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The effect of some systemic nematicides on the control of Heterodera rostochiensis in the field

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Abstract

A stochastic model to estimate the multiplication of *Heterodera rostochiensis* at low densities ('maximum' multiplication) in field experiments was developed. This was done to analyse the results of four trials performed to investigate the effect of some systemic nematicides on this multiplication.

Varying effects were found using aldicarb in three years while methomyl and oxamyl did not do better. A comparison between phenamiphos and phensulfothion yielded no significant differences.

Introduction

In the Netherlands, potatoes must be grown in rotation, with potatoes at safe intervals, with or without chemical control of the nematodes. The multiplication of *H. rostochiensis* on a susceptible potato variety should be (more than) offset by the reduction of the nematodes during the growth of resistant potatoes, crops other than potatoes, and by chemical treatment. This system aims at a reduction of the nematode populations to low densities.

In studies on the rate of multiplication, density dependency appeared to be an important phenomenon. Seinhorst (1970) summarized and described the first experiments on this subject in nematology by Jones in 1956 with *H. schachtii*, Seinhorst in 1966 with migratory nematodes and Den Ouden in 1967 with *H. rostochiensis*. Here intraspecific competition as the cause of a gradually decreased rate of multiplication, a ceiling level of final densities and the concept 'maximum rate of increase' are mentioned. This maximum rate of increase, the multiplication at low nematode densities, is a standard by which results of the control of *H. rostochiensis* are calculated and accurate estimation of this factor is desired.

Intensive sampling is not feasible in practice because of the enormous amount of work involved and the chance of disturbing small experimental plots by initial sampling. So only rather inaccurate estimates on initial and final nematode densities can be obtained. In the analysis of the data of the experiments described here, an attempt has been made to develop a method for the evaluation of observations in these and similar field trials.

Previous pot trials with aldicarb and methomyl gave varying but generally good effects depending on ways of application (Kaai and Den Ouden, 1967; Den Ouden, 1968a).

These results led to field trials on the effect of aldicarb and methomyl in 1968 and 1969. In 1970 phensulfothion and phenamiphos were examined and in 1971 the effect of oxamyl was compared with that of aldicarb.

Layout of experiments

The experiments were done on loam with approximately 25 % of the particles smaller than 2 μm and nematode densities ranging from 0–140 eggs/g of soil. First, large areas were sampled to select sites where approximately 75 % of the area had densities of 0–8 cysts per kg of soil and 25 % had higher densities.

In 1968, the experiments were on plots of 20 m × 1.5 m or of 10 m × 1.5 m (Fig. 1). These were subdivided into subplots of 1 m × 1.5 m for separate sampling. In 1969, 1970 and 1971 each treatment was carried out on plots of 1.5 m × 1 m and the treatments were combined in blocks so that they were spread equally over the field with the varying nematode density. In spring and autumn an area 1.50 m × 0.75 m in the centre of the plots was sampled (Fig. 1) by taking 80 cores of approximately 20 g of soil from the layer 0–20 cm for each sample. Nematode densities were determined on 1500 g of the well-mixed sample, by Seinhorst's method for the elutriation of cysts

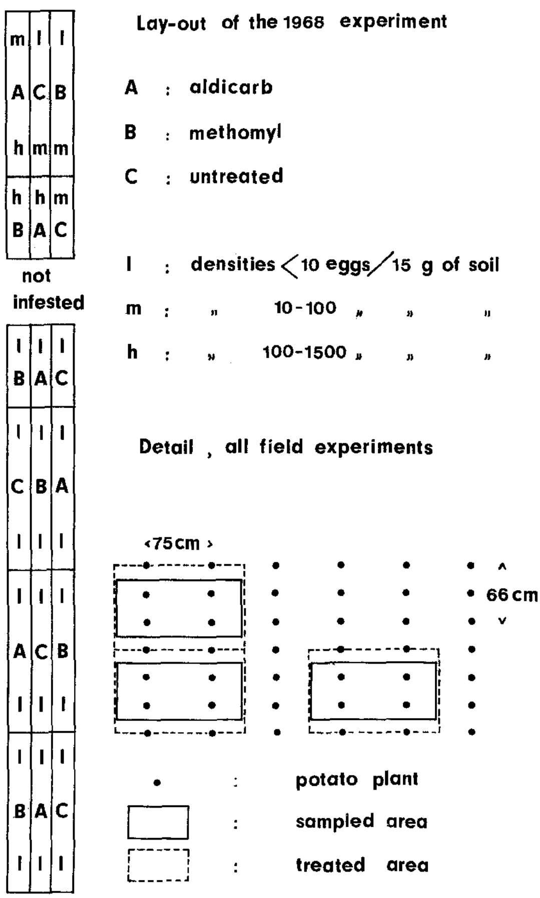

Fig. 1. Layout of the experiment.

