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Dosage of nematicidal fumigants and mortality of nematodes

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Abstract

Results of field experiments reported in the literature suggest a linear relation between log dosage of dichloropropene injected into the soil and probit mortality of plant parasitic nematodes. In most cases probit mortality increases by about half a unit per doubling of the dosage of fumigant. This is in accordance with the distribution of sums of concentration-time (CT) products for dichloropropene in the soil according to investigations by Leistra (1971 and in litt.). The relation between log dosage x of the chemical and probit mortality y can be described by the equation $y = a\,x + b$ (a and b constants). For a the name dosage increase efficiency is proposed. It is to be expressed in probit units per doubling of the dosage. The way in which the chemicals spread through the soil can be derived from the relation between dosage and mortality. Experiments should therefore always be done with a fairly large range of dosages including some of which only little effect is expected.

Results of field experiments with dazomet, metamnatrium and methyl isothiocyanate, reported in the literature also suggest a linear relation between log dosage and probit mortality. The average dosage increase efficiency for the top 20 cm of the soil was higher than with dichloropropene.

Introduction

The proportion of a nematode population killed in the soil by a treatment with a nematicidal chemical depends on the distribution of sums of concentration-time (CT) products large enough to kill this nematode. Chemicals, especially fumigants are deposited in a very small soil volume from which they must disperse through the soil in one way or another. This means that sums of CT products decrease with increase of the distance from the place of deposition of the chemical even if the soil is placed in a closed container with walls impermeable to the chemical. In such cases the proportion of the soil that receives a certain sum of CT products gradually increases with the dosage of the chemical. If the chemical would have been distributed uniformly immediately upon putting it in the soil either no or all soil would receive a certain sum of CT products. The proportion of the soil between certain depths that receives a sum of CT products of a nematicidal compound sufficient to kill a certain nematode species is the same as the proportion of the population of this nematode that is killed by the treatment. The latter therefore is a measure of the first. If the dispersal of the chemical is optimal increasing the dosage will lead to a considerable increase of the proportion of the soil volume in which nematodes are killed; if the dispersal is poor this proportion will increase relatively little. The relation between dosage of the chemical and proportion of the nematode population killed therefore is a measure for the way the chemical dispersed in the soil. On the other hand insight into the relation between dosage and effect is necessary to decide whether a certain degree of control should be

obtained by a single treatment with a relatively high dosage, repeated treatments, or combinations of different treatments. Such an application requires a relationship between dosage and effect according to a simple constant pattern determined by few parameters, the values of which can be predicted fairly accurately.

Results of experiments with dichloropropene reported in the literature

Despite the importance of the problem and extensive investigations on the improvement of the effect of soil treatments no serious efforts have been reported in the literature to draw general conclusions on the relation between dosage and effect from the results of the hundreds of field experiments with nematicides. There is only a short communication by Peters (1954) that the relation between log dosage of dichloropropane-dichloropropene mixture and probit mortality is linear except at very high mortalities, but the experiments on which this opinion was based have never been published. A review of the literature revealed that most of the results reported could not be used for an investigation of the relation between dosage and mortality, because the (often fairly high) mortalities were not determined with sufficient accuracy or were not determined at all. Often only secondary effects were measured like yield increase or

Fig. 1. Relation between dosage of dichloropropene and mortality of nematodes in different field experiments with DD mixture and dichloropropene. Full lines: experiments by Nollen and Mulder (1969). Broken lines from top to bottom: Seinhorst, 1972; Seinhorst et al., 1956; Seinhorst and Riezebos, 1959; Kaai and Windrich, 1971.

