Neth. J. Pl. Path. 80 (1974) 61–71

Predictions on effectivity and after-effects of metam-sodium by simulating soil fumigations

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Accepted 3 December 1973

Abstract

Soil fumigations with metam-sodium in the field were simulated with computation models. The results were expressed in the concentration-time product (dose) for methyl isothiocyanate, the active conversion product of metam-sodium.

Adequate nematode control with peaty soils will be difficult as a result of the greater extent of adsorption and dilution, and seems only possible under somewhat drier soil conditions. Injection as a line gives less favourable dose patterns than injection as a plane, particularly with the wider shank spacings and when soil is not pre-cultivated to injection depth.

The duration of the period with after-effects may range from a few weeks to several months. Soil temperature is the main factor in this respect, which is related to the predominance of methyl isothiocyanate decomposition as compared with the other decay processes.

Introduction

An important aim of the study of fumigant behaviour in soil is to get the possibility to predict effectivity and after-effects under a wide variety of conditions. Several basic data on metam-sodium and on methyl isothiocyanate, the active and volatile conversion product, were needed (Smelt and Leistra, submitted for publication). To make the predictions as quantitative as possible, computation models were needed, some of which were discussed by Leistra (1973). These models had to be tested for some well-defined experiments (Leistra et al., submitted; Smelt et al., submitted). After this, the stage was attained at which the computation models can be used to make predictions.

In soil fumigation, there is a complex of factors determining – at a certain application rate – the effectivity against, for example, plant parasitic nematodes. These factors are related to fumigant properties, application technique, soil moisture condition, soil structure condition, and weather condition. The effect of soil moisture content and soil temperature on the dose patterns of methyl isothiocyanate in soil was discussed by Leistra and Smelt (1973). Soil organic matter is an important factor, as large areas of peaty sand soil have to be disinfected. The characteristics of a fumigant may make special demands on application technique and accompanying soil cultivation.

Methyl isothiocyanate has a broad biocidal activity spectrum and residues may occur in follow-up crops. Maximum efforts should be made to limit the necessary waiting period as the main applications are in narrow crop rotations in horticulture and arable farming. For this, quantitative information should be available on the effect of factors like soil moisture content and temperature on the duration of the after-effect period. To trace the needs for further studies on environmental consequences of the applications, a balance-sheet of decay processes in soil is needed.

Effect of soil organic-matter content

Methyl isothiocyanate is only weakly adsorbed in soils (Smelt and Leistra, submitted) and one may wonder whether this implies that there is little effect of soil organic matter on effectivity. To check the effect, a number of soil fumigations with 400 l of metam-sodium solution (0.38 kg/l) per ha was simulated. The first situations deal with injection by horizontal-blade injection of a humic sand soil with 5% organic matter in the plough layer. The moisture contents corresponded with about pF 2.0 (Case 1) and pF 2.5 (Case 2), respectively. The first content is near the wet end of the favourable soil moisture range. Further details on the simulated situations are given in Table 1.

The concentration-time products (doses) computed for the injection of the humic sand soil are represented in Fig. 1. Methyl isothiocyanate is somewhat more toxic to

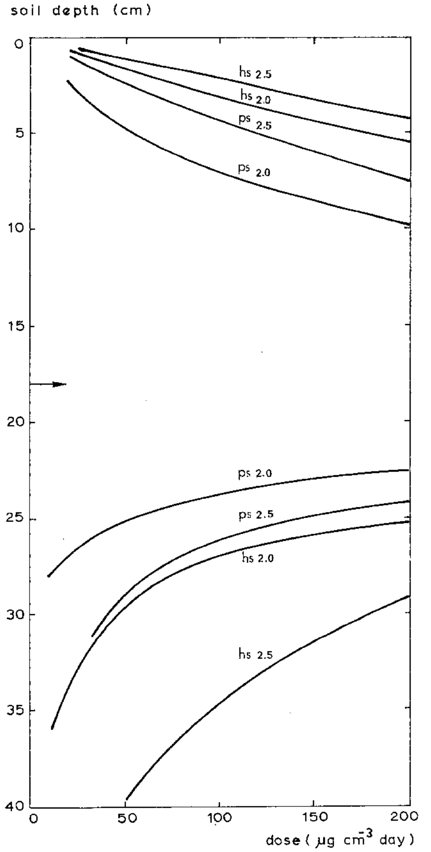

Fig. 1. Doses for methyl isothiocyanate in the water phase. hs = humic sand, ps = peaty sand. Moisture contents corresponding with pF 2.0 and pF 2.5, respectively.

