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QUANTITATIVE EFFECT OF FUMIGATION WITH 1, 3-DICHLOROPROPENE MIXTURES AND WITH METHAM SODIUM ON THE SOIL NITROGEN STATUS

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ABSTRACT

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It is a well-known fact that soil fumigation with 1, 3-dichloropropene mixtures and metham sodium influences the nitrogen status of the soil. Fumigation gives a partial sterilization of the soil. Lysis of the killed biomass provides the surviving flora with new substrate which leads to an extra mineralisation, the so-called flush. The gain in nitrogen is approx. 5—10 kg N/ha.

The inhibition of the process of nitrification retards the conversion of ammonium nitrogen, which is strongly adsorbed to the soil, to nitrate.

In agriculture, soil fumigation normally takes place in autumn. The gain in nitrogen in spring after autumn fumigation can be attributed to a reduction in loss of nitrogen by diminished leaching and diminished denitrification of nitrate.

The gain in nitrogen depends on the rate of mineralisation, time of recovery of nitrification and weather conditions during the winter. Important factors are also type of soil and date of fumigation.

The differences between 1, 3-dichloropropene mixtures and metham sodium can be attributed to their different behaviour towards the nitrifiers.

INTRODUCTION

For the growing of potatoes, about 30 000 ha of land are fumigated yearly in The Netherlands. As fumigants, the 1, 3-dichloropropene-containing mixtures such as Shell DD, Vidden D and Telone, are mainly used. In recent years, the use of metham sodium has increased and a further increase is expected. The biocidal effect of both chemicals is not restricted to the killing of nematodes. The use of these chemicals has raised the question whether soil fertility is influenced.

The effect of partial sterilisation (Waksman and Starkey, 1923; Gasser and Peachy, 1964) and the well-known inhibition of nitrification (Tam, 1945; Wolcott et al., 1960; Koike, 1961) by both chemicals made an effect on the nitrogen status likely. The question arose whether the recommendations to the farmers about fertilisation with nitrogen, based on the amount of inorganic nitrogen remaining after winter, should be corrected for those soils which were given autumn fumigation. The investigations were at first restricted to the sandy soils in the northeastern part of The Netherlands. As marine sediments have recently been involved in soil fumigation, these soils were included in the investigations. After the introduction of metham sodium as fumigant against the potato eelworm, a comparative study of DD and metham sodium (MS) was made.

METHODS AND MATERIALS

Soil

Field trials were carried out on soils on which potatoes were grown. The sandy soils (partly peaty sand soils) varied in organic matter content, the marine sediments mainly in clay content. For the marine sediments the fraction $< 16\ \mu m$ is given. The lutum content ($< 2\ \mu m$) of these soils is about 2/3 of the fraction $< 16\ \mu m$.

Soil from field trials was taken for pot experiments.

Chemicals

Shell DD and Vidden D, both containing 55% 1, 3-dichloropropene were used at a rate of 250 l/ha.

A metham sodium solution (AA MONAM) containing 380 g metham sodium per litre was used at a rate of 400 l/ha.

Mode of injection

Fields of large size were injected with a blade or plough injector, commonly used in practice.

Small fields were injected with a hand injector, at a rate of 16 injections/m^2. The injection depth was in all cases 18 cm.

Soil sampling

Samples were taken from the layer 0—40 cm deep. Nitrogen was determined as much as possible immediately after sampling, otherwise the samples were stored at 2° C.

Detection of nitrogen

The method of Cotte and Kahane (1946) was used for determination of mineral nitrogen. The amount of nitrogen was given in µg/kg dry soil. From the volume weights the amount of nitrogen, in kg/ha, in the layer 0—40 cm was estimated.

EFFECT OF PARTIAL STERILISATION

Chemicals with a broad action spectrum such as DD and MS kill a considerable part of the biomass. Lysis of the killed biomass provides the surviving microflora with new and to some extent, readily available substrate. The mineralisation of this substrate together with probably a small priming effect gives an extra contribution to the inorganic nitrogen content, the so-called "flush". The contribution depends on the amount of biomass, which is connected with the type of soil.

