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PRINCIPLES AND POSSIBILITIES OF DETERMINING DEGREES OF NEMATODE CONTROL LEADING TO MAXIMUM RETURNS

I *Protection of one crop sown or planted soon after treatment*

by
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Although methods to prevent crop losses caused by nematode attack have been investigated and practiced for many years the economics of nematode control and the factors governing it have not yet been analyzed to a great extent. As a result, several treatments are known that decrease nematode populations and increase crop yields, but there is no way of ascertaining, even theoretically, how much treatment is required in a given case to obtain the maximum return. It is quite possible that, even if a system was known for the calculation of treatments giving maximum returns, the necessary estimations of values of the various parameters would not be accurate enough to make practical use of it. However, only if a system is identified can values of parameters and their variation be investigated. Therefore, an attempt is made here to describe the quantitative relationships between nematode density, treatment and yield. Our knowledge of the relevant parameters and their estimation in practical cases is discussed.

Crops are protected against damage by nematodes by decreasing the density of nematode populations before the crop to be protected is sown or planted or by preventing the nematodes from feeding on the plants. Nematode populations are decreased by treating the soil with contact nematicides or by practicing crop rotation with non hosts or resistent plants. Plants are protected against attack by treating them with so called systemic nematicides (generally by applying these to the soil at sowing or planting time). In both cases the effect of the control measures depends on the effort made e.g.

quantity of nematicide applied (Seinhorst, 1973a; Kaai, 1972, 1973; Weischer, 1969) and the nunmbers of seasons host and non host crops are grown.

Control measures may aim to protect a single crop from damage in a given year (generally by a chemical treatment applied shortly before sowing or planting) or to balance the multiplication of a nematode on one or more host crops in a rotation (by crop rotation and/or chemical treatment).

Protection of one crop

To find the quantity of nematicide to be applied to obtain the greatest return following the application of a crop sown soon after treatment, it is necessary to know the relation between cost of application of different dosages of a chemical and the expected gain in yield. These two variables are related through a chain of relationships, that all can be considered separately both theoretically and in experiments:

1) The (average) density of the nematode to be controlled in the field to be treated.

2) The relation between average density of the nematode to be controlled and the yield of the crop to be protected in the field if untreated (to determine the loss to be expected without treatment).

3) This relation (2 above) after treatment. Most probably 2 and 3 do not differ very much (which will further be assumed). However, the possibility that the treatment influences the activity of the surviving nematodes cannot be ruled out (Seinhorst, 1967).

4) The relation between dosage of the chemical and effect on the density of the nematodes to be controlled in the field to be treated.

5) The relation between dosage of the chemical and yield increase or decrease other than through killing nematodes.

If the increase of the nematode population on host crops is to be balanced at an economically optimum level the relation between density of the nematode to be controlled and its rate of multiplication (or decrease) on the different crops in the rotation must also be known.

Of all these only the average density of a nematode in a field can still be determined shortly before the treatment is to be made, All the relations mentioned must be known from previous experiments which must also provide a base for sufficiently accurate estimations of parameters in these relations relative to the field to be treated.

The average nematode density in a field and its relation to expected yield

Determining the average density of a nematode population in a field and its relation to expected yield at different distributions of the nematode is discussed by Seinhorst (1973[b]). If the relation between nematode density P and yield expressed as a proportion of the yield in the absence of nematodes y is given by the equation $y = m + (1 - \mathrm{m})\, z^{P-T}$ for $P \geq T$ and $y = 1$ for $P \leq T$ (1), z^{-T} being 1.05 to 1.1 and m a factor < 1, mostly ≤ 0.5, then the relation between the average nematode density in a field P (av) and relative yield y (av) is adequately described by the equation $y\,(\mathrm{av}) = m_i + (1 - m_i)\, z^{\mathrm{P\,(av)} - 0.7\,T}$ for $P\,(\mathrm{av}) \geq 0.7\,T$ and $y = 1$ for $P\,(\mathrm{av}) \leq 0.7\,T$ (2) if only $P\,(\mathrm{av}) < 100\,T$ (Seinhorst, 1973[b]). In this equation m_i is not a true minimum yield as in equation (1) but a constant of the proper value to make equation (2) fit to actual relations between P (av) and y (av) for a limited range of values of P (av). Therefore, if the relevant values of m_i, T and P (av) can be estimated with a sufficient degree of accuracy and, moreover, the relation between dosage of a nematicide and mortality of the treated nematode population is known, the maximum dosage of the nematicide that is economically justified can be found (provided side effects of the treatment on yield are negligible).

