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The Relationship Between Population Density of *Heterodera schachtii*, Soil Temperature, and Sugarbeet Yields

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Abstract: In two glasshouse experiments, relations between sugarbeet root dry weight (y, expressed as a percentage of the maximum dry root weight), and preplanting populations of *Heterodera schachtii* (P_i) were described by the equation $y = 100(Z)^{P_i-T}$, in which Z = a constant slightly smaller than 1, and T = the tolerance limit (the value of P_i below which damage was not measureable). T varied with temperature; it was 65 eggs/100 g soil at 23 and 27 C and 430 eggs/100 g soil at 19 C. At 15 and 31 C there was no loss of root dry weight up to the maximum preplanting populations tested. In a field experiment in the Imperial Valley the relation between root yield (y) and P_i was $y = 100\ (0.99886)^{P_i} - 100$, and the tolerance limit was 100 eggs/100 g soil.
Key Words: sugarbeet nematode, *Beta vulgaris*, pathogenicity.

Heterodera schachtii Schmidt is an important pest of sugarbeet in many parts of the world, although crop losses can be alleviated by cultural methods, crop rotation, and nematicides. Nematicides should be applied only when yield increase more than pays the cost of treatment, i.e., when the population density is greater than the economic threshold, which is influenced by soil type, soil temperature, soil moisture, and the cost of treatment.

Jones (6) found a linear relation between the preplanting density of *H. schachtii* (P_i) and sugar yield (y). Seinhorst (12) asserted that such a relation cannot hold for the whole range of nematode densities, and fitted to Jones's and other data the equation

$$y = \frac{Y_p - Y_{min}}{Y_{max} - Y_{min}} = CZ^{P_i} = Z^{P_i - T}$$

in which Y_p = yield at population P_i, Y_{min} = minimum yield at greatest population densities, Y_{max} = yield in the absence of nematodes, C = a constant slightly larger than 1, Z = a constant slightly smaller than 1 representing the proportion of food left over after one nematode has attacked, and T = the tolerance limit, i.e., the population below which no damage is done.

From this and earlier work in infested fields (4), 1,000 eggs/100 g soil is considered to be the level above which it is unwise to grow sugarbeets in peat soils in England. In Holland, management decisions are based upon six ranges of population densities; for example, 300–800 eggs/100 g soil is expected to cause moderate damage, whereas 800–1,750 eggs/100 g soil would cause severe damage. Rotation length is advised according to the population categories (3).

In laboratory experiments *H. schachtii* reproduces most rapidly at soil temperatures of 21–27 C (8, 11, 13, 14). The optimum temperature for egg hatch is 25 C (14) with the lowest recorded temperatures for hatch being 10 C for cysts *in vitro* and 18 C for free eggs (1). Upper limits are given of 35–36 C for hatch (1, 14) and 32.5 C for completion of the life cycle (13). Average soil temperatures vary greatly in the places where sugarbeets are grown but are usually below the optimum. This paper reports on two glasshouse experiments to test the influence of soil temperature on the relation between sugarbeet yields and preplanting densities of *H. schachtii.*

Soil temperatures are higher in the Imperial Valley of southern California than in most areas where sugarbeets are grown. That affects the multiplication of *H. schachtii* since five generations can be completed during the growing season, compared with one to three generations in more temperate areas (5, 13). Since the tolerance limits may also differ between the Imperial Valley and other areas, a field experiment was made to test the yields of sugarbeet in fumigated and unfumigated plots with various preplanting population densities of *H. schachtii.*

METHODS

Glasshouse experiments: Relation between sugarbeet yields and preplanting population densities of *H. schachtii* at five

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soil temperatures were tested in two experiments. Soil for both experiments was a sandy loam from Moreno, Riverside County, California. A range of population densities was obtained by mixing heavily and lightly infested soils from the same field (Expt. 1) or heavily infested soil with uninfested soil from an adjacent field (Expt. 2). The soil was dried for 2 weeks before being mixed to decrease numbers of ectoparasitic nematodes. Five preplanting population densities were tested in each experiment: 30, 177, 324, 617, and 1,205 eggs/100 g soil in Expt. 1, and 0, 504, 1,009, 2,018, and 4,035 eggs/100 g soil in Expt. 2. Soil containing each of the population densities was placed in containers 25 cm high × 20 cm in diameter in constant-temperature baths at 15 (Expt. 1 only), 19, 23, 27, or 31 C, giving 25 treatments in Expt. 1 and 20 treatments in Expt. 2. Treatments were replicated three times in Expt. 1 and four times in Expt. 2. Each container was sown with three sugarbeet seeds (variety US-H9) and reduced to one seedling shortly after emergence. After 104 days the beets were weighed, complete roots systems were dried at 49 C for 3 days, and postharvest population densities of *H. schachtii* were determined.