Fig. 1. Doses voor methyl isothiocyanaat in de waterfase. hs = humeus zand, ps = venig zand. De vochtgehaltes komen overeen met respectievelijk pF 2.0 en pF 2.5.

Table 1. Soil properties with diffusion and distribution characteristics for methyl isothiocyanate. D_a is the coefficient for diffusion in air, D_p that for diffusion in the gas-filled pore system.

Case no, soil type, moisture tension	Temperature, decomp. rate constant (day^{-1})	Layer (cm)	Bulk density ($g cm^{-3}$)	Water phase ($cm^3 cm^{-3}$)	Gas phase ($cm^3 cm^{-3}$)	D_p/D_a ratio	Distribution soil/gas phase	Capacity factor ($cm^3 cm^{-3}$)
1	15 °C	0–4	1.25	0.31	0.20	0.06	42	120
humic sand	0.06	4–10	1.25	0.31	0.20	0.04	42	120
pF 2.0		10–18	1.30	0.33	0.16	0.025	42	126
		18–28	1.45	0.33	0.10	0.007	34	121
		28–50	1.55	0.26	0.14	0.015	17	83
2	15 °C	0– 4	1.25	0.21	0.30	0.15	42	98
humic sand	0.06	4–10	1.25	0.21	0.30	0.12	42	98
pF 2.5		10–18	1.30	0.22	0.27	0.08	42	102
		18–28	1.45	0.22	0.22	0.02	34	97
		28–50	1.55	0.17	0.23	0.04	17	63
3	15 °C	0– 4	0.92	0,41	0.20	0.06	168	243
peaty sand	0.06	4–10	0.92	0.41	0.20	0.04	168	243
pF 2.0		10–18	0.97	0.44	0.16	0.025	168	258
		18–28	1.12	0.45	0.10	0.007	134	247
		28–50	1.25	0.38	0.14	0.015	67	166
4	15 °C	0– 4	0.92	0.32	0.30	0.15	168	224
peaty sand	0.06	4–10	0.92	0.32	0.30	0.12	168	224
pF 2.5		10–18	0.97	0.33	0.27	0.08	168	235
		18–28	1.12	0.33	0.22	0.02	134	222
		28–50	1.25	0.29	0.23	0.04	67	147
5	15 °C	0– 2, + track	1.10	0.28	0.27	0.12	9.5	71
loam	0.11	2– 8	1.30	0.33	0.13	0.01	9.5	84
pF 2.1		8–18	1.30	0.33	0.13	0.01	9.5	84
		18–28	1.35	0.34	0.10	0.007	8.7	85
		28–50	1.30	0.33	0.13	0.015	8.7	83
6	15 °C	0– 2, + track	1.10	0.28	0.27	0.12	9.5	71
loam	0.11	2– 8	1.10	0.28	0.27	0.08	9.5	71
pF 2.1		8–18	1.30	0.33	0.13	0.01	9.5	84
7	15 °C	0– 2, + track	1.10	0.28	0.27	0.12	9.5	71
loam	0.11	2– 8	1.20	0.30	0.20	0.04	9.5	76
pF 2.1		8–18	1.20	0.30	0.20	0.04	9.5	76
8	15 °C	0– 4	1.10	0.28	0.27	0.12	9.5	71
loam	0.11	4–10	1.10	0.28	0.27	0.09	9.5	71
pF 2.1		10–18	1.25	0.31	0.17	0.03	9.5	79
		18–28	1.35	0.34	0.10	0.01	8.7	85
		28–50	1.30	0.33	0.13	0.02	8.7	83
9	15 °C	0– 4	1.10	0.22	0.32	0.16	9.5	58
loam	0.11	4–10	1.10	0.22	0.32	0.135	9.5	58
pF 2.5		10–18	1.25	0.25	0.23	0.06	9.5	66
		18–28	1.35	0.27	0.17	0.015	8.7	70
		28–50	1.30	0.26	0.20	0.03	8.7	68
10	15 °C	0– 4	1.10	0.34	0.20	0.06	9.5	84
loam	0.11	4–10	1.10	0.34	0.20	0.04	9.5	84
pF 1.5		10–18	1.25	0.39	0.09	0.01	9.5	96
		18–28	1.35	0.41	0.03	0.005	8.7	100
		28–50	1.30	0.39	0.07	0.01	8.7	96
11	5 °C	0– 4	1.10	0.28	0.27	0.12	17	111
loam	0.05	4–10	1.10	0.28	0.27	0.09	17	111
pF 2.1		10–18	1.25	0.31	0.17	0.03	17	123
		18–28	1.35	0.34	0.10	0.01	16	133
		28–50	1.30	0.33	0.13	0.02	16	129
12	5 °C	0– 4	0.92	0.48	0.14	0.03	270	406
peaty sand	0.02	4–10	0.92	0.48	0.14	0.02	270	406
pF 1.5		10–18	0.97	0.50	0.09	0.01	270	426
		18–28	1.12	0.50	0.04	0.005	216	406
		28–50	1.25	0.43	0.09	0.01	108	276