The relation between dosage of nematicide, rate of survival of nematodes and yield

According to Seinhorst (1973[a]) the relation between log dosage c of a nematicide and probit mortality p of nematodes is given by the equation $p = a\,c + b$. In this equation a (the dosage increase efficiency) often is close to 0.5 probit unit per doubling of the dosage (increase of log dosage by 0.30) but may be as high as 1 probit unit per doubling of the dosage. To calculate relations between increase of dosage of nematicide and gain in yield, a dosage killing 75% of the nematodes was assumed as the unit dosage. Calculations were then made for a range of dosages starting at 0.5 and increasing by steps of 0.5 unit, for $a = 0.5$ and $a = 1$ and of a range of values of $P = 2^x T$, x *being* 0, 1, 2 ....7. The percentage survival after treatment with each of the dosages of nematicide can be found in Fig. 1. By multiplying the values of P by this percentage the density after treatment expressed as a multiple of T is found and the corresponding yield can then be found with the help of equation (1) or equation (2). Figs. 2 and 3 give the relative yields obtained by different

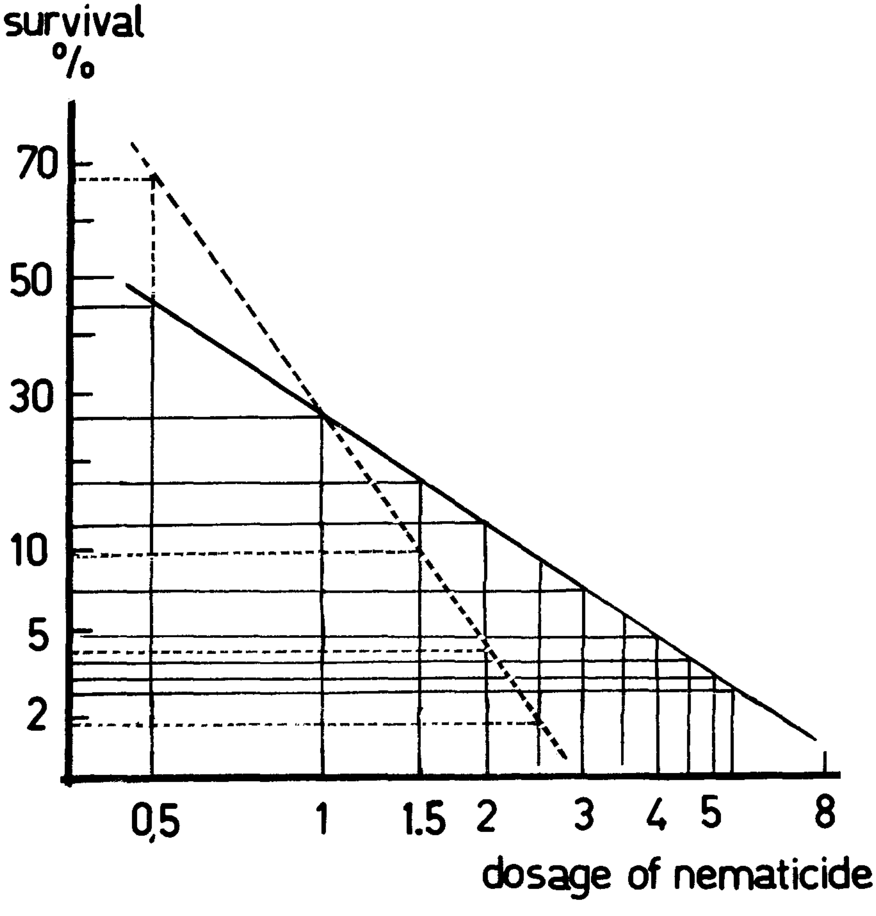

Fig. 1 - Relation between log dosage of nematicide and probit survival. Dosage increase efficiency (d.i.e.) solid line: 0.5 probit unit per doubling of the dosage, broken line one probit unit per doubling of the dosage.

dosages treating different initial densities (expressed as mutiples of T) assuming $a = 1$ (Fig. 2) and $a = 0.5$ (Fig. 3). From these figures the gain to be obtained (in % of the yield in the absence of nematodes) by increasing a given dosage of nematicide by half a unit dosage was derived for different initial nematode densities (Figs. 4 and 5). If the value of the crop expected in the absence of nematodes is known, the dosage of nematicide that still is economically justified can be determined. Apparently the gain to be obtained by increasing the dosage of nematicide by half a unit dosage is smaller the closer the yield is to that in the absence of nematodes. Also it is particularly unprofitable to decrease high nematode densities to densities close to the tolerance limit by a conventional chemical treatment.