In a number of sandy soils, the flush was measured after fumigation with DD. Results are summarized in Fig.1 (mean values). From this figure, it can be seen that the contribution of the flush to the inorganic nitrogen content, expressed in kg N/ha, varies from 4 to 12 kg, depending on percentage and type of organic matter. In the soils with a high organic matter content, the organic matter consists mainly of material (peat) highly resistant to microbial decomposition. Above 10% organic matter, the flush remains constant. Although the organic matter content of marine sediments is generally lower (1—3%), the total biomass is not necessarily smaller. As an average for all soils, the flush is estimated at 10 kg N/ha after DD and MS treatment.

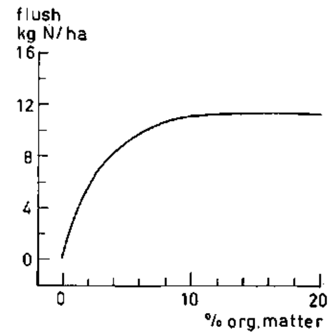

Fig.1. Relation between the flush and the organic matter content on sandy and peaty sand soils.

INHIBITION OF NITRIFICATION

Inhibition of nitrification after fumigation results in an accumulation of NH_4-nitrogen, both from flush and normal mineralization. In this form, the nitrogen is strongly adsorbed to soil particles. The possibility of loss of nitrogen by leaching or denitrification of nitrate is decreased.

Inhibited nitrification during autumn and winter after fumigation may result in a higher amount of inorganic nitrogen in the soil in spring.

The level of NH_4-nitrogen which can be reached depends on different factors.

Rate of mineralisation and date of fumigation

The process of mineralisation is a microbial process and depends on physica and chemical properties of the soil. The presence of fresh substrate in the form of protein-rich plant residues after harvest and rather high soil temperatures, are good conditions for rapid mineralisation.

In connection with this, the date of fumigation is important. Inhibited nitrification at a high rate of mineralisation leads to high levels of NH_4-nitrogen. Late fumigations at lower rates of mineralisation result in lower ammonium levels and the nitrogen mineralised and converted to nitrate before the fumigation is subject to leaching and denitrification. However, the possibility of recovery of the nitrification before the winter is greater after an early fumigation

The amount of NH_4-nitrogen present in March after autumn fumigation witl DD on different dates on different soils, is given in Fig.2 and 3.

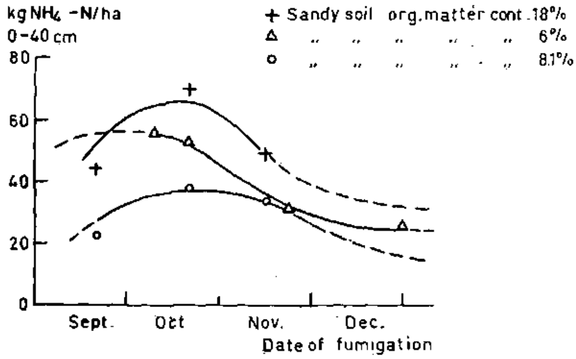

Fig.2. The amount of NH_4-nitrogen in kg N/ha on sandy soils in March after autumn fumigation with DD at different dates.

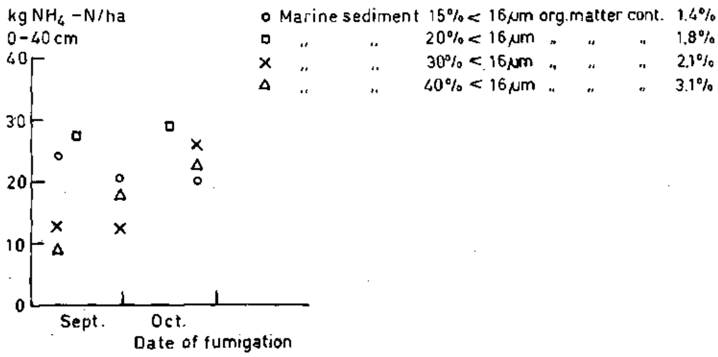

Fig.3. The amount of NH_4-nitrogen in kg N/ha on marine sediments in March after autumn fumigation with DD at different dates.

From Fig.2 is seen that early fumigations show lower NH_4-contents, as a result of partly recovered nitrification. Later fumigations give lower NH_4-contents because of lower rates of mineralisation (lower soil temperatures). The highest level is found when fumigation is performed in the first half of October, the main fumigation period (normal date). There is some difference between the soils (the soils with 18 and 8.1% organic matter are peaty sand soils) with regard to rate of mineralisation. On most of the sandy soils, a NH_4-level corresponding to about 50 kg N/ha can be expected after fumigation at the normal time.