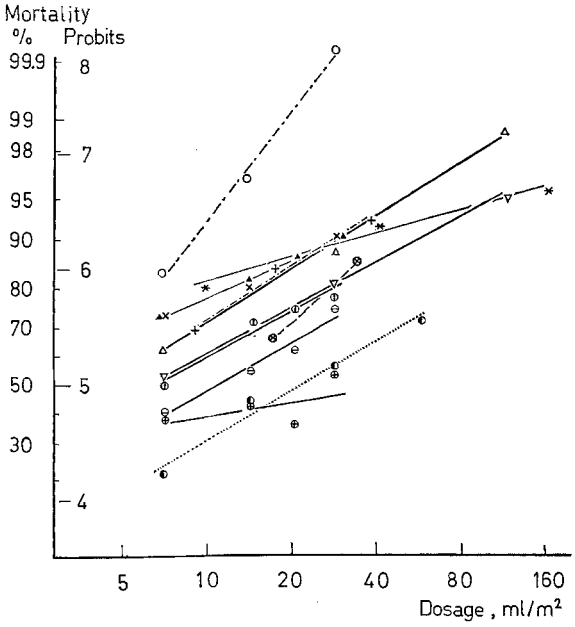

Fig. 1. Verband tussen dosis dichloorpropeen en sterfte van nematoden in verschillende veldproeven met DD mengsel en dichloorpropeen. Getrokken lijnen: proeven van Nollen en Mulder, 1969. Gebroken lijnen van boven naar beneden: Seinhorst, 1972; Seinhorst et al., 1956; Seinhorst en Riezebos, 1959; Kaai en Windrich, 1971.

reduction of galling by *Meloidogyne*. These generally are not linearly related to nematode mortality. A small number of experiments with nematicidal fumigants was found in the literature which allowed the derivation of a relation between dosage and mortality. The relation between log dosage and probit mortality in these experiments is rendered in Fig. 1. For further details of these experiments the reader is referred to the original publications.

General pattern of the relation between dosage of a soil fumigant and precentage kill of nematodes

According to Fig. 1 the relation between log dosage of the chemical and probit mortality of the nematodes was linear or close to linear in all these experiments. The slopes of most lines drawn through the points are remarkably similar: when the dosage of the chemical was doubled probit mortality increased between 0.4 and 0.6 units in seven out of the twelve cases, by one unit in one, by 0.35 units in two and by less than 0.3 units in two cases. Thus the slope seems to be largely independent of the mortality at a given dosage. The lines in Fig. 1 can be described by the equation $y = a\,x + b$ in which y = probit mortality, x = log dosage of the chemical, a = the increase of y per unit increase of x and b = probit mortality at the (arbitrary) dosage 1. For a the name 'dosage increase efficiency' is proposed. It is to be expressed in 'probit units per doubling of the dosage'.

Dispersal of fumigant through soil and relation between dosage and mortality of nematodes

According to investigations by Leistra (1971) sums of CT products of fumigants at different depths in the soil can be calculated if certain characteristics of the soil are known. The results of calculations of concentrations at various times after application of a fumigant are in agreement with measured concentrations and therefore the calculated sums of CT products can be considered to be those really occurring in the soil. Calculations were made for three dosages of dichloropropene in a sandy soil with a uniform profile from 0 to 20 cm depth by M. Leistra and J. Smelt of the Laboratory for Research on Insecticides at Wageningen (personal communication). The results are given Fig. 2.

The proportions of the soil profile down to a certain depth that receive certain sums of CT products at certain dosages of fumigant derived from this figure are given in Fig. 3. In all cases dosage increase efficiency again is about 0.5 probit unit per doubling of the dosage when percentages of the soil receiving a certain sum of CT products exceed 60. At smaller percentages increase of the dosage is more effective. This is also suggested by the results of a field experiment by Nollen and Mulder (1969) (Fig. 4), here presumably below about 80%.

Sums of CT products at a given place in the soil are determined by the net increases and decreases of the concentration of the fumigant in the course of time. If in the model soil used to calculate the data rendered in Fig. 2 upward transport of the fumigant from the source at 15 cm depth would have been slower but the rate of transport through the top layer the same, sums of CT products up to a certain distance above the depth of injection would have been larger but those closer to the soil surface

Fig. 2. Sums of concentration-time (CT) products at different depths in the soil for cis 1,3 dichloropropene 15 days after application in a sandy soil with 5% organic matter, 15–20% moisture and at 12°C. Dosages of the fumigant are in ml DD mixture per m^2 (Data supplied by M. Leistra and J. Smelt, Laboratory for Insecticide Research, Wageningen).

