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The influence of soil steaming on some properties of the soil and on the growth and heading of winter glasshouse lettuce. I. Changes in chemical and physical properties

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Summary

The change in some chemical properties due to steaming is described and discussed in relation to facts already observed by other investigators. The most marked changes are an enhanced solubility of salts and organic substances. The concentration of NH_4-N increases and persists for a long time. It decreases when the nitrification becomes active again. Available manganese is found to be enormously increased and again the high concentration is maintained for a long time. Leaching proved favourable depressing the surplus of soluble salts and soluble organic material. However, the amount of available manganese increased by this treatment. The addition of gypsum had no effect on the Mn or NH_4-N availability; without effect was also the addition of nitrifying bacteria. The addition of ground straw, if added in an appropriate quantity, appeared to be favourable, immobilizing the large quantity of NH_4-N and also reducing the available Mn. Steaming of soil only caused small changes in the pH (water). The changes in some other soil properties are discussed.

Introduction

Soil steaming is necessary in the glasshouse to protect the main crop (tomatoes or cucumber) from diseases caused by soil fungi and nematodes. As a rule, steaming in the glasshouses is performed in late summer and then in the autumn winter lettuce is planted. The main drawback of this procedure is the poor heading of the lettuce and a too luxurious vegetative growth and failure of fruit setting (especially of the first bunch) of the following tomato crop.
The aim of this study was to trace the factors in steamed soil responsible for the bad heading in winter lettuce.

Materials and methods

The investigation was performed in Mitscherlich pots with one plant per pot of the variety Proeftuin's Blackpool. The soil used was a mixture of clay and underlaying peat. Its main characteristics were: 22% organic matter, 0.1% $CaCO_3$ and a pH (water) of 7.1. This soil is typical for the appearance of the above-mentioned effects after steaming.

As well the steamed as the fresh soil were treated in the following ways:

1. *Leached* to remove a part of the water-soluble substances, which are increased by steaming. Water was poured quickly on the pots till a layer of about 10 mm was formed on the soil. This procedure was repeated three times with intervals of one day.
2. *Left untreated.*
3. *Dressed with gypsum* (2 tons per ha). By this treatment the damage to the crops, caused by too high a concentration of ammonium carbonate would be prevented (Hofmann, 1939).
4. *Provided with ground straw* (0.3 %, dry basis) to immobilize the excess of ammonium nitrogen brought about by steaming (33 ppm). The C/N ratio was hereby raised to 25. This moderate C/N ratio was presumed to be high enough for immobilization of an excess of soluble nitrogen but still sufficiently low for a continuous mineralization of nitrogen during the growth of the crop. A stimulation of microbial life also may be a favourable consequence of the straw addition.
5. *Enriched with nitrifying organisms* with the intent to stimulate the conversion of ammonia to nitrate.

Each of these treatments had ten replicates.

The soil was steamed in an apparatus consisting of a trough with a perforated bottom hanging in another trough above boiling water. Hereby the soil was heated to 100 °C for half an hour, whereafter it cooled down rapidly. During the treatment the soil became very wet and had to be dried to a manageable state, mixing it twice in the meantime. One month after steaming the soil was put into the pots and planted.

Per pot the following fertilization was given: 0.15 g N as NH_4NO_3, 0.8 g P_2O_5 as $Ca(H_2PO_4)_2$, 0.2 g K_2O as K_2SO_4, and 0.2 g MgO as $MgSO_4 . 7H_2O$. Next to this the following amounts of micro-elements were given, viz. per cubic metre of soil: 10 g $CuSO_4$, 3 g borax, and 3 g $(NH_4)_2MoO_4$.

The soil samples were mainly analyzed by the Horticultural Research and Experiment Station at Naaldwijk applying the methods used there (Den Dekker and Van Dijk, 1963). N, P, K and pH were determined in water extracts of air-dried soil. The amounts of N, P, and K are given in ppm of the soil (dry weight). Mg, Mn, Fe, and Al were determined after an extraction of the soil with a buffer solution at pH 4.8. The amounts of these elements are presented in ppm of the extract.

The experiment described here started in November 1961 and was terminated in March 1962. The 'moment of steaming' is designated as the start of the experiment.

Results

Nitrogen, soluble salt, phosphorus, potassium, magnesium, manganese, iron and aluminium were considered the growth factors presumably affected by steaming. They will be discussed consecutively.

