109	937	2194	547	165	66	74	63	212	214		
J_3				30	112	806	1011	1623	245	191	137	29	21	0	0		
J_4♀					17	116	315	869	456	135	159	200	13	0	4		
♂						102	246	944	561	261	203	54	8	0	4		
♀						14	83	652	940	732	907	1058	118	42	23	4	
Cysts									7	120	1352	1429	1894	3017	1526	1900	
	Spring chickpea (sown 2/3/86)																
J_2							1046	1711	1338	1630	139	116	184	46			
J_3									250	812	378	124	43	61	46	27	
J_4♀									31	515	899	416	43	31	30	17	19
♂									8	189	450	163	49	77	45	60	48
♀										120	1660	1153	343	100	61	77	78
Cysts											46	279	1389	1343	812	915	1250

egg numbers the maximum number of eggs would be produced on the available roots [$Pf = rya\,(-{}^{e}\log q)^{-1}$]. Eq. (2) would then apply but for a reduction due to hatching of first generation eggs and a smaller maximum per unit weight of root than at smaller initial egg numbers, due to destructive action of the nematodes as described by Seinhorst (1986a) for *Globodera* on potato. Pf values at 64 and 128 eggs/cm^3 soil were indeed considerably smaller than according to eq. (2). In the absence of a host, populations declined during the experiment by 33% in 1985 and 50% in 1986.

Numbers of cysts generally increased where there were 32 or fewer eggs/cm^3 soil in the chickpea experiments and decreased with larger initial numbers (Table II), but numbers of cysts in the microplots sown to lentil increased even at the larger populations tested. With some exceptions percentages of new cysts (final cyst numbers minus initial ones expressed as percentages of final cyst numbers, assuming no old cysts were lost) were the smaller the larger the initial numbers. Egg numbers of *H. ciceri*/cyst were negatively correlated with initial population numbers on winter chickpea and lentil where initially there were one or fewer eggs/cm^3 soil and on spring chickpea 64 or more eggs/cm^3 soil. Average numbers of eggs/cyst with populations smaller than those mentioned above were 303, 228 and 119 on winter chickpea, lentil and spring chickpea, respectively (Table II).

Development of H. ciceri *on chickpea.* Second stage juveniles were found within chickpea roots by the time the plants emerged in both winter and spring chickpea (Table III). Large numbers occurred in the roots until 27 March in winter sown chickpea and until 10 April in spring sown chickpea, after which they declined to fewer than 150 per 5 g roots from mid-April. Third stage juveniles appeared 42 days after plant emergence in winter chickpea and only

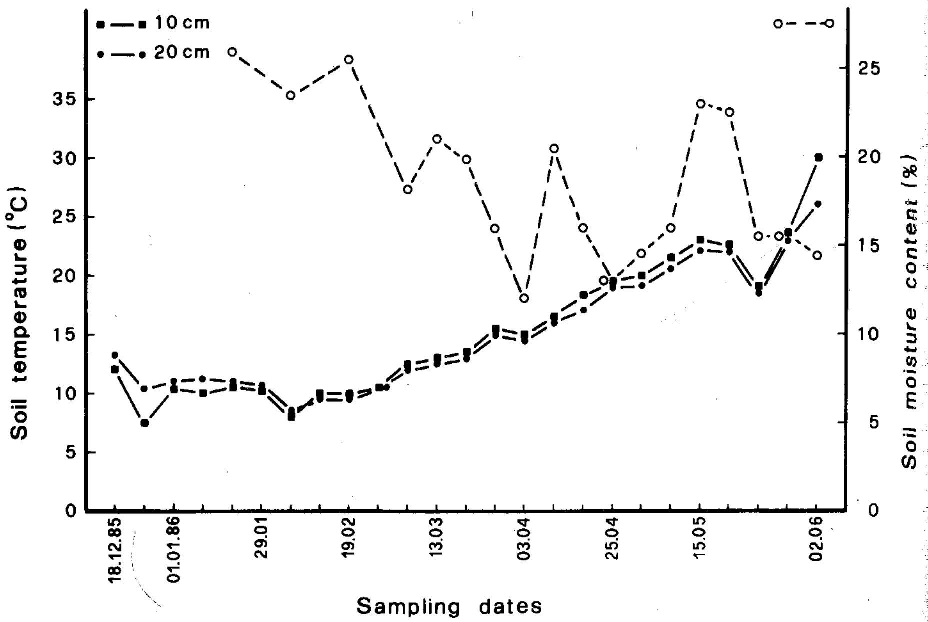
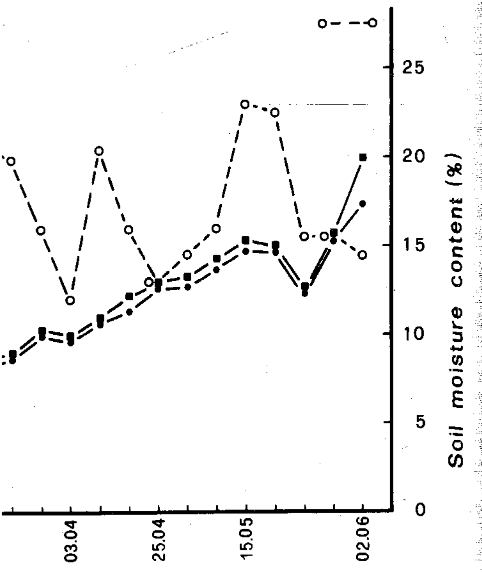