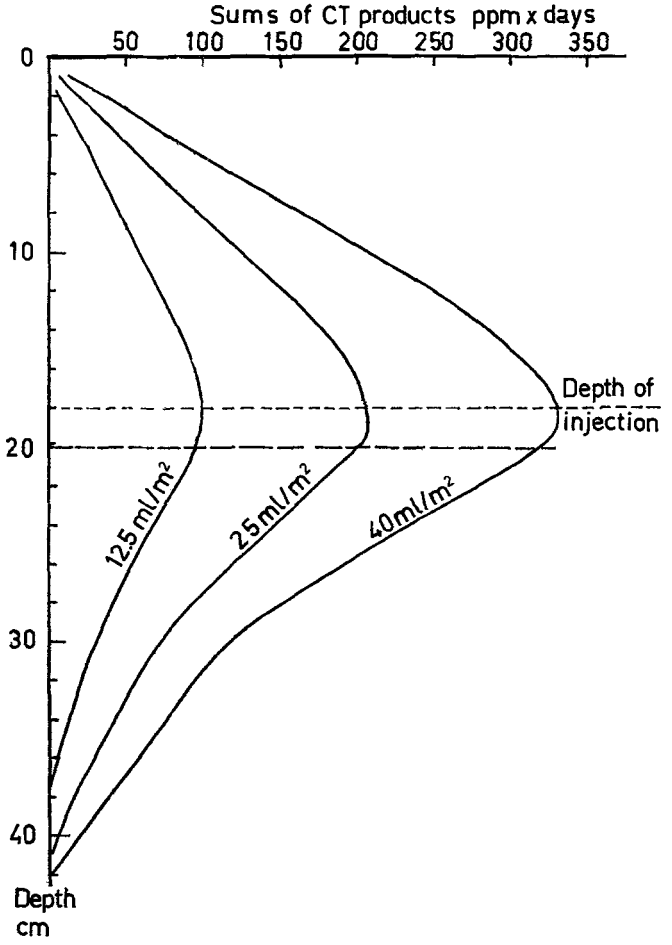

Fig. 2. Sommen van concentratie-tijd (CT) produkten op verschillende diepten in de grond voor cis 1,3 dichloorpropeen 15 dagen na toediening in een zandgrond met 5% organische stof, 15–20% vocht en bij 12°C. Doses van het nematicide zijn gegeven in ml DD mengsel per m^2 (gegevens verstrekt door M. Leistra en J. Smelt, Lab. voor Insecticide Onderzoek, Wageningen).

smaller than in Fig. 2. This would have resulted in a lower dosage increase efficiency.

A faster upward transport at the same rate of transport through the top layer would have resulted in a higher dosage increase efficiency (upper line in Fig. 1). Rapid transport through all layers leads to both low percentages of the soil column receiving a certain sum of CT products and to low dosage increase efficiencies (Kaai and Windrich, 1972, data in Fig. 1). Particularly loose top layers lead to a decrease of the dosage increase efficiency with increase of the dosage. The relation between log dosage and probit mortality therefore allows us to draw fairly far reaching conclusions on the

Fig. 3. Relation between dosage of DD mixture (ml/m²) and percentage of soil volume between 0 and 20 cm depth that received a certain sum of CT products according to Fig. 2. Lines 1 to 5: sums of CT products 25, 50, 75, 85 and 90 ppm × days respectively.