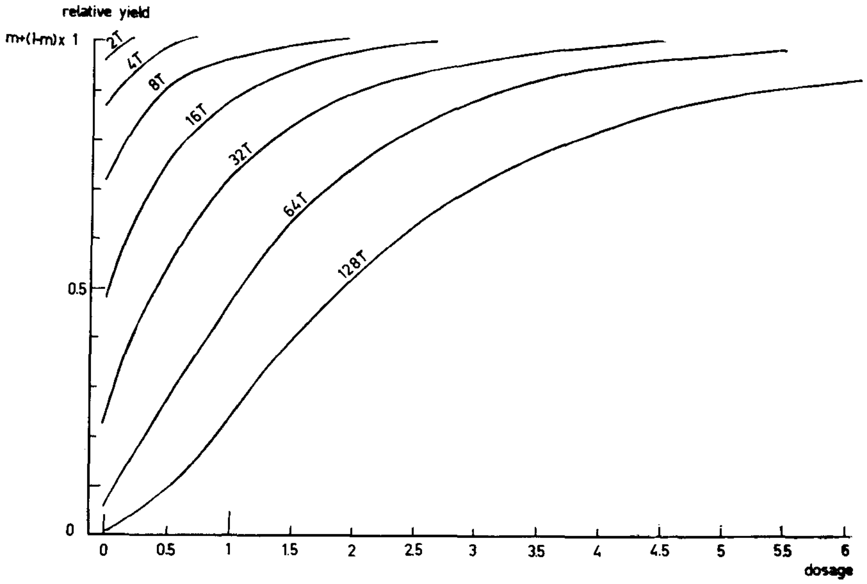

Fig. 2 - Relation between dosage of nematicide and relative yield at different initial nematode densities. If d.i.e. = 0.5 probit unit per doubling of the dosage.

Importance of the dosage increase efficiency

Figures 2, 3, 4 and 5 indicate the great effect of the efficiency of the treatment on the economic result. The dosage necessary to obtain a 75% kill (the unit dosage of the figures) generally is larger