Fig. 1. Proefveldschema.

Table 1. List of treatments and expected effectivity ranking[1].

Code	Nematicide	Formulation	Dosis a.i. (g/m²)	Method of application and time of harvest	Year	Expected rank of effectivity
1	aldicarb	Temik 10 G	0.5	band 20-cm wide, early September	1969	4
2	aldicarb	Temik 10 G	0.5	broadcast, early Sept.	1968/1969/ 1971	2
3	no	–	–	–	1968/1969/ 1970/1971	5
4	methomyl	Lannate 90% W.P.	2.0	band 20-cm wide, early September	1969	4
5	phenamiphos	Nemacur P. 5% granules	2.5	broadcast, early Sept.	1970	2
6	phensulfothion	Terracur P. 5% granules	2.5	broadcast, early Sept.	1970	4
7	oxamyl	Vydate 25% e.c.	0.7	broadcast, early Sept.	1971	2
8	methomyl	Lannate 5% granules	0.5	broadcast, early Sept.	1968	3
9	aldicarb	Temik 10 G	0.5	broadcast, mid Juli	1971	1

[1] These treatments are not authorized for application in potatoes in the Netherlands.

Tabel 1. Lijst der behandelingen en verwachte volgorde van effectiviteit.

(Seinhorst, 1964) and Bijloo's method for determining the egg content of *Heterodera* cysts, modified by Seinhorst and Den Ouden (1966).

Approximately 100 samples of each treatment were examined per field. The soil was treated and potatoes were planted very shallow (cv. 'Bintje') on the same day. The different treatments are shown in Table 1. The chemicals were mixed with the soil only when the potatoes were hilled; therefore no nematicide whatsoever was introduced mechanically into the soil below the base of the hills.

Analysis of the data

Model

The following notation and assumptions (per experiment) are proposed.

T_j = the jth treatment,

X_{ij} = the real nematode density on the ith plot is treated with T_j, at the start of the experiment,

Y_{ij} = ditto, at the end of the experiment,

$\underline{x}_{ij}$ = the random variable 'the nematode density in a random soil sample taken from the ith plot treated with T_j at the start of the experiment',

$\underline{y}_{ij}$ = ditto, at the end of the experiment,

x_{ij} = the value actually found of $\underline{x}_{ij}$ in a particular experiment,

y_{ij} = ditto, of $\underline{y}_{ij}$,

$E(\underline{z})$ = the expected value of a random variable $\underline{z}$,

var $(\underline{z})$ or σ_z^2 = the variance of the random variable $\underline{z}$,

c.v.$(\underline{z})$ or $\sigma_z/E(\underline{z})$ = the coëfficient of variation of a random variable $\underline{z}$,

σ_z = the standard deviation of a random variable $\underline{z}$.

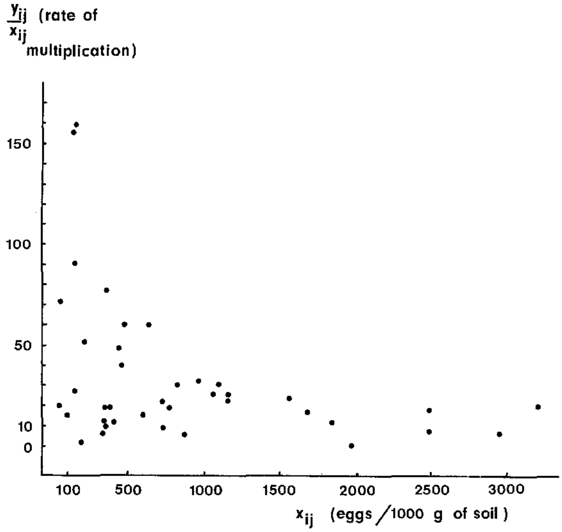

Fig. 2. The relation between the ratios y_{ij}/x_{ij} (rate of multiplication) and the values of x_{ij} (initial density). Treatment: 5.