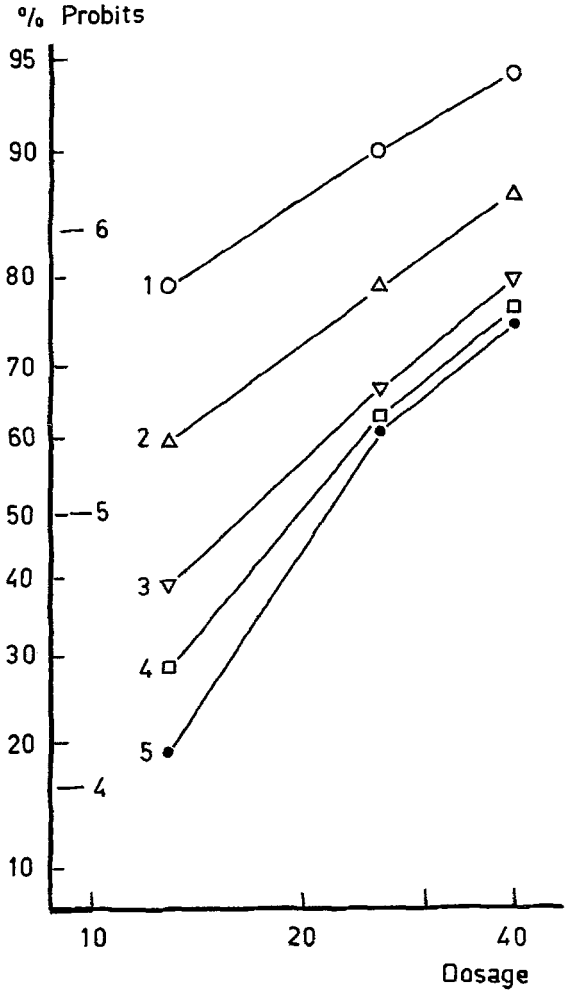

Fig. 3. Het verband tussen dosis DD mengsel en percentage van het bodemvolume tussen 0 en 20 cm diepte, dat een bepaalde som van CT produkten ontving volgens Fig. 2. Lijnen 1 tot en met 5: sommen van CT produkten respectievelijk 25, 50 75, 85 en 90 dpm × dagen.

distribution of the chemical in the soil if a sufficiently wide range of dosages is investigated. With small ranges one has to rely on the linearity of this relation as derived from Fig. 1 and 5, which in general seems justified for limited mortality ranges. Fig 2 and 3 show in particular that the same dosage increase efficiency as for lower dosages can only be maintained through higher dosages if escape of the chemical through the top layer is obstructed. Therefore other than single treatments with a high dosage of a fumigant should always be considered if high mortalities are wanted all through the top 20 cm.

Fig. 4. Relation between dosages of dichloropropene and mortality of nematodes according to Nollen and Mulder (1969).

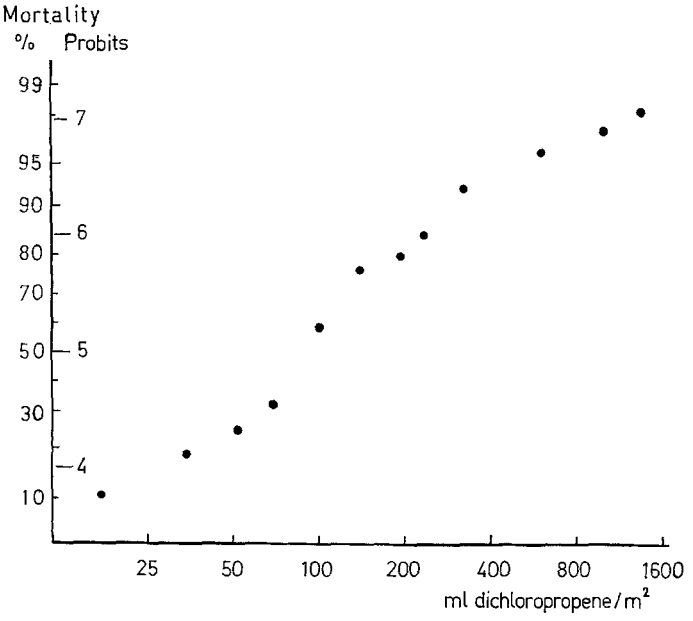

Fig. 4. Verband tussen dosis dichloorpropeen en sterfte van aaltjes volgens Nollen en Mulder (1969).