Field experiment: This was conducted in a Holtville clay soil near Imperial City, Imperial County, California, where *H. schachtii* had been detected during the harvest of the previous beet crop, in 1973. The field was fumigated on September 5, 1976, with Telone II at 56 1/ha, one shank/bed, 25 cm deep. Five strips 6.1 m (8 rows) wide by 366 m long were left unfumigated. The unfumigated strips were 61 m (80 rows) apart. In each of them 5 subplots 6.1 m wide by 6.1 m long were established. These were separated from each other by 55 m. Soil samples 0–30 cm deep were taken from each unfumigated plot on September 5, and the number of *H. schachtii* eggs/g soil was determined. In addition, 25 plots were established in the commercially fumigated parts of the field adjacent to the unfumigated plots.

Beets from 6.1 m of the center four rows of both fumigated and unfumigated plots were hand-harvested and weighed on May 9 and 10, 1977. Sugar percentages were calculated in the Holly Company sugar factory nearby. Soil samples 0–30 cm deep were taken from each plot on May 10 and 11, 1977, when postharvest population densities of *H. schachtii* were determined.

RESULTS

Glasshouse experiments: At 15 and 31 C, root dry weights were unaffected by preplanting populations up to the maximum tested. At 19, 23, and 27 C root dry weights were decreased by increasing preplanting populations. Data from the two experiments were combined, and regression curves (Fig. 1) were fitted according to the equation

$$y = 100\,(z)^{P_i - T} \text{ in which } P_i > T$$
$$y = 100 \qquad \text{in which } P_i < T \qquad \text{(equation 1)}$$

Tolerance limits (T) were estimated visually. Root dry weight (y) is expressed as a percentage of the mean root dry weight when $P_i < T$; Z = a constant smaller than 1. In Expt. 1, mean root dry weights, with $P_i < T$, were 11.3 g (15 C), 10.2 g (19 C),

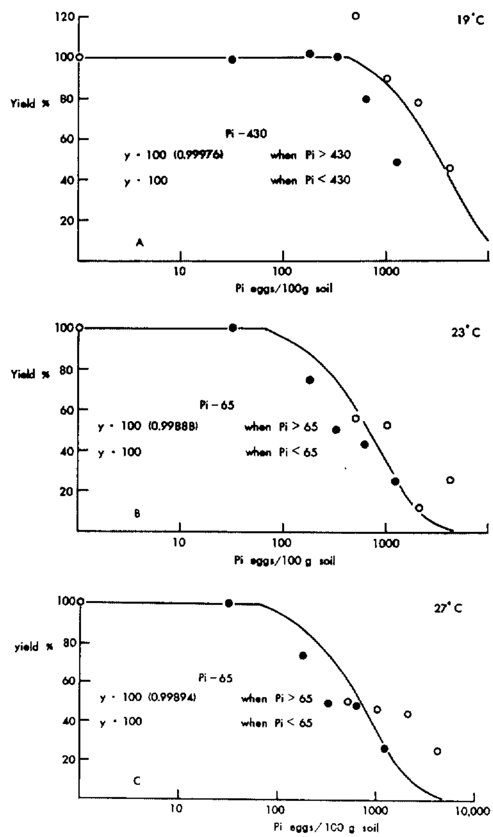

FIG. 1. (A–C). Effect of *Heterodera schachtii* on sugarbeet root dry weight at three soil temperatures. A) 19 C; B) 23 C; C) 27 C. • (Expt. 1); o (Expt. 2).

11.3 g (23 C), 10.9 g (27 C), and 11.0 g (31 C); in Expt. 2, mean dry root weights, with $P_i < T$, were 18.9 g (19 C), 23.4 g (23 C), 24.1 g (27 C), and 20.0 g (31 C).

Postharvest population densities of *H. schachtii* were variable, probably because the nondraining, impermeable containers were difficult to water evenly. Population increase (P_f/P_i, Table 1) was usually greatest at 23 C, less at 27 C, and least at 19 C. Populations declined by about 50% at 15 C in Expt. 1 and 90% at 31 C in Expt. 2, indicating that although some eggs hatched, the life cycle was not completed. In Expt. 1 at 31 C, new cysts were seen on roots, and the number of eggs was 2 to 3 times as great. The lack of development in Expt. 2 is probably due to variation in the temperature of the 31 C hot-water baths, since the upper limit for development is around 32.5 C (13).

Field experiment: Neither root yield nor sugar percentage was significantly affected by soil fumigation (mean yield in unfumigated plots was 48.2 tonnes (metric)/ha at 16.6% sugar; mean yield in fumigated plots was 48.8 tonnes/ha at 16.4% sugar). The tolerance limits in both fumigated and unfumigated plots were estimated as 100 eggs/g soil. The regression equation in unfumigated plots was:

$$y = 100\,(0.99886)^{P_i - 100} \text{ in which } P_i > 100$$
$$y = 100 \text{ in which } P_i < 100$$
(equation 2)

The correlation coefficient was 0.873 ($P < 0.001$). The root yield (y) is expressed as a percentage of the yield in plots where $P_i < T$. Sugar percentage was unaffected by increasing *H. schachtii* populations.

The numbers of *H. schachtii* 0–30 cm deep in unfumigated plots increased greatly during the growing season. The mean preplanting population density (P_i) of 200 eggs/100 g soil increased to a mean postharvest population density (P_f) of 2,571 eggs/100 g soil. Multiplication rates were greatest at small preplanting population densities; at large preplanting densities (> 600 eggs/100 g soil) the poorly yielding damaged plants were unable to support large populations of *H. schachtii* throughout the season (Table 2).