Fig. 2. Het verband tussen y_{ij}/x_{ij} (vermenigvuldigingsgraad) en de waarden van x_{ij} (begindichtheid). Behandeling: 5.

A basic assumption is that the multiplication of the nematodes in the particular experiments can be described deterministically as follows: For initial densities X_{ij} smaller than some boundary value X_b, the ratio between the final density Y_{ij} and X_{ij} is a factor C_j (the maximum multiplication) which is dependent only on treatment T_j and not on the value of X_{ij}. For X_{ij} greater than X_b, the multiplication rate decreases (see Fig. 2) with increasing X_{ij}. Hence: $Y_{ij} = C_j. X_{ij}$ for all $X_{ij} < X_b$.

Another basic assumption is that the multiplication rate is only influenced by differences between treatments and not by those between plots. The following discussion only applies to the values of X_{ij} that are smaller than X_b, since there is no usable model that describes the relation between Y_{ij} and X_{ij} for the whole range of X_{ij} values. A stochastic model for the data is then:

$\underline{y}_{ij} = C_j. X_{ij}. \delta_{ij}$

$\underline{x}_{ij} = X_{ij}. \gamma_{ij}$

where δ_{ij} is a random term generated by two factors:

1. a random error introduced during the application of the treatment to the plot, and
2. the random sampling procedure.

All δ_{ij}s are mutually independent and have 1 as the expected value (over the whole experimental procedure).

Var (δ_{ij}) is unknown but is undoubtedly a function of X_{ij} (previous experience). Also the type of the distributions of the δ_{ij}s is unknown. γ_{ij} is a random term generated by the random sampling procedure.

The properties of the γ_{ij}s are the same as those of the δ_{ij}s with exception of generation by (1).

All δ_{ij}s and γ_{ij}s are mutually independent.

Considering the ratio $\underline{y}_{ij}/\underline{x}_{ij}$, its expected value and its variance can be approximated by:

$E(\underline{y}_{ij}/\underline{x}_{ij}) = C_j[1+\{\text{c.v.}(\underline{x}_{ij})\}^2]$

$\text{var}\ (\underline{y}_{ij}/\underline{x}_{ij}) = C_j^2 \times f\{\text{c.v.}\ (\underline{y}_{ij}),\ \text{c.v.}\ (\underline{x}_{ij})\}$

where f is an increasing function of both c.v. $(\underline{y}_{ij})$ and c.v. $\underline{x}_{ij})$. Hence, $\underline{y}_{ij}/\underline{x}_{ij}$ is a positively biased estimator of C_j and the bias decreases with decreasing c.v. $(\underline{x}_{ij})$. As can be seen in the graphs of y_{ij}/x_{ij} plotted against x_{ij}, (see below) the bias decreases with increasing x_{ij}, which is a logical result. The variance will also decrease with increasing X_{ij}. To check this reasoning, y_{ij}/x_{ij} was plotted, per experiment per treatment, against x_{ij} as estimate of the unknown X_{ij}. This resulted in a series of similar graphs of which the one in Fig. 2 is a typical example. These graphs seem to support the above reasoning.

Analysis

The ratios y_{ij}/x_{ij} were chosen for the analysis of the data because the complications that result from this choice are, according to our judgment, more manageable than those that result from other choices (e.g. by using logs of x and y). The procedure can be described as follows:

1. The data were discarded from the plots with $x_{ij} = 0$ and from the plots where it was suspected that X_{ij} was greater than X_b. Though it is hard to evaluate the merits of such a selection the data were screened rigorously in order to retain only those data fitting the stochastic model derived on page 132.

Graphs of y_{ij}/x_{ij} against x_{ij} were used for a second screening of the data. We chose boundary value b_j so that for all the plots with $x_{ij} \geqslant b_j$, the plotted relationship was practically horizontal. The following equation, based on preceding arguments should hold for these plots:

$E(\underline{y}_{ij}/x_{ij}) = C_j[1 + \{\text{c.v. } (\underline{x}_{ij})\}^2]$ where $\{\text{c.v.}(\underline{x}_{ij})\}^2$, hence the bias, is reasonably constant and practically negligible.

2. With the remaining data the factors C_j were estimated and differences between C_js tested for each experiment as if the experiments had been completely randomized (see the basic assumption on page 132). Thus each C_j was estimated by averaging the ratios y_{ij}/x_{ij} of the remaining plots (Table 2).