Fig. 9. Mean soil temperatures at 10 and 20 cm depth in a nearby area and soil moisture content in the microplots for the investigation of the development of *Heterodera ciceri* in 1985-1986.

15 days after plant emergence in spring chickpea. Fourth stage females and males were found in winter sown chickpea by 6 and 13 March, respectively, and occurred together with third stage juveniles on spring chickpea. Females were formed by 13 March on spring chickpea and nearly one month later on winter chickpea. However, the time required by the females to become brown cysts was 22 days (4 April) on winter chickpea and only 6 days (16 April) on spring chickpea. By that time nearly the same amount of day degrees (212-227) above 10° since plant emergence (Kaloshian *et al.*, 1986) (Table III; Fig. 4) had accumulated. On winter chickpea few eggs (11%) contained second stage juveniles by 16 April, and all eggs one month later. On spring chickpea, 11% of the eggs were embryonated on 25 April and 81% by the end of the investigation (5 June). Gelatinous matrices were produced on both winter and spring sown chickpeas, but only in one case (on winter chickpea) did one of them contain two eggs.

Numbers of cysts in the soil (Fig. 9) remained the same until 16 April and 2 May, on winter and spring chickpeas, respectively, but increased rapidly thereafter, concomitant with the formation of new cysts. The data on numbers of eggs/cyst confirmed the results of the previous experiment, since they were much larger within cysts on winter sown chickpeas. However, numbers of eggs/cyst declined slowly up to 10 April in the winter chickpea experiment and until 25 April in the experiment with spring chickpeas, and increased later on.



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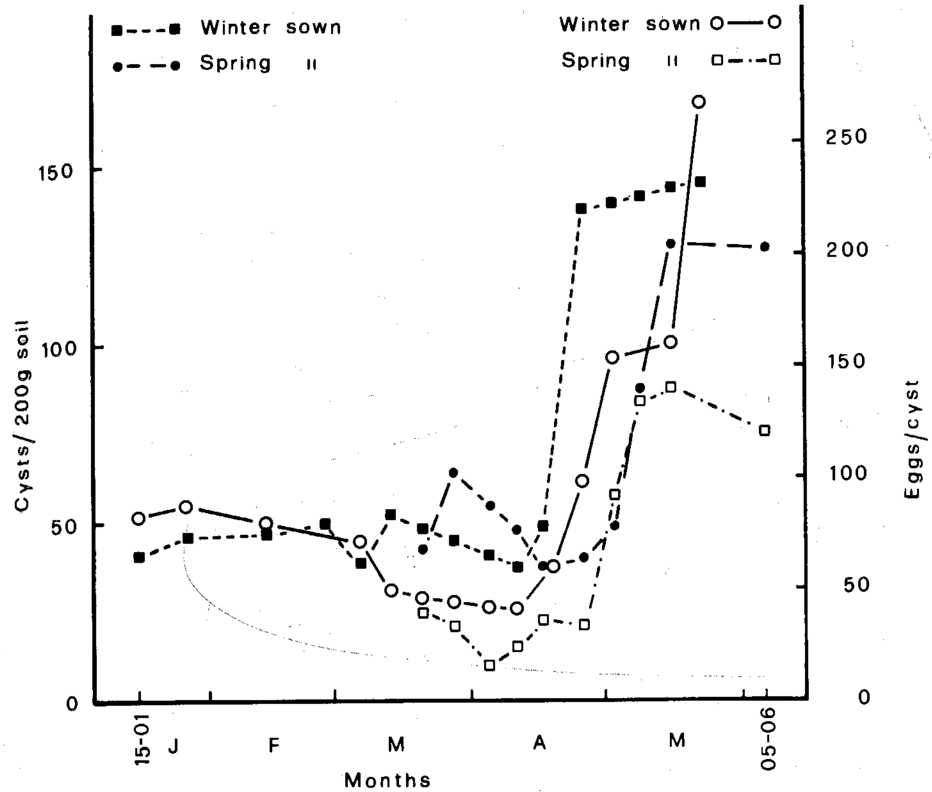