The picture for marine sediments (Fig.3) is still incomplete, more data are needed. The mutual differences among the soils are small. For these soils, the period suitable for tillage operations and fumigation is normally shorter than for sandy soils because of a greater sensitivity to weather conditions. Although there is an indication that later fumigations give higher NH_4-levels, the differences remain small.

The levels are much lower than on sandy soils, corresponding to about 20 kg N/ha.

Duration of the inhibition of nitrification

By following the course of the NH_4-content in the soil after fumigation, the recovery of nitrification was studied. Results for a sandy soil and a marine sediment are given in Fig.4 and 5.

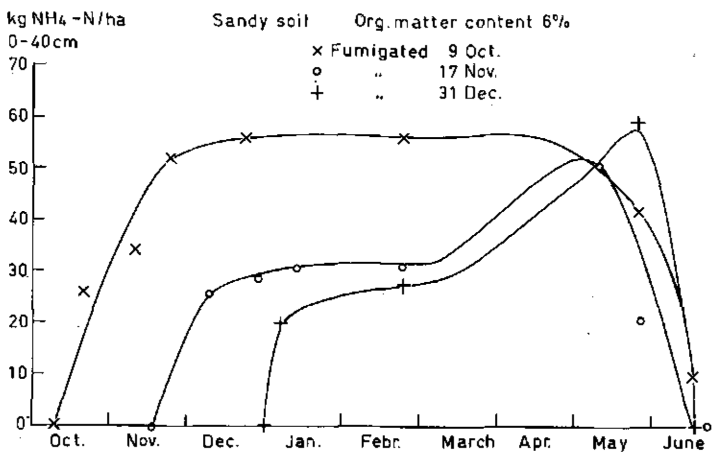

Fig.4. The course of the NH_4-content on a sandy soil after fumigation at different dates.

Fumigation of sandy soils (Fig.4) at the normal time, resulted in an NH_4-content which remained constant for some time after winter. Apparently in this period, the rate of mineralisation is equal to the rate of nitrification. Not until the end of May or the beginning of June did the NH_4-level reach its

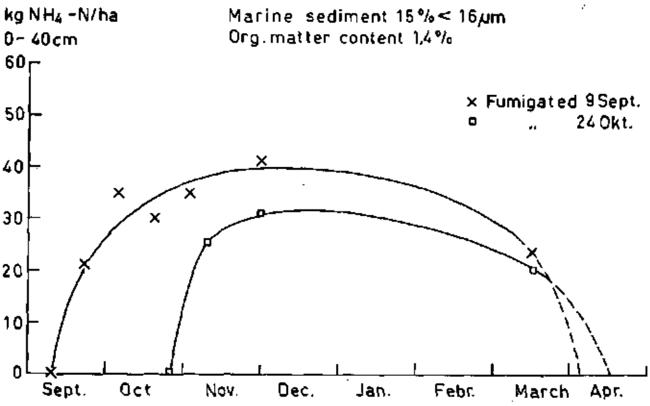

Fig.5. The course of the NH_4-content on a marine sediment after fumigation at different dates.

normal low value as a result of recovery of the nitrification process. Late fumigations show a further increase of the NH_4-content in spring. Apparently the rate of mineralisation is higher than the rate of nitrification. However, the NH_4-level reached its normal low value in the same period as after fumigation on the normal date.

Fig.5 suggests that the NH_4-level in marine sediment reaches its maximum in autumn and a decrease is already seen during winter. The earlier the fumigation the sooner the recovery of nitrification. The diminished mineralisation at a late fumigation, resulting in a lower NH_4-content before winter, seems to be compensated for by a slower recovery of the nitrification during winter.

The behaviour of the chemical towards the nitrifiers

By following the course of NH_4-content in the soil, a comparison was made between DD and MS with respect to their toxicity for the nitrifiers. For a sandy soil results are given in Fig.6 for a marine sediment in Fig.7.

Fig.6 shows that fumigation of a sandy soil with MS resulted in a lower NH_4-content after winter, in comparison with DD. Nitrification was reduced after fumigation with MS. This contrasts with the effect of DD, which completely inhibited nitrification for some time after treatment. With late fumigations the differences between DD and MS become smaller. MS probably behaves more like DD at lower soil temperatures. From the total amount of inorganic nitrogen (not given in Fig.6) it was seen that the mineralisation after DD treatment was equal to the mineralisation after MS treatment.