Tabel 1. Bodemeigenschappen met diffusie- en verdelingskarakteristieken voor methyl isothiocyanaat. D_a is de coëfficiënt voor diffusie in lucht, D_p die voor de diffusie in het gasgevulde poriënsysteem.

nematodes than the dichloropropenes (Goring, 1972), so a fairly high mortality percentage may be expected at 50 μg cm^{-3} day. The position of the dose lines near the soil surface is favourable: there is only a thin layer with low doses. At the highest moisture content, doses at depths greater than 30 cm are low. The low soil moisture content is more favourable, as is shown by the wider zone with high doses. Especially the dose pattern at greater depths is much more extended. With bio-assays, the best pattern of action was also found with moisture contents that were low in the favourable range (Vanachter and Van Assche, 1970).

A representative profile was taken of peaty sand soil with an organic-matter content of 20% in the plough layer. Moisture contents corresponded with pF 2.0 (Case 3) and pF 2.5 (Case 4), respectively. The volume-fraction gas-filled pores, the diffusion coefficients for this pore system, and the decomposition rate constant were kept at the same value as with the humic sand soil so the effect of these factors was eliminated. The greater adsorption and the greater dilution in the water phase are left as differences. Details are given in Table 1.

The computed dose patterns for the peaty sand soil are also represented in Fig. 1. With the moisture content near pF 2.0 the pattern is unfavourable. Parasites in a top layer of several centimetres are poorly controlled, while activity of the compound in deeper layers is also poor. At the lower moisture content (pF 2.5) the dose pattern is much better. However, the zone of control is still smaller than with the humic sand soil.

The capacity factors given in Table 1 show that the comparatively great adsorption and dilution in the peaty sand soil result in a substantially higher retention of the fumigant. This reduces both the concentration in the water phase and the diffusion rate.

A comparatively great part of the compound is broken down before the important extremes of the dose patterns are reached. Because application of higher dosages to these soils is undesirable, application at rather low soil moisture contents will be the only possibility to obtain an adequate control.

Nematode mortality percentages for a series of four field experiments on humic sand soil and for a series of four on peaty sand soil in the comparatively dry autumn of 1969, indeed show a distinct effect of soil organic matter content (Hijink, 1972). From these data it also follows that a reasonable result with peaty sand soils at normal dosages can be achieved, provided there is careful application under optimum soil moisture conditions.

Line injection

One may wonder whether injection as a line is appropriate for a chemical like metam-sodium. The slower diffusion of methyl isothiocyanate and the higher decomposition rate as compared with other fumigants may cause a poor overlap of the dose patterns.

A differential equation that can be used to describe diffusion in a heterogeneous two-dimensional system in space, together with a suitable numerical solution was given by Leistra (1972). The diffusion from a line source can be described in a plane perpendicular to the injection line. Vertical reflection planes are those through the injection lines and those midway between two adjacent lines. Computations can be limited to a repetition unit, one of which is shown in Fig. 2. Over this cross-section unit an imaginary grid of points is placed and a square compartment assigned to each point. Several types of heterogeneities can be simulated in this system, though in a schematic way. The coefficients for diffusion between the points are averaged on the analogy of the laws on parallel or series connection in electricity theory and the fumigant capacity factors are averaged according to layer transition position.