Other compounds

A small number of experiments with metamsodium (Na-N-monomethyl-dithiocarbamate (Nollen and Mulder, 1969; den Ouden, 1958, Klinkenberg and Seinhorst, 1956), one with N, N' dimethylthiuramdisulfide (Seinhorst and Knoppien, 1960) and three with dazomet (3–5 dimethyltetrahydro -1-3-5-2 H thiadiazine 2 thione) (Nollen and Mulder, 1969; Seinhorst, 1972; Seinhorst, Bijloo and Klinkenberg, 1956) on sandy soil permit investigation of the relation between dosage of these closely related compounds and the mortality they cause in the top 20 cm of the soil. Again the reader is referred to the original publication for a description of the experiments. Seinhorst et al. (1956) applied dazomet to the surface of the soil after which it was raked through the top 2 to 5 cm on ... plots, whilst other plots were dug to a depth of about 15 cm. There was little difference between the effects of the two methods of application. Also mortalities of *Rotylenchus uniformis* and of *Pratylenchus crenatus* were of the same order. Therefore, methods of application and counts of the two species were considered replications of the same treatments and the determination of densities at three different dates after treatment replicated determinations of the same densities. Fig. 5 gives the relations between log dosage of these chemicals and probit mortality in the different experiments.

Dosage increase efficiencies are more than half a unit in seven out of ten cases and at least half a unit in all cases and therefore generally higher than in the experiments with dichloropropene. However dichloropropene also killed a large proportion of the

Fig. 5. Relation between dosage of various nematicides and mortality of nematodes; 1, 2: Seinhorst and Klinkenberg (1956); 3: Seinhorst (1972); 4: den Ouden (1958); 5, 6: Seinhorst and Knoppien (1960); 7: Seinhorst et al. (1956); 8, 9, 10: Nollen and Mulder (1969). Dosages are in ml of active material per m^2 for metamsodium and methylisothiocyanate and in g per m^2 for dazomet and N, N'dimethylthiuramdisulfide. Methods of application: 9, 10, injected at 15 cm depth; 1, 2, 4, 5, 6, 7 (partly), 8 soil rototilled or dug after application of chemical to surface; 3, 7 (partly) to surface without further mixing.

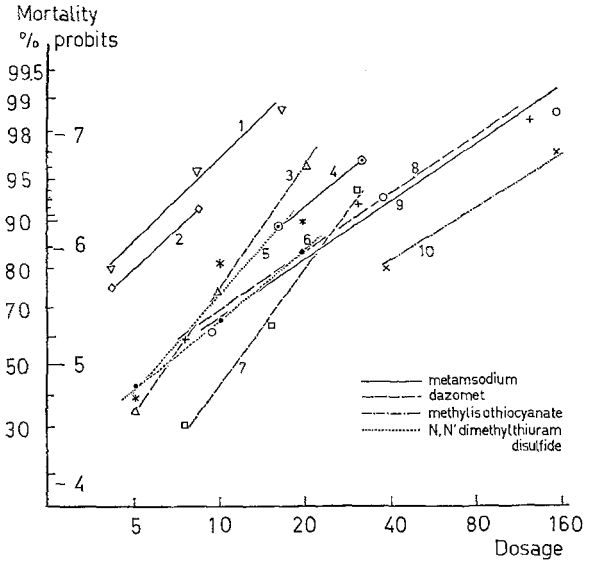

Fig. 5. Verband tussen doses van verschillende nematiciden en sterfte van aaltjes; 1, 2: Seinhorst en Klinkenberg (1956); 3: Seinhorst (1972); 4: den Ouden (1958); 5, 6: Seinhorst en Knoppien (1960); 7: Seinhorst et al. (1956); 8, 9, 10: Nollen en Mulder (1969). Doses in ml actieve stof per m^2 voor metamnatrium en methylisothiocyanaat en in g per m^2 voor dazomet en N, N' dimethylthiuramdisulfide. Methode van toediening: 9, 10, geïnjiceerd op 15 cm diepte; 1, 2, 4, 5, 6, 7 (gedeeltelijk), 8, grond gefreesd of gespit na aanbrengen van middel op oppervlakte; 3, 7 (gedeeltelijk) aan oppervlakte zonder verdere menging.