The NH_4-content in March after fumigation with MS on the normal date amounts to 30 kg N/ha.

According to Fig.7, the picture for marine sediments is as follows: In comparison with DD, the NH_4-content decreases more rapidly after fumigation with MS. Complete recovery of nitrification before winter occurred with early

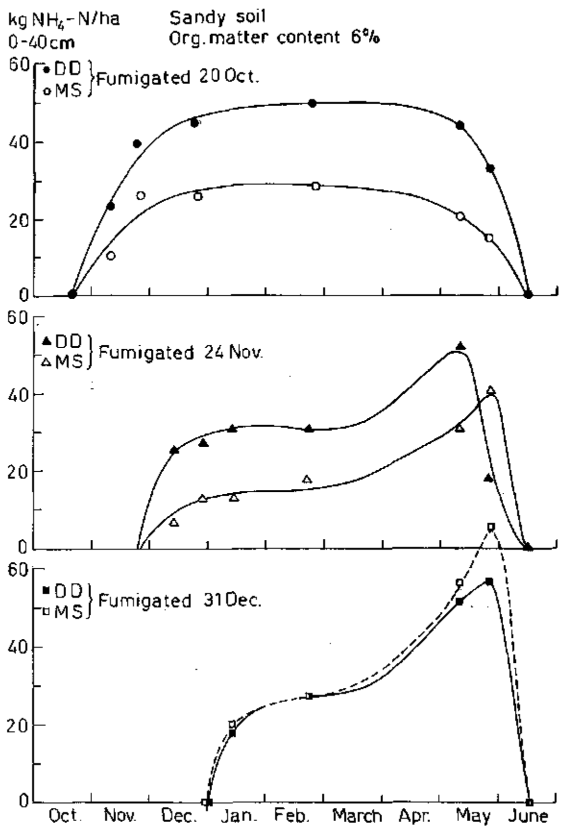

Fig.6. The course of the NH_4-content after fumigation with DD and MS on a sandy soil.

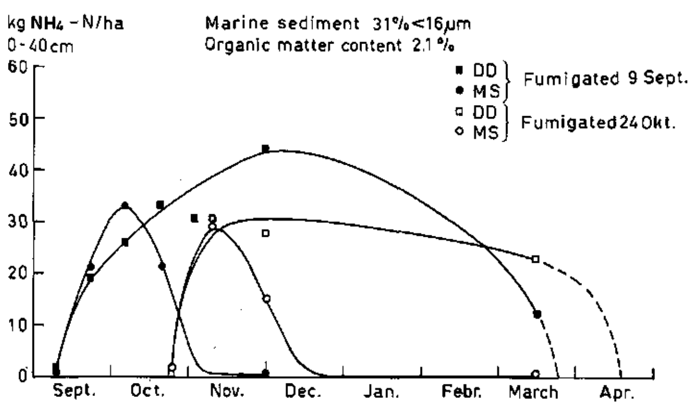

Fig.7. The course of the NH_4-content after fumigation with DD and MS on a marine sediment.

fumigations with MS. The partial recovery of nitrification before winter in the case of late fumigations with MS, is completed in winter. No NH_4-nitrogen after fumigation with MS is found in March.

THE GENERAL INFLUENCE OF THE WEATHER DURING WINTER ON THE INORGANIC NITROGEN CONTENT OF THE SOIL AFTER WINTER

The main losses of nitrogen during winter result from leaching and denitrification of nitrate. Depending on rainfall, the loss in nitrogen may vary from no loss in dry winters to complete loss after wet winters.

With fumigation with DD or MS for sandy soils in fact, a dry winter is imitated. The completely or at least strongly reduced nitrification prevents loss of nitrogen. On marine sediments the degree of recovery of nitrification, in periods of rainfall, determines how great the loss in nitrogen will be.

From other investigations of these soils (untreated) it is known (Van der Paauw, 1963) that the difference between a dry and wet winter in terms of total inorganic nitrogen remaining after winter for most soils is about 40 kg N/ha.

After a normal winter in The Netherlands (average rainfall of 75, 65, 60 and 40 mm for November, December, January and February, respectively, according to the KNMI (Royal Dutch Meteorological Institute)), about 20 kg N/ha can be found on sandy soils and about 25 kg N/ha on marine sediments (G.J. Kolenbrander, unpublished data).