In a series of computations, application of 400 l of metam-sodium solution (0.38 kg/l) per ha with a shank injector was simulated. The computations were programmed in FORTRAN and runs were made with a CDC 6400 computer. A space interval, Δx, of 2 cm was taken. The soil was a loam soil with an organic matter content of 2.3% in the plough layer, a moisture content corresponding with about pF 2.1, and a temperature of 15 °C. In the first run (Case 5a), injection in non-precultivated soil was simulated. The soil in tracks of 4 cm wide was assumed to be disturbed by the shanks, whereas the soil between the tracks was not disturbed. The combination of soil moisture content and soil structure was such that vapour diffusion could take place throughout the soil, though at a low rate in the undisturbed soil sections. In the second run (Case 6a) a soil was taken that was rototilled to a depth of 8 cm. In the third run, injection was assumed to be preceded by ploughing to 18 cm depth (Case 7a). Injection depth was 18 cm and the distance between two adjacent shanks was 20 cm. Details on the situations are given in Table 1.

The computed dose patterns for methyl isothiocyanate in the water phase are given in Fig. 2. Without precultivation there is a strong undulating dose pattern, with a

Fig. 2. Dose pattern of methyl isothiocyanate after injection of metam-sodium in lines at a distance of 20 cm. Iso-dose lines for 50, 100, and 200 μg cm^{-3} day. np = no precultivation, sr = shallow rototillage, pl = ploughed, ● = position of the injection line.

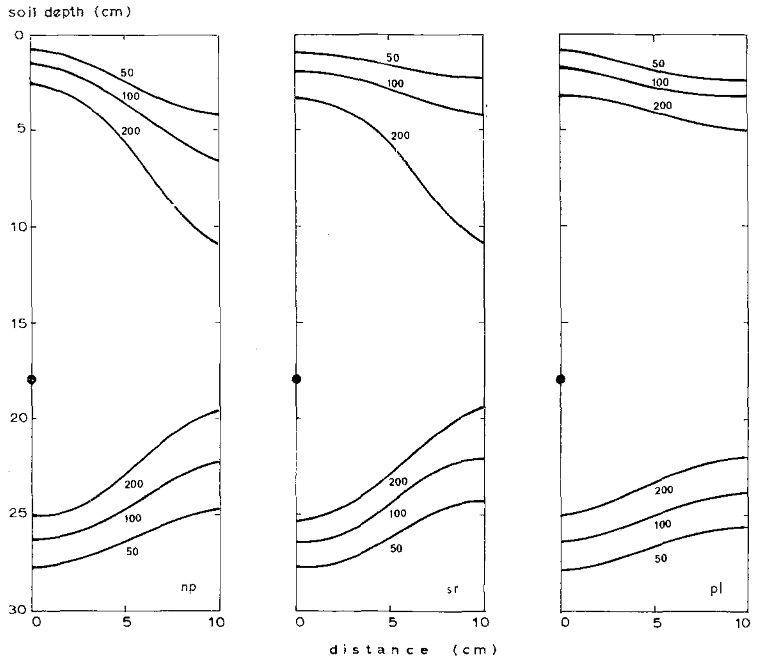

Fig. 2. Dosispatroon van methyl isothiocyanaat na injectie van metam-natrium in lijnen op een afstand van 20 cm. Iso-dosis lijnen voor 50, 100 en 200 μg cm^{-3} dag. np = geen voorbewerking, sr = ondiep frezen, pl = ploegen, ● = plaats van de injectielijn.

comparatively small zone with the higher doses between the injection tracks. In addition, the dose pattern is rather flat here as is shown by the great distance between the different iso-dose lines. Such doses are build up of low concentrations, which are likely to be less effective. These flat patterns also indicate that, for somewhat less favourable conditions, the iso-dose lines will shift over great distances.