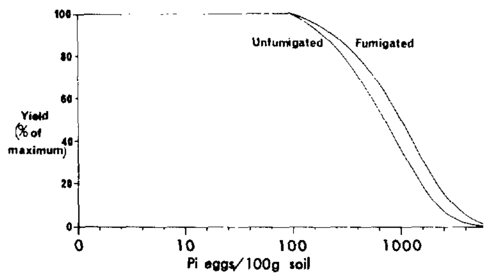

FIG. 2. Effect of *Heterodera schachtii* on sugarbeet yield in a field experiment, Imperial County, California.

TABLE 2. Increase rates (P_f/P_i) for *H. schachtii* in the field experiment.

P_i range (eggs/100 g soil)	No. of plots	P_i mean (eggs/100 g soil)	P_f mean (eggs/100 g soil)	Increase rate
3–100	7	25	1476	x 59
101–600	8	297	5512	x 19
> 600	2	1216	3233	x 3

TABLE 1. Increase rates (P_f/P_i) for *H. schachtii* on sugarbeet in two glasshouse experiments.

Preplanting population density (eggs/100 g soil)	Expt. no.	Increase rate				
		15 C	19 C	23 C	27 C	31 C
0	2	—	—	—	—	—
30	1	1.1	22.3	48.7	75.8	1.7
177	1	0.6	7.0	33.5	30.8	2.9
324	1	0.6	4.0	18.1	7.9	3.3
504	2		4.7	15.0	8.0	0.2
617	1	0.4	1.4	4.3	2.2	2.3
1009	2		2.2	7.6	6.7	0.1
1205	1	0.4	7.9	10.9	9.3	3.5
2018	2		0.9	1.5	1.2	0.1
4035	2		0.7	0.5	0.9	0.1

DISCUSSION

In the glasshouse experiments the tolerance limit T was influenced by soil temperature and was lowest (65 eggs/100 g soil) at 23–27 C. That is consistent with the results of the field experiment, in which the tolerance limit was 100 eggs/100 g soil and the average soil temperature at 15 cm was around the optimum for nematode development for much of the growing season (Table 3). The tolerance limit at 19 C was 430 eggs/100 g soil in the glasshouse experiments, and the nematodes failed to develop or harm plants at 15 C; those soil temperatures are more nearly those in temperate climates (Table 3). In England, where average monthly temperatures rarely reach the optimum for *H. schachtii,* the tolerance limit is 1,000 to 2,000 eggs/100 g soil (7, 12), and in Holland the economic threshold is 300 to 800 eggs/100 g soil (3).

If Eq. 1 adequately described the relationship between P_i and y, the economic threshold T_E (at which the value of the increased yield from an effective nematicide treatment becomes greater than the cost of the treatment) is given by:

$$T_E = \left\{ \log \left(\frac{x - A/B}{x} \right) \times \frac{1}{\log Z} \right\} + T$$

in which A = the cost of the treatment (\$/ha) and B = the price of sugarbeet (\$/tonne). In the Imperial Valley, if Eq. 2 is generally applicable (i.e., Z = 0.99886 and T = 100), the price of sugarbeet (B) is \$30/tonne, the cost of an effective nematicide treatment (A) is \$90/ha, and the potential yield (x) is 62 tonnes/ha, then the economic threshold T_E is 143 eggs/100 g of soil. Further experiments are needed to be certain that Eq. 2 is generally applicable to the Imperial Valley.

The failure of soil fumigation to increase yields significantly in the field experiment was probably because too little fumigant was applied. In other field experiments in the Imperial Valley, fumigation at greater rates gave large yield increases when the preplanting population density of *H. schachtii* exceeded 200 eggs/100 g soil (2, 9, 10).

Seasonal variations in the economic threshold and nematode increase rates are likely to be smaller in the Imperial Valley (where most soil moisture is provided by controlled irrigation and soil temperatures follow a similar pattern every year) than in areas with less predictable climates. Hence, in that area, the greatest difficulties in applying information on economic thresholds and rates of population increase and decline to programmes of nematode control by crop rotation or the use of nematicides result from erratic distribution of the nematode. Nevertheless, by considering large fields as several smaller sections (e.g., 4 ha each), and by sampling each section individually, it may be possible to make valid predictions on the amount of yield loss which would result from the average population density occurring in each section and hence be able to choose the most economical control measure to adopt.

TABLE 3. Soil temperatures throughout the growing season in southern California and England.

Broom's Barn Experimental Station, Suffolk, England		Imperial Valley Field Station, Imperial County, California	
Month	Temperature (°C) at a 10-cm depth 10 year mean 1965–74	Month	Temperature (°C) at a 15-cm depth 1975–76
March	3.9	September	32.0
April	6.9	October	27.7
May	11.7	November	20.3
June	15.5	December	14.5
July	16.7	January	15.0
August	15.9	February	18.4
September	13.4	March	19.7
October	9.7	April	15.6
November	4.9	May	28.4
		June	35.0

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