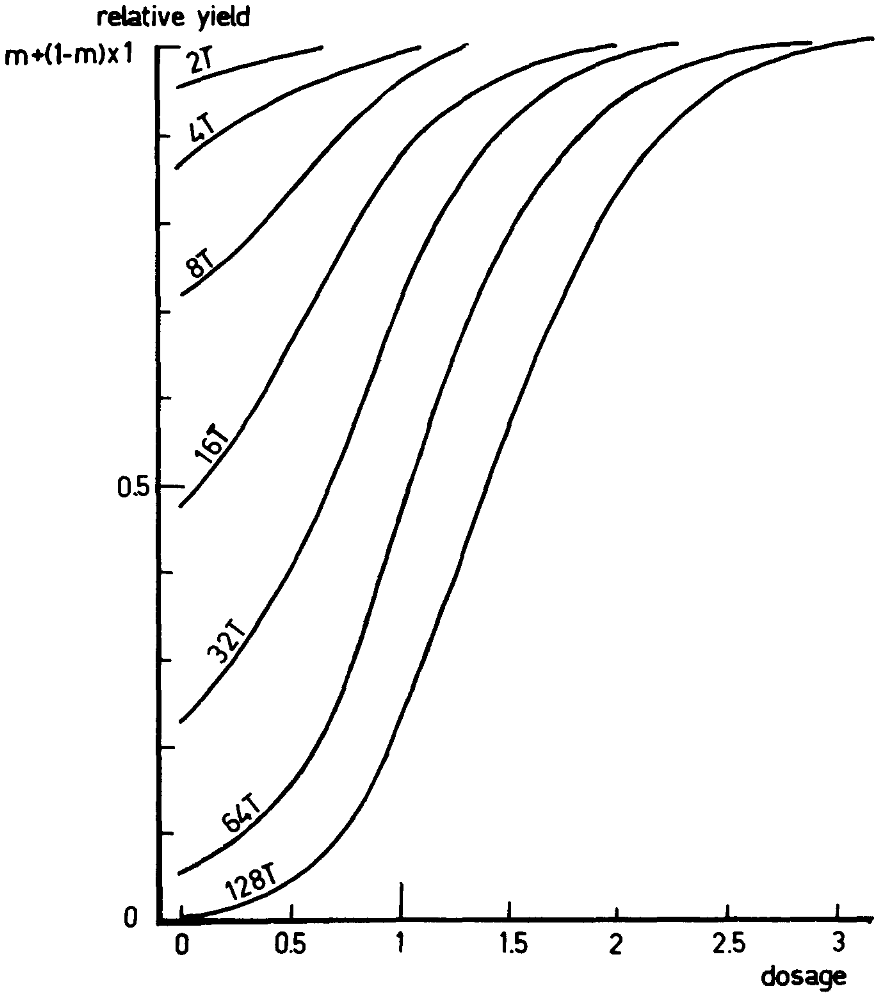

Fig. 3 - Relation between dosage of nematicide and relative yield at different initial nematode densities if d.i.e. = 1 probit unit per doubling of the dosage.

the smaller the dosage increase efficiency (d.i.e.). Therefore, the difference in dosage necessary to kill more than 75% of the nematodes with treatments with different dosage increase efficiencies is still larger than the figures suggest. Above all, it appears, the decision on what dosage to apply requires a fairly accurate estimation of the dosage increase efficiency to be expected. Experiments with

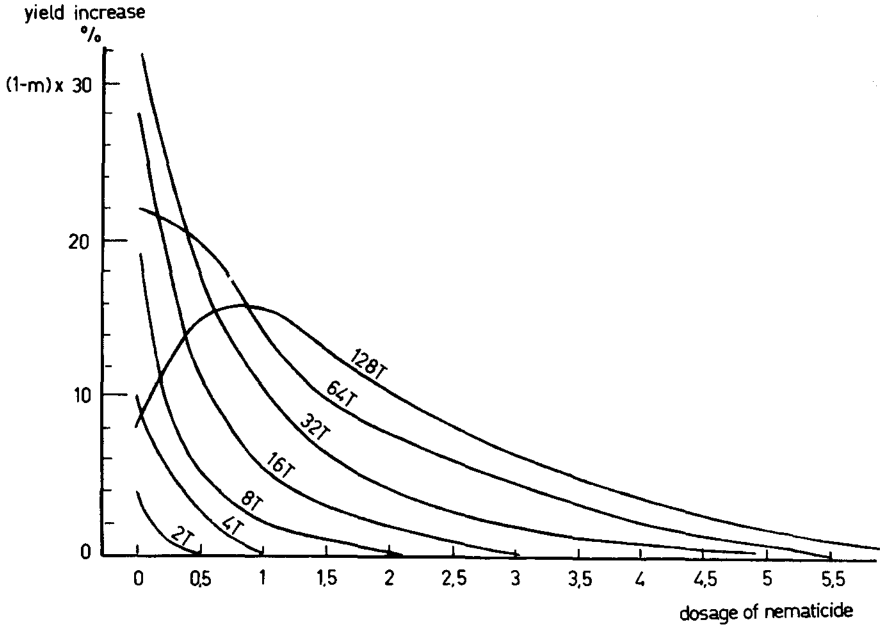

Fig. 4 - Relation between dosage of nematicide and increase of relative yield to be obtained at different initial nematode densities by increase of the dosage of nematicide by 0.5 a unit, if d.i.e. 0.5 probit unit per doubling of the dosage.

nematicides therefore should aim at establishing relations between readily determined characteristics of the soil in the state in which it is to be treated, on the one hand, and the dosage necessary to kill a certain proportion of the nematode population and the dosage increase efficiency on the other hand (see also Seinhorst 1973[a], and Leistra, 1972).