After shallow rototillage as precultivation, a better overlap is obtained with the lower doses in the top of the profile. The position of the line for 200 $\mu g\ cm^{-3}$ day is almost the same as before, so the pattern is still rather flat. The dose pattern underneath the injection depth is little affected by this shallow cultivation. With injection in a ploughed soil, about the same position of the 50 $\mu g\ cm^{-3}$ day line is found, while undulation of the lines for the higher doses is comparatively small. The average position is much closer to the soil surface and the pattern is much steeper than in the previous cases. Underneath the injection depth, undulation is less and a deeper average penetration is found, though the effect is less than near the soil surface. Injection as a plane was simulated for the same conditions as in Case 7a. The position of the iso-dose lines were very close to the average position of the dose lines with line injection under similar conditions.

For a careful injection with a shank injector, much tractive power is needed. For that reason one is occasionally inclined to decrease the number of shanks and to increase the distance between the shanks at the same time. In a series of computations,

Fig. 3. Dose pattern of methyl isothiocyanate after injection of metam-sodium in lines at a distance of 30 cm. Iso-dose lines for 50, 100, and 200 $\mu g\ cm^{-3}$ day. np = no precultivation, sr = shallow rototillage, pl = ploughed.

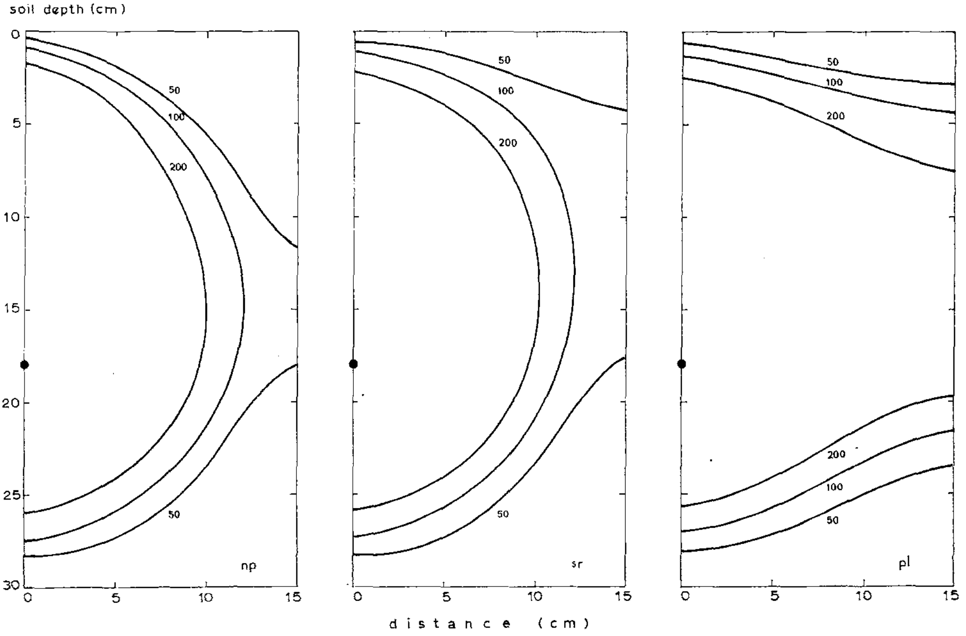

Fig. 3. Dosispatroon van methyl isothiocyanaat na injectie van metam-natrium in lijnen op een afstand van 30 cm. Iso-dosislijnen voor 50, 100, en 200 $\mu g\ cm^{-3}$ dag. np = geen voorbewerking, sr = ondiep frezen, pl = ploegen.

injection with the shanks at a distance at 30 cm was simulated (Cases 5b, 6b, 7b). For the rest, the situations were identical to those in the corresponding cases with 20 cm distance between the shanks.

The computed dose patterns for the wide shank spacings are given in Fig. 3. With the injection in non-precultivated soil, a poor overlap of the dose patterns is obtained. The zone of overlap of the 50 $\mu g\ cm^{-3}$ day line is small and the lines for the higher doses do not overlap at all. After shallow rototillage, the position of the line for the lowest dose is somewhat better, but that for the higher doses is hardly affected, just like that for the iso-dose lines underneath the injection depth. With injection in ploughed soil, the dose pattern is much more favourable. There is an overlap of the higher doses and the position of the line for 50 $\mu g\ cm^{-3}$ day is closer to the soil surface. However, the amplitude in the undulation of the iso-dose lines is substantially greater than with the 20 cm shank spacing.