nematodes between 20 cm and 40 cm depth. The chemicals mentioned in Fig. 5 certainly did not do this in the lower dosages (Seinhorst, 1972, Seinhorst and Knoppien, 1960). Therefore, if the layer between 20 cm and 40 cm had been included in the measurements of mortalities the results with dichloropropene of Fig. 1 would probably have been the same or better and those of the experiments of Fig. 5 less good. The results of Seinhorst (1972) and Seinhorst et al. (1956) with dazomet indicate a remarkably good penetration of the chemical to deeper layers when applied to the soil surface. The very high mortalities obtained with metamsodium by Klinkenberg and Seinhorst (1956) are probably due to very favourable conditions for the action of the chemical in the dune sand on which the experiment was done.

Conclusions

Although theoretically this is not strictly necessary the relation between log dosage of nematicides and probit mortality of nematodes was linear or indistinguishable from

linear in all investigated cases with dosage ranges up to 1:16. Only in one case with a dosage range of 1:64 was a devation from linearity (in accordance with theoretical considerations) suspected. Therefore, for all practical applications except extrapolations to very high mortalities the relation may be considered to be linear. This means that to improve the accuracy of estimations of high mortalities in experiments, increasing the range of fumigant dosages is to be preferred to increasing the quantity of soil investigated after treatments causing very high mortalities. This is especially so as the dosage increase efficiencies measured in this way tell why the results are what they are. In this way they supply valuable information on the reliability of the data as a basis for estimations of mortality rates to be expected in other fields and the factors that influence these expectations. Results of experiments with ranges of dosages also supply a good basis for decisions whether in order to obtain a given mortality, one treatment with a high dosage should be given or alternative treatments (repeated treatments with lower dosages, combined treatments or treatments with a soil cover) must be considered.

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Samenvatting

Dosis van vluchtige nematiciden en sterfte van nematoden

De resultaten van een aantal in de literatuur vermelde veldproeven suggereren een lineair verband tussen log dosis van dichloorpropeen, dat op een bepaalde diepte in de grond werd gebracht en probitsterfte van planteparasitaire aaltjes. In de meeste gevallen steeg de probitsterfte met ongeveer een halve eenheid per verdubbeling van de dosis van het nematicide. Dit is in overeenstemming met de verdeling van sommen van concentratie-tijd (CT) produkten van dichloorpropeen in de bodem volgens onderzoekingen van Leistra (1971 en persoonlijke mededeling) (Fig. 2 and 3). Het verband tussen log dosis x van het bestrijdingsmiddel en probitsterfte y kan in deze gevallen worden beschreven door de vergelijking $y = a\,x + b$ (a en b constanten). Voor a wordt de naam 'effect van dosisvergroting' voorgesteld en als eenheid probit-eenheid per verdubbeling van de dosis. Uit het verband tussen sterfte en effect van dosisvergroting kan de wijze, waarop het nematicide zich door de grond verspreidde, worden afgeleid. Proeven met nematiciden dienen daarom te worden gedaan met een vrij grote reeks doses waarbij van enkele slechts een gering tot matig effect wordt verwacht. In de literatuur vermelde veldproeven suggereren ook een lineair verband tussen log dosis dazomet, metamnatrium en methylisothiocyanaat en probitsterfte (Fig. 5). Het effect van dosisvergroting in de bovenste 20 cm van de grond was groter dan bij dichloorpropeen (Fig. 1).

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