Table 2. A: Estimates of maximum multiplication, determined according to the method described on page 133. B: Estimates of maximum multiplication as a percentage of 'untreated'.

Year of experiment		Treatments (see Table 1)								
		1	2	3	4	5	6	7	8	9
A	1968		13	33					18	
	1969	4	3	6	4					
	1970			33		18	23			
	1971		3	14				4		2
B	1968		40	100					54	
	1969	73	55	100	77					
	1970			100		56	70			
	1971		21	100				26		13

Tabel 2. A: Schattingen van de maximum vermenigvuldiging verkregen met de op blz. 133 beschreven werkwijze. B: Schattingen van de maximum vermenigvuldiging per proef uitgedrukt als percentage van die op onbehandelde veldjes.

Table 3. Comparison of the treatments by Wilcoxon's two samples location test.

Year	Treatment A versus treatment B	Number of observations of treatment A	Number of observations of treatment B	Alternative hypothesis (see expected ranks, Table 1)	P value
1968	2 vs 3	9	13	$2 < 3$	≈ 0.06
	2 vs 8	9	13	$2 < 8$	> 0.10
	3 vs 8	13	13	$3 > 8$	0.10
1969	1 vs 2	11	11	$1 > 2$	> 0.10
	1 vs 3	11	10	$1 < 3$	> 0.10
	1 vs 4	11	7	$1 \neq 4$	> 0.20
	2 vs 3	11	10	$2 < 3$	≈ 0.10
	2 vs 4	10	7	$2 < 4$	≈ 0.05
	3 vs 4	10	7	$3 > 4$	> 0.10
1970	3 vs 5	6	16	$3 > 5$	≈ 0.15
	3 vs 6	6	11	$3 > 6$	> 0.10
	5 vs 6	16	11	$5 < 6$	> 0.10
1971	2 vs 3	13	15	$2 < 3$	< 0.001
	2 vs 7	13	12	$2 \neq 7$	> 0.20
	2 vs 9	13	18	$2 > 9$	0.10
	3 vs 7	15	12	$3 > 7$	< 0.001
	3 vs 9	15	18	$3 > 9$	< 0.001
	7 vs 9	12	18	$7 > 9$	≈ 0.03

Tabel 3. Vergelijking van de behandelingen door middel van de toets van Wilcoxon.

The treatments were compared by testing them in pairs with Wilcoxon's twosample location test (Table 3).

The relation between the nematode densities before treatment and after harvest of the potatoes is shown in Fig. 3 for one of the 14 treatments only.

Fig. 2 shows that the variation in the estimates of the maximum multiplication at low initial densities is very high.

Discussion

In 1968, 1969 and 1971, aldicarb spread over the soil before planting reduced maximum multiplication to 40, 55 and 21 %, respectively (Table 2, B). In an earlier experiment on the same soil type (Den Ouden, 1968a) multiplication was reduced to 16 %. In 1969 aldicarb, applied before planting in a 20-cm wide band, caused a smaller reduction. However, the difference between the methods of application was not significant (Table 3).

In 1968, methomyl resulted in a smaller reduction than did aldicarb, when both were applied broadcast and at the same dosage. However, the low number of usable data and their high variation resulted in a difference which was not significant even at the 10 % level (Table 3). Also, in 1969, a band application of methomyl at a dosage four times as high did not work better than aldicarb.