Even with careful application by shank injector under favourable soil conditions, the overlap of the pattern of effective doses may thus be poor. Especially if soil is not precultivated to injection depth, the effectivity will be lower than with other types of apparatus. With increasing distance between the shanks, the overlap of the effective-dose patterns becomes much worse. In practice there are often a number of additional difficulties like the comparatively great chance of blockage in the sprayers, the lack of check possibilities with respect to the release rate, a too flexible mounting of the shanks, too many shanks in proportion to available tractive power, poor finishing-off particularly of the injection tracks, etc. Each of these imperfections can make the dose pattern much more unfavourable than outlined here.

Duration of the period with after-effects

It is well-known that the duration of the period in which after-effects may occur is strongly dependent on soil and climatic conditions. However, there may be a doubt about the relative importance of factors like soil moisture and temperature. Predictions on the necessary length of the waiting period under various conditions are helpful in making recommendations. In a series of computations, soil fumigation by application with a horizontal-blade injector of 400 l of metam-sodium solution per ha was simulated. The concentration at the injection depth was taken as a measure of the residue level of methyl isothiocyanate. Constant conditions were taken, details of which are given in Table 1.

In the first run (Case 8), fumigation of a moist loam soil (pF about 2.1) at 15 °C was simulated. The concentrations computed for the injection depth of 18 cm are represented in Fig. 4. After four weeks, the concentration had fallen to low values. For the same soil under drier conditions (pF about 2.5, Case 9) the decrease in concentration was more quickly. When the soil is injected under too wet conditions (pF about 1.5, Case 10), the period with after effects is somewhat longer than that under moist conditions. Temperature effect was studied by simulating fumigation of the moist loam soil at 5 °C (Case 11). In Fig. 4 it is shown that the decrease in concentration is much slower than at the higher temperature. For estimations on the duration of the period with risk of after-effects, soil temperature should be taken into account first of all.

To trace differences per soil type, fumigations of a humic sand and a peaty sand soil at 15 °C were simulated. Moisture contents in the standard situations corresponded

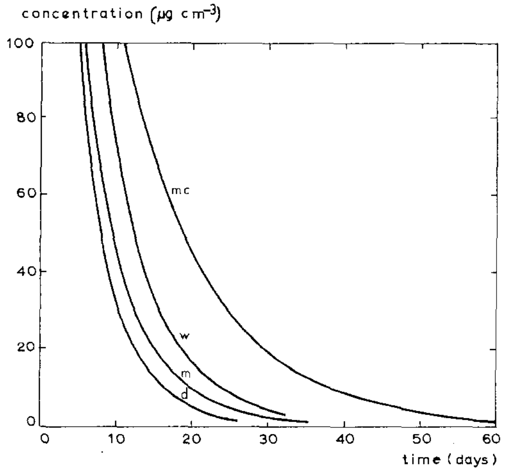

Fig. 4. Concentration of methyl isothiocyanate in the water phase at injection depth (18 cm) in a loam soil. m = moist, d = dry, w = wet, mc = moist and cold (5 °C).

Fig. 4. Concentratie van methyl isothiocyanaat in de waterfase op injectiediepte (18 cm) in een kleigrond. m = vochtig, d = droog, w = nat, mc = vochtig en koud (5 °C).

with about pF 2.0 for both, the humic sand (Case 1) and the peaty sand (Case 3). Details on the selected situations are given in Table 1. The concentrations computed for methyl isothiocyanate at the injection depth are given in Fig. 5. The decrease to low values in the humic sand soil takes about seven weeks, so the period with possible after-effects is much longer than for the loam soil. The difference is mainly caused by the lower decomposition rate in the humic sand soil. Initially, concentrations in the peaty sand soil are lower than those in the humic sand soil due to the greater adsorption and the greater dilution. However, difussion is slower in peaty sand and decrease to low concentrations takes almost the same time. With fumigation under drier conditions (pF about 2.5) of the humic sand soil (Case 2) and the peaty sand soil (Case 4) the low values are found after five weeks.