Effect of degree of irregularity of the nematode distribution in the field and of the value of m

The difference in yield increase to be obtained by reduction of the nematode population at different degrees of irregularity of its distribution, or at different values of *m*, may be fairly large as can be seen by choosing different values of *m* in Figs. 4 and 5. Therefore they may be a factor in the decision whether to treat a

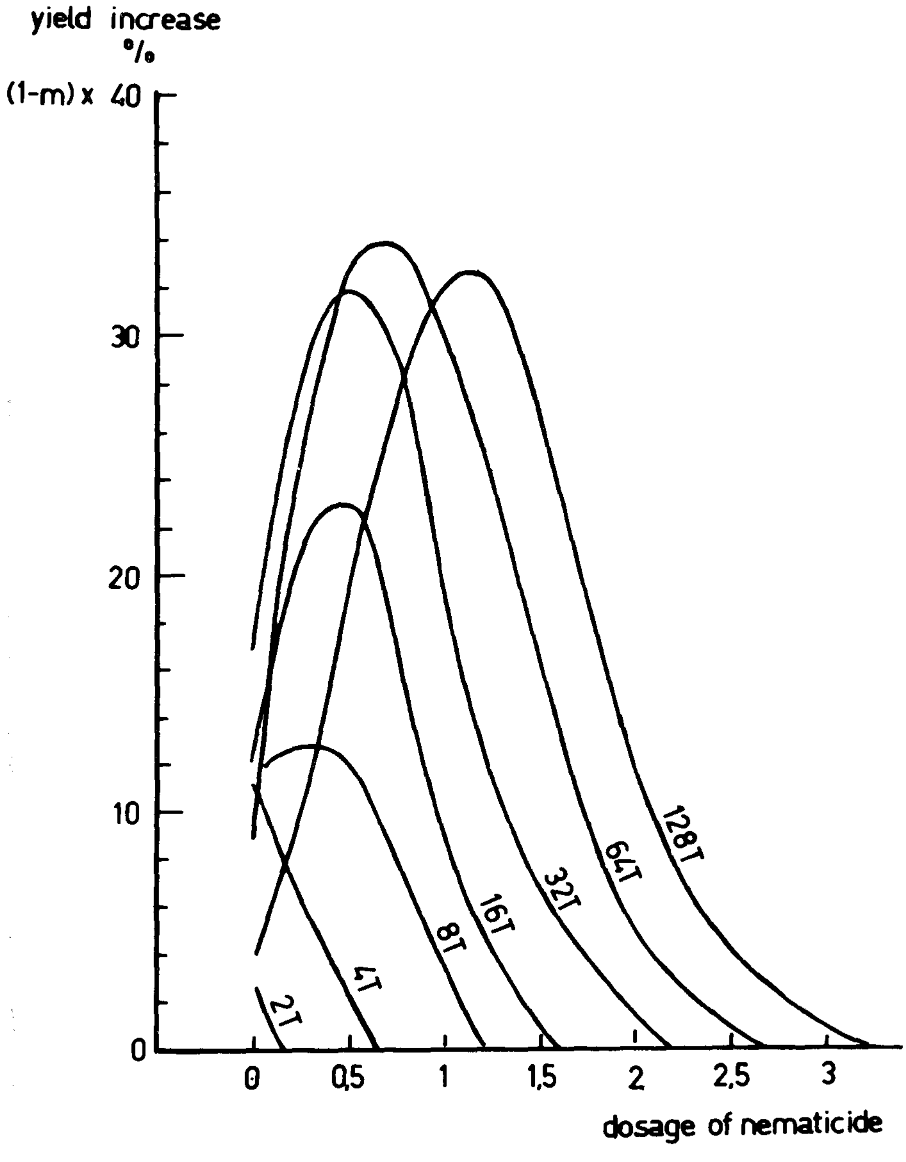

Fig. 5 - Relation between dosage of nematicide and increase of relative yield to be obtained at different initial nematode densities by increase of the dosage of nematicide by 0.5 unit, if d.i.e. = 1 probit unit per doubling of the dosage.

field at all or to grow a crop which is expected to be undamaged. Insight into the nematode distribution must then be obtained either by investigating a fair number of samples from the field to be treated or by relying on previously made observations on the distribution of the nematode in similar fields. The first method will generally be too costly, and if not, treatment would pay anyway. The second method may be quite sufficient, if enough observations are available. Brown (1969) states that *Heterodera rostochiensis* was not distributed very irregularly in the fields he investigated. This may be the case with most nematode species which can be considered indigenous in a region. On the other hand a fair range of densities may still occur in a field without causing an intolerable deviation of the relation between average density and yield from that in the case of a random distribution of the nematode (Seinhorst, 1973[b]). However, an estimation is required of the value of m (or m_i) [equations (1) and (2)] within the limits set by the accuracy of the estimations of P (av) and T. Here again, a general value found in a number of experiments (e.g. the 0.5 of Brown, 1969 and of den Ouden, 1973 for *H. rostochiensis* on potatoes) may be applicable.