Fig. 10. Changes in the numbers of *Heterodera ciceri* cysts/200 g of soil and eggs of the nematode/cyst observed in microplots with winter and spring sown chickpea, in 1986.

DISCUSSION

Investigation of the pathogenicity of *H. ciceri* confirmed the destructive effect of this nematode, particularly on chickpea and, to a lesser degree, also on lentil. Initial tolerance limits of winter sown chickpea and lentil were 0.22 and 0.6 eggs/cm^3 soil, respectively, according to the size of the plants in the beginning of May, estimated by length times diameter square. Minimum relative sizes were about 0.5, not taking the much smaller sizes at 64 and 128 eggs/cm^3 soil into account. By the end of the experiments T had increased apparently to 1 and 2 eggs/cm^3 soil, whereas curves according to eq. (1) fitted well to all final plant and seed weights with $m = 0$ for winter sown chickpea and $m = 0.5$ for lentil. The apparent discrepancy between the observations on 5 May and those at the end of the experiments could largely be solved by fitting growth curves according to Seinhorst (1986b) to the data. They suggest that *H. ciceri* densities >10 eggs/cm^3 soil cause a condition in chickpea very similar to "early senescence" caused by *Globodera pallida* in certain potato cultivars, but not in lentil, despite yellowing of leaves at >8 eggs/cm³ soil during six to ten weeks before the end of the experiment. The good fit of curves according to eq. (1) to final plant weights is, therefore, accidental and does not mean that growth proceeded at all nematode densities according to Seinhorst's (1986b) suppositions for growth reduction by small to medium nematode populations.

The growth curves do not solve the problem of the shift of the tolerance limits entirely. Part of the cause could be experimental error (as suggested by Fig. 7), but part of it also is a limitation of growth because of exhaustion of growth factors in limited supply. The limitation of growth is then positively correlated with plant size, as is described by Seinhorst (1981b) for oats attacked by *H. avenae*, growing on a restricted quantity of water. However, only experiments under more strictly controlled conditions than those described, with determination of plant weights at regular intervals, could provide an answer.

The experiments do show why attacks in the field are more conspicuous in chickpea than in lentil. Not only is the tolerance limit of chickpea half to a third of that of lentil, but also, the growth of the former is much more strongly reduced at >10 eggs/cm³ soil than that of the latter even at 20 to 40 eggs/cm³ soil, due to "early senescence" stopping growth of chickpea and not of lentil up to several weeks before harvest time.

Another problem is which tolerance limits and minimum yields are to be used as a basis for advice on the amount of control of *H. ciceri* required for economic cultivation of chickpea or lentil. Such advice must be based on the relation between nematode numbers and yield at populations up to about eight times the tolerance limit, depending on the value of m (Seinhorst, 1982). The true tolerance limits of chickpea and lentil most probably are about 0.25 and 0.6 eggs/cm³ soil, respectively. However, if the conditions under which these crops are grown generally lead to a levelling off of difference in plant sizes with small *H. ciceri* numbers, the large tolerance limits should be used together with $m = 0$ for chickpea and about 0.5 for lentil. If the growth curves of Figs 5 and 6 applied until harvest, m for yields at 0.25 to 16 eggs/cm³ soil and of lentil at 0.5 to 32 eggs/cm³ soil would both increase to 0.7. Therefore, using the tolerance limits and minimum yields of Figs 3 and 4 in all cases would lead to an overestimation of yields at nematode densities T to $4T$ of not more than 3 to 5%. Only an understanding of the mechanism of the levelling off of yields at the end of the growing season and of the likelihood of its occurrence could provide a better basis for practical advice. In all cases severe losses of chickpea are to be expected with >10 eggs of *H. ciceri* per cm³ soil and large losses of lentil with >20 eggs/cm³ soil.