To show how long residues may persist under adverse conditions, fumigation of a rather wet peaty sand (pF about 1.5) at 5 °C was simulated (Case 12). Several months are needed for the concentrations at the injection depth to drop to low values. With

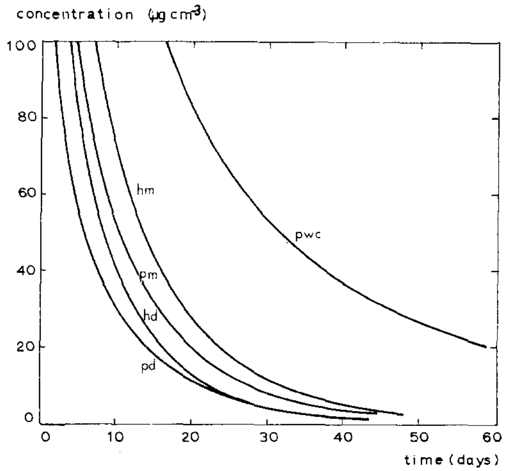

Fig. 5. Concentration of methyl isothiocyanate in the water phase at injection depth (18 cm). hm = humic sand, moist; hd = humic sand, dry; pm = peaty sand, moist; pd = peaty sand, dry; pwc = peaty sand, wet and cold.

Fig. 5. Concentratie van methyl isothiocyanaat in de waterfase op injectiediepte (18 cm). hm = humeus zand, vochtig; hd = humeus zand, droog; pm = venig zand, vochtig; pd = venig zand, droog; pwc = venig zand, nat en koud.

fumigation under cold and wet conditions late in autumn, there is thus a great risk of damage being done to the crop grown in spring.

Balance-sheet of decay processes

With a few extensions of the computer programs, the balance-sheet of decay processes can be approximated. The amount, V_{up} (j) diffusing per time step, Δ t, from computation compartment 2 to the soil surface can be approximated with:

$V_{up}(j) = D_p\, C_g(2,j)\, \Delta t/\Delta x.$

D_p is the fumigant diffusion coefficient for the soil gas phase, C_g the concentration in the gas phase, and Δx compartment thickness. The same type of equation can be used to estimate amounts of fumigant diffused downwards at a selected depth, for example 50 cm in the profile. The amount, B(i, j), broken down and taken up by organisms per compartment and per time step can be approximated with:

$B(i, j) = (1\text{-}\exp(\text{-}k_r\, \Delta t))\, C_g(i, j)\ \varnothing(i, j)\, \Delta\, x.$

A first-order rate equation is assumed with rate constant k_r.The fumigant capacity factor, $\varnothing$, of the soil was defined by Leistra (1972). The summation of all these amounts over the fumigation period gives the balance sheet of decay processes. These computations were included in those on the period with after-effects and details for the situations are given in Table 1.

At 15 °C, the amounts decomposed in the humic sand and loam profiles corresponded with about 70 % for the drier conditions (Cases 2 and 9) to about 95 % for the wetter conditions (Cases 1 and 8). In the humic soils with low decomposition rates, diffusion is slower so there is more time for break-down. Diffusion to depths greater than 50 cm was negligible in all instances. The supplementary part of methyl isothiocyanate was removed by evaporation at the soil surface. Leaching is not considered here, but may be important under certain conditions (Leistra, 1973). This balance sheet for methyl isothiocyanate is very different from that for the fumigants decomposing more slowly in soil, with which evaporation at the soil surface is the predominant decay process.

Conclusions

Computation models are suitable to trace the effect of one single factor on effectivity and on the duration of the period with after-effects. The relative importance of the various factors and the nature of their effects is clearly shown. Results for metam-sodium and its active conversion product methyl isothiocyanate are remarkable in several respects. Although adsorption is comparatively low, sufficient effectivity with peaty soils will be more difficult to attain than with humic sand and loamy soils. Retardation of the diffusion in peaty soils is comparatively great as a result of both, the stronger adsorption and the greater dilution at the usually higher moisture contents. There is then more time available for decomposition near the injection position. One of the most remarkable results is that fumigation at the lower soil moisture contents in the favourable range gives comparatively high concentration-time products for methyl isothiocyanate.

With injection of metam-sodium as a line, precultivation of the soil is a very important factor. In practice, cultivation is often shallow which will be an obstacle for the achievement of the desired effectivity. The line injection geometry itself is presumably not a drawback, provided the distance between the shanks is 20 cm or less. However, several technical improvements are needed with the shank injectors before reliable use is feasible.