Variation of tolerance limits

Tolerances of a crop to certain nematode species are not only difficult to determine, because this requires large field experiments with properly prepared ranges of densities, but also they probably vary from place to place and from year to year. These variations probably are largest for *Ditylenchus dipsaci* on onions and other plants, as in this case parts of the plant growing just above and below soil level are attacked. These are more exposed to variations in external conditions due to the weather than root nematodes which operate in deeper soil layers where temperature and moisture content vary less. Kaai (1966) found that *D. dipsaci* densities at which 50% of the onions in field experiments were attacked ranged from about 5 to 100 nematodes per 500 g soil in different years and even from 10 to 100 nematodes per 500 g of soil in different places in the same field in the same year. Experiments by Steudel and Thielemann (1970) indicate that under conditions favourable for early attack by *H. schachtii* (late sowing) the tolerance limit of sugar beet was about 3 eggs per g soil and under unfavourable conditions for early attack (late sowing) not more than 7 eggs per g ($z^{-T} = 1.05$). There would be hardly any difference at all, however, if the minimum yield was 50% in the second case instead of 0% as assumed for the tolerance limits of 3 eggs and 7 eggs per g soil. The data do not allow a decision on which of the two possibilities is the most likely one. Seinhorst (1965) derived a tolerance limit of sugar beet to *H. schachtii* of 20 eggs per g soil from the results of microplot experiments by Jones (1956) in two different years (10 eggs per g soil if z^{-T} had been assumed to be 1.05 instead of 1.1). However to apply equation (1) m had to be assumed to be about 0 in one and 0.5 in the other year. Den Ouden (1973) derived tolerance limits of 2.5 to 5 eggs per g soil from the data of four field experiments by Brown (1969) assuming that equation (1) applied. It would be most interesting if tolerance limits were derived for all field experiments mentioned by Brown (1969). For six out of nine of his own field experiments den Ouden (1973) derived tolerance limits between 1 and 2.5 eggs per g soil. All these observations may indicate that limits of tolerance to attack by root nematodes generally do not vary too much under varying external conditions. Also, if we may assume that tolerances to stem nematode attack vary more than those to root nematodes we might conclude that the latter generally vary less than the range of about 1 to 20 found for the first. However, still too little is known about root nematode tolerances to come to reliable conclusions on their variation.

Relation between degree of variation of tolerance limits and average losses through the years when average nematode densities are kept equal to the average tolerance limit

If it is supposed that the logarithms of the true tolerance limits are distributed normally with the logarithm of the assumed tolerance limit as a mean and that the logarithm of the estimated average density is distributed normally with log true average density as a mean then log density, after a treatment reducing the estimated average density to the estimated tolerance limit, is distributed normally with log true tolerance limit as a mean. If further, the relation between nematode density and yields is supposed to be according to equation (1) with $m = 0$ and $z^{-T} = 1.05$, the average loss of yield can be calculated for different standard errors of densities relative to the true tolerance limit of populations surviving treatments that reduced the estimated average density to the supposed tolerance limit. This loss appeared to be $0.5.10^{S}\%$ if S is the standard error (log scale). If for exemple population densities are between ¼ T and 4 T (T = true tolerance limit) in 95% of the cases, then $S = \log 2\ \mathrm{T} = \log T — \log T/2 = \log 2 = 0.3$ and the loss over a large number of years is $0.5.10^{0.3}\% = 1\%$. Therefore, if only the average tolerance limit is known accurately, variations from year to year do not lead to great losses. However, estimations of tolerance limits can only be based on observations in a limited number of years on small numbers of fields. Therefore, unless they vary little from year to year and from field to field errors leading to considerable losses could easily occur here. If an estimated tolerance limit is twice the true average tolerance limit losses are increased by about 5%. The possibilities of estimating tolerances would be greatly improved if the relation between tolerance limits in pots and in the field could be known and therefore the first could be translated into the latter.