ESTIMATION OF THE INORGANIC NITROGEN CONTENT IN FUMIGATED FIELDS AFTER WINTER

On the basis of rainfall and the results of the fumigation experiments, an estimation of the amount of inorganic nitrogen after winter was made for soils fumigated at the normal time. The results are summarized in Table I. The gain in inorganic nitrogen after fumigation with DD on sandy soils varies from 10 kg N/ha (flush and dry winter) to 50 kg N/ha (wet winter). After a normal winter, the gain is about 30 kg N/ha. Fumigation with MS gives a gain of 10—30 kg N/ha, after a normal winter about 20 kg N/ha.

TABLE I

The amount of inorganic nitrogen in kg/ha remaining after winter in soils fumigated with DD and metham sodium (MS)

	Sandy soils			Marine sediments		
	Untreated	DD	MS	Untreated	DD	MS
Dry	40	50	50	40	50	50
Normal	20	50	40	25	35	25
Wet	0*	50*	30*	0*	20*	0*

*All nitrate-N lost.

The gain in nitrogen on marine sediments after fumigation with DD and MS is much lower; for DD it is 10—20 kg N/ha and for MS, 0—10 kg/ha.

CONSEQUENCES OF THE EFFECT OF FUMIGATION ON NITROGEN STATUS OF THE SOIL

Consequences in a quantitative sense

A correction of the recommendations for nitrogen fertilization for sandy soils after fumigation with DD or MS at the normal date is needed, especially to prevent lodging of cereals.

A relatively small gain in nitrogen can be expected in marine sediments after fumigation with DD and MS. The necessity of a correction on fertilization with nitrogen for these soils, especially after fumigation with MS, is doubtful.

Consequences in a qualitative sense

The form in which nitrogen is available to the plant influences the uptake of ions and the chemical composition of the plant (Wolcott et al., 1960; Kirkby and Hughes, 1970). After soil fumigation, the ammonium content may reach toxic levels for some crops (Davidson and Thieghs, 1966), especially when ammonium-containing fertilizers are given in the absence of nitrate and under inhibited nitrification. In The Netherlands, such conditions were present in a few cases after a wet winter on sandy soil after fumigation with DD. A retarded growth of barley was seen. With resumed nitrification at the end of May, the crop started growing, but gave a low yield.

In cases where toxic levels of ammonium nitrogen can be expected, it is advisable to give fertilizer nitrogen at least partly in the form of nitrate.

CONCLUSIONS

(a) The partial sterilisation effect of DD and MS contributes about 10 kg N/ha to the inorganic nitrogen level in soil.

(b) The ammonium level found in the soil in March after autumn fumigation depends on date of fumigation, rate of mineralisation, duration of inhibition of nitrification (toxical effect of the chemicals on the nitrifiers) and type of soil.

(c) The recovery of nitrification on marine sediments is more rapid than on sandy soils.

(d) DD is more toxic to the nitrifiers than MS.

(e) The amount of rainfall during autumn and winter determines what gain in nitrogen can be expected.

(f) For sandy soils a correction on the recommendation for fertilization with nitrogen is needed, especially for cereal production. It is still doubtful if a correction is needed for marine sediments.

(g) In cases where toxic levels of ammonium nitrogen can be expected, it is advisable to give the fertilizer nitrogen at least partly in the form of nitrate.

ADDENDUM

Some additional results on the effect of fumigation on the nitrogen status of the soil.

The winter of 1973—1974 with a rainfall in the months October, November, December, January and February of 105 mm (75); 100 mm (75); 85 mm (60); 65 mm (60) and 30 mm (40), respectively, can be considered as being in between normal and wet winters. The numbers between brackets give the rainfall for a normal winter.

The gain in inorganic nitrogen on sandy and peaty soils in March 1974 after fumigation in autumn 1973 was 30—40 kg N/ha for DD and 20—30 kg N/ha for metham sodium (MS), completely in agreement with the estimated values in Table I.

In the marine sediments again, a complete recovery of the process of nitrification before the winter was seen after fumigation with MS, whereas the recovery was incomplete after fumigation with DD. The gain in nitrogen in MS-fumigated fields was negligible but varied from 5—10 kg N/ha in DD-fumigated fields. For MS these results are in agreement with the estimated values in Table I, for DD the results are about 5 kg N/ha lower than the estimated values.

From these results and from the results of preceding years, the conclusion seems justified that there is no need to reconsider the advice to fertilize marine sediments with nitrogen after fumigation with DD and metham sodium.

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