Soil temperature seems to be the predominant factor with regard to the length of the waiting period. With applications of metam-sodium late in autumn or in winter there is a great chance that active concentrations are still present in spring. Dependent on the amounts of rainfall, leaching will be more or less deep. Usually, part of the residue will be left in the root zone and part of it may be leached out of the profile. The great importance of soil temperature is related to the predominance of decomposition in the decay of methyl isothiocyanate. Restriction of the application of metam-sodium to the period up to early autumn seems desirable.

The soil behaviour characteristics of methyl isothiocyanate are such that in several respects adapted recommendations are needed for its use. Many difficulties dealing with both effectivity and side-effects, can be avoided by following such recommendations.

Samenvatting

Voorspelling van effectiviteit en nawerking door het simuleren van grondontsmettingen met metam-natrium

De combinatie van rekenmodellen met basisgegevens over diffusie, verdeling over de fasen en afbraak maakt het mogelijk voorspellingen te doen over het afzonderlijke effect van elk der belangrijke factoren bij grondontsmetting met metam-natrium. De effectiviteit werd vergeleken aan de hand van de concentratie-tijd produkten van het actieve omzettingsprodukt methyl isothiocyanaat.

In een simulatie serie werd de factor organische-stof gehalte van de grond gevariëerd. Daarbij bleek dat het moeilijk zal zijn om bij venige zandgronden (dalgronden) een voldoende bestrijding van nematoden te bereiken (Fig. 1). Het beste effect is nog te verwachten onder wat drogere bodemomstandigheden.

Gesimuleerd werd ook de injectie van metam-natrium als lijn, zoals dat bij tandinjectie voorkomt. De positie van de iso-dosis lijnen werd vergeleken met de positie bij injectie als een vlak met een schaar- of ploeg-injecteur (Fig. 2 en 3). Vooral bij een ruime tandafstand en het weglaten van voorbewerking tot de injectiediepte is het dosispatroon bij tandinjectie ongunstiger.

De duur van de periode met nawerking kan variëren van enkele weken tot verscheidene maanden. Het vochtgehalte van de grond heeft hierop enige invloed. De belangrijkste factor is hier echter de bodemtemperatuur (Fig. 4 en 5), omdat de afbraak van methyl isothiocyanaat bij hogere temperaturen aanzienlijk sneller verloopt. Naast de afbraak als belangrijkste verdwijningsproces, is er ook nog wat vervluchtiging aan het bodemoppervlak. De diffusie naar diepere lagen is uiterst beperkt, maar er moet wel rekening worden gehouden met de kans op uitspoelen onder natte en koude omstandigheden. Ook met het oog op de nevenwerkingen moet gestreefd worden naar een zo vroeg mogelijke toepassing in de zomer of in het begin van de herfst.

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Book review

K. F. Baker, G. A. Zentmeyer & E. B. Cowling (ed.): Annual Review of Phytopathology, Vol. 11. Annual Reviews Inc., Palo Alto (Calif.), USA 1973: 559 pp.; author and subject indexes; cloth bound, dust jacket; Price $ 12 (USA) and $ 12.50 (elsewhere).

With this volume the second decade of Annual Review of Phytopathology has begun. It starts with an interesting preface by Dr C. W. Bennett, which presents some considerations of factors important in the growth of the plant pathology against the author's long personal experience with virus diseases and virus research.

The 22 reviews that follow, with extensive lists of references, contain a wealth of information on various specialized subjects. Several are grouped under headings such as pathogens, morphology and anatomy, physiology of host-pathogen interaction, epidemiology, influence of environment, chemical control, and control by biological means and by cropping methods. Some subjects of more general interest are: a historical study of 'the great Bengal famine' in 1943, mainly due to an epidemic of *Helminthosporium oryzae* in rice (Padmanabhan); an appraisal of 'threatening plant diseases' (Thurston); 'a lysosomal concept for plant pathology' (Wilson); a discussion of 'genetic variability in crops' especially in their host-pathogen interactions (Day); 'trends in breeding for disease resistance in crops' (Roana), and a survey of 'the development and future of extension plant pathology in the United States' (Sherf).

The number of subjects is too large and their nature too divergent for a detailed review. Most of the contributions are outstanding and will be welcomed especially by those who cannot themselves cope with the flood of scientific literature.

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