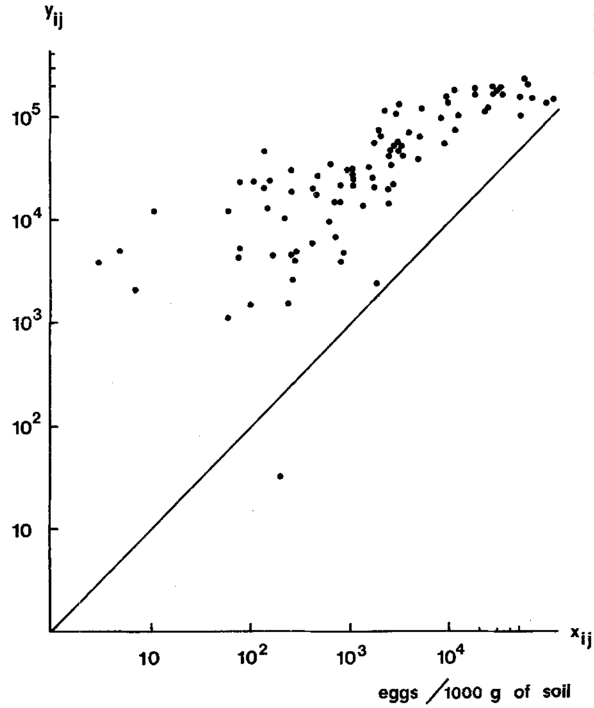

Fig. 3. The relation between the sample values of the nematode densities prior to treatment (x_{ij}) and after harvest of the potatoes (y_{ij}). Treatment: 5.

Fig. 3. Het verband tussen de uitkomsten der bemonsteringen uitgevoerd voor het planten (x_{ij}) en na de oogst van de aardappelen (y_{ij}). Behandeling: 5.

The data obtained with aldicarb in 1971 showed better results than those found in the 1968 and 1969 experiments. Oxamyl was almost as effective as aldicarb. The reduction of the multiplication by aldicarb seemed to be greater in the early harvested fields than in the late ones. However, this comparison is not allowed because previous work (Den Ouden, 1968b) has shown that the multiplication on untreated, early-harvested fields was in two cases (on sand and loam soil) about 33% lower than on late-harvested ones.

The treatment with phenamiphos in 1970 resulted in a reduction of the multiplication comparable with that caused by aldicarb in 1969. The variable results with aldicarb in three different years make this comparison risky. Phenamiphos as a purely systemic nematicide is less effective than aldicarb (Den Ouden, 1971a); comparison of phenamiphos and oxamyl in vitro and in sandy soil shows a lower nematicidal effect and persistence of the latter (Bunt, 1975). The effect of phensulfothion was less than that of phenamiphos though the difference was not significant, even at the 10% level, in a onesided test (Table 3).

It is assumed that the 'maximum' multiplication is 50 times (a rather high figure); that the decrease of the population under crops other than potatoes is 35% (leaving 65% of the original population) (Huysman, 1961; Den Ouden, 1960) and 80% with resistant potatoes (Huysman, 1957). After four years without chemical control and a crop rotation of once susceptible potatoes, once resistant potatoes and twice a crop other than potatoes, a nematode density would be obtained equal to $50 \times 0.65^2 \times 0.2 = 4 \times$ the original one which should be sufficiently low to result in 'maximum' multiplication. Chemical control during this period should then at least reduce the population to 1/4 to maintain the status quo. This reduction cannot be achieved with certainty with systemic nematicides applied by the methods described above. In case of a lower degree of multiplication, a lower final figure would be found and then a smaller reduction of the multiplication could be accepted. However, multiplications higher than 25 × have been shown to occur in more than 25% of 132 observations on different soils (Den Ouden, 1971b).

Experiments with systemic nematicides in England by Whitehead et al (1972, 1973a, b) on fields with rather high nematode densities resulted in a greater reduction of the multiplication than the experiments described above. This is presumably caused by the 15 cm-deep rotavation after the application of the chemicals; this is confirmed by the pot trials mentioned in the introduction and by another greenhouse experiment (Den Ouden, 1977) where aldicarb was mixed in or applied to the soil in different ways. Furthermore it was found (Den Ouden, 1975) that the effect of aldicarb applied on the surface of pots at higher initial densities was density dependent and that the effect of the treatment on the multiplication decreased strongly with depth in the pots. The degree of density dependency changes with the dosage of the chemical.

Samenvatting

Veldproeven over de werking van enkele systemische nematiciden bij de bestrijding van Heterodera rostochiensis

Voor het bepalen van de vermenigvuldiging van *Heterodera rostochiensis* bij lage dichtheden (de 'maximum' vermenigvuldiging) in veldproeven werd een stochastisch model ontwikkeld. Dit werd gedaan ten behoeve van de analyse van de resultaten uit vier proeven welke zijn uitgevoerd om de werking van enige systemische nematiciden op deze vermenigvuldiging te onderzoeken.

Het effect van aldicarb was verschillend in drie jaren terwijl methomyl en oxamyl niet beter werkten dan aldicarb. Een vergelijking tussen phenamiphos en phensulfothion leverde geen significant verschil op (Tabel 1, 2, 3).

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