Maximum numbers of *H. ciceri* were about 300 eggs/cm³ soil on winter sown chickpeas and about 100 eggs/cm³ soil on spring sown chickpeas and on lentil. Final numbers at initial ones between 0.125 and 2 eggs/cm³ soil were the same on winter sown chickpeas and on lentil: about 100 eggs/cm³ soil. Rates of

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multiplication from these initial numbers on spring sown chickpeas were much smaller than on the other two crops: only about 4.5 times. This could mean that control of the nematode will be much easier when growing spring sown chickpeas than winter sown ones or lentil. However, average reproduction rates at small nematode densities in the field probably are larger than about 5 times.

Kaloshian *et al.* (1986) reported that some juveniles may emerge from new females. This may explain the slight increase in the numbers of second stage juveniles found within roots of winter chickpea during the first half of May and also the large reproduction rates at low initial egg numbers requiring the assumption of a second generation. However, juveniles invading late in May did not develop into older stages probably because (according to Fig. 5) the plants had started senescing. Because of this early senescing the data in Table III cannot be used to demonstrate presence or absence of a second generation.

The same sum of day degrees was required by the nematode to reach the cyst stage in winter and spring chickpea (212-227), but this sum was much smaller than the 360 day degrees reported by Kaloshian *et al.* (1986) at 20°. Greco *et al.* (1986a) stated that females of *H. goettingiana* turn into cysts sooner in late spring than earlier in the year, which resulted in many cysts having the shape and size of fourth stage females while containing few eggs. In Syria soil temperature at 10 cm depth is in the range of 20-27° in April and may have induced females to become cysts more rapidly than earlier at lower temperatures. This may also explain the smaller number of eggs/cyst observed in the spring than in the winter chickpea (Fig. 9).

We thank Dr. J. W. Seinhorst for criticism and advice, Mr. S. Hajjar for technical assistance and Mr. V. Radicci for preparing drawings and photographs.

RÉSUMÉ

Effect de Heterodera ciceri *sur la production du pois chiche et de la lentille et développement du nématode sur pois chiche en Syrie*

Des expériences on été conduites pendant la période 1984-1986 pour estimer les pertes de production du pois chiche et de la lentille causées par les infestations de *Heterodera ciceri* en Syrie et pour étudier le développement du nématode. Des pots contenant 5,5 dm³ de sol ont été encemencés avec du pois chiche de printemps et des microparcelles contenant 34 dm³ de sol on été ensemencés en 1985-1986 avec du pois chiche d'hiver ou des lentilles. Il y avait neuf pots et dix microparcelles pour chaque espèce de plante et chaque densité de population (0; 0,125; 0,25; 0,5; 1; 2; 4; 8; 16; 32; 64 et 128 oeufs de *H. ciceri*/cm³ de sol). Seize microparcelles ont été ensemencés avec du pois chiche d'hiver et quatorze avec du pois chiche de printemps pour étudier le développement du nématode. D'après la hauteur des plantes les seuils de nuisibilité étaient 0,22 et 0,6 oeufs/cm³ de sol et les productions minimum 0,6 et 0,47 pour le pois chiche d'hiver et pour la lentille, respectivement. Les seuils de nuisibilité (*T*) de 1, 1,15 et 2,51 oeufs/cm³ ont été calculés pour le poids des grains et le poids total des plantes, respectivement pour le pois chiche de printemps et d'hiver et pour la lentille. Les productions relatives minimum étaient 0 pour le pois chiche et 0,5 pour la lentille. Le contenu en protéine est diminué par les infestations du nématode. Les larves de deuxième stade du nématode ont penétré les raci-

nes du pois chiche d'hiver et de printemps lorsque les plantes ont levé. Les femelles apparurent le 13 mars et le 10 avril respectivement sur les racines du pois chiche d'hiver et de printemps, et les kystes 14 et 6 jours plus tard, après une accumulation de 212 et 227 degrés-jour. Les taux de reproduction de *H. ciceri* à densité de populations très basses étaient élevés (249-297) et presque les mêmes pour le pois chiche d'hiver et la lentille mais seulement de 4,5 pour le pois chiche de printemps.

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Accepted for publication: December 22, 1987.