SUMMARY

Control measures may aim at the protection of one crop in a given year from damage or at (out) balancing the multiplication of a nematode on one or more hosts in a rotation.

The effect of a chemical control measure aiming at the protection of one crop in a certain field is determined by: 1) the average density in the field of the nematode to be controlled and its distribution pattern; 2) the relation between nematode density and yield of the crop to be protected; 3) the relation between dosage of the chemical and nematode survival. The relation between average nematode density P before treatment, dosage of chemical applied and relative yield y to be obtained after treatment is worked out in Figs. 2, 3, 4 and 5 assuming that $y = m + (1 — m)\ z^{P — T}$ in wich m is determined partly by the distribution of the nematode in the field and $z^{—T}$ is assumed to be 1.05 and further that probit mortality p is related to log dosage c according to $p = ac + b$ in which a is assumed to be 0.5 or 1 and b = 0.75.

Average nematode densities in a field can be determined with a sufficient accuracy for advisory purpose, but distribution patterns, tolerances and minimum yield must be inferred from observations in a limited number of field experiments.

RIASSUNTO

Principi e possibilità per determinare i gradi di controllo di nematodi in funzione del massimo tornaconto. I - Protezione di una coltura messa a dimora subito dopo il trattamento.

Le misure di controllo nei confronti di un nematode fitoparassita possono mirare a proteggere una coltura, in una determinata stagione, dal danno del

parassita o a ridurre la moltiplicazione del nematode su una o più colture in rotazione.

L'effetto di trattamenti chimici miranti alla protezione di una coltura in un dato campo è determinato da:

1) la densità media del parassita nel campo e la sua distribuzione;
2) la relazione tra densità del parassita e la produzione della coltura da proteggere;
3) la relazione tra la dose del nematocida e la sopravvivenza del nematode.

La relazione tra la densità media del nematode *P* prima del trattamento, la dose del nematocida somministrato e la relativa produzione *s* ottenuta con il trattamento è schematizzata nelle figure 2, 3, 4 e 5, supponendo che $y = \mathrm{m} + (1 - \mathrm{m})\, z^{p-t}$, dove *m* è determinato in parte dalla distribuzione del nematode nel campo, z^{-t} è ritenuto essere 1,05 e il tasso di mortalità *p* è in relazione con il logaritmo della dose di applicazione *c* secondo $p = ac + b$, dove *a* è ritenuto essere 0,5 o 1 e $b = 0{,}75$. La densità media dei nematodi in un campo può essere determinata, per scopi pratici, con una certa accuratezza, ma distribuzione, tolleranza e produzione minima devono essere ricavate da osservazioni in un limitato numero di campi sperimentali.

RÉSUMÉ

Principes et possibilité pour déterminer les degrés de contrôle de nématodes en fonction de l'avantage le plus grand. I - Protection d'une culture mise à demeure sitôt après le traitement.

Les mesures de lutte peuvent avoir pour but de préserver des dommages une culture pour une année donnée, ou bien de contrebalancer la multiplication d'un nématode sur un ou plusieurs hôtes au cours de la rotation.

1. La densité moyenne, dans le champ, du nématode que l'on veut combattre et son mode de distribution.

2. La relation entre la densité du nématode et la récolte de la culture à protéger.

3. La relation entre la dose du produit et le taux de survie du nématode. La relation entre la densité moyenne du nématode P avant le traitement, la dose de produit appliqué et la récolte relative *y* devant être obtenue après traitement, est établie dans les figures 2, 3, 4 et 5, fixant: d'abord que $y = m + (1 - m)\, z^{P-T}$ dans laquelle m est déterminé partiellement par la distribution du nématode dans le champ et z^{-T} est fixé à 1,05 et, de plus, que la mortalité probit p est liée au logarithme de la dose *c* selon la loi $p = ac + b$ dans laquelle *a* est fixé a 0,5 ou 1 et $b = 0{,}75$.

Les densités moyennes de nématodes dans un champ peuvent être déterminées avec une précision suffisante pour des buts de conseils pratiques, mais les types de distribution, les tolérances et les récoltes minimales ne peuvent être établies qu'à partir d'observations dans un nombre limité d'essais au champ.

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