Nitrogen. The steaming of this soil caused an immediate increase of 33 ppm mineral nitrogen, due to a liberation of NH_4-N from decomposed organic material, primarily the biomass. The increase in NH_4-N during steaming was already known (Russell and Petherbridge, 1912; Davies and Owen, 1951; Davies, 1953; and others).

Table 1 NH_4- *and* NO_3-*N (ppm) present in steamed and unsteamed soil during the experiment*

	1 day after steaming			*56 days after steaming*			*79 days after steaming*		
	NH_4-N	*NO_3-N*	*total*	*NH_4-N*	*NO_3-N*	*total*	*NH_4-N*	*NO_3-N*	*total*
not-steamed soil			24	2	72	74	0	91	91
steamed soil			57	79	43	122	73	70	143

Apart from this direct increase of the amount of mineral nitrogen, the mineralization rate of nitrogen in the soil after steaming proved higher than in the fresh soil, due to an accelerated decomposition of available organic matter. The mineral nitrogen, accumulating in this period, especially during the first weeks, was exclusively ammonium-nitrogen. This is a well-known fact in steamed and partially sterilized soil (Richter, 1896; Koch and Lüken, 1907; Pickering, 1908a, b; Russell and Hutchinson, 1909; Russell and Petherbridge, 1912; Potter and Snyder, 1918; Baldwin, 1922; Herzog, 1939; Van Koot, 1942; Malowany and Newton, 1947; Simpson and Newton, 1949; Davies and Owen, 1951, 1954; Roll-Hansen, 1952; Lapensee, 1959; Strømme, 1962; Davidson and Thiegs, 1966; Simone-Sylvestre, 1967). The formation of nitrate was retarded during the first weeks; 56 days after steaming the largest part of the inorganic nitrogen was still NH_4-N and even after 79 days the amounts of NH_4-N and NO_3-N were about equal (Table 1). The exterminated nitrifying organisms seem to be slowly replaced by a new population.

Fig. 1 illustrates the course of nitrogen mineralization for all the objects of the steamed and fresh soil. The starting points for these curves are the amounts of nitrate and ammonia nitrogen present in the soil just after steaming. The start points of the

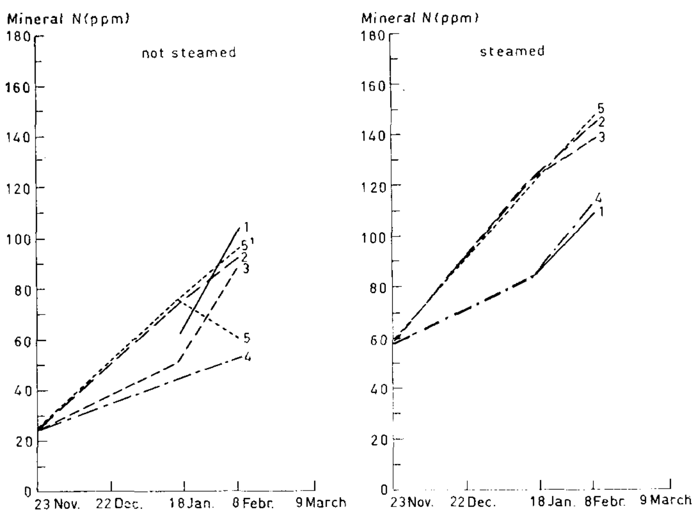

Fig. 1 Nitrogen mineralization in fresh and steamed soil, influenced by the treatments: (1) leached, (2) not leached, (3) as (2) plus gypsum, (4) as (2) plus ground straw, (5) as (2) plus nitrifying bacteria

curves of the leached samples are lower than the others. As these points are not exactly known, only the last parts of these curves are given. Leaching had more influence in removing inorganic and mineralisable nitrogen in steamed than in unsteamed soil. Addition of ground straw depressed the nett mineralization due to immobilization (Strømme, 1962). The decline in curve 5 of the fresh soil after 18 January must be an artefact, a trend like that marked 5^1 had to be expected.

The concentration of *water-soluble salts* of the soil is expressed in percents of the air-dry soil. This and the other remaining soil constituents are brought together in Fig. 2 as block-diagrams, showing the situation:

1. at the start, just before steaming and fertilization,
2. four weeks after steaming, and
3. at the end of the experiment (17 weeks after steaming) for the steamed and fresh soils. For the last period cropped and fallow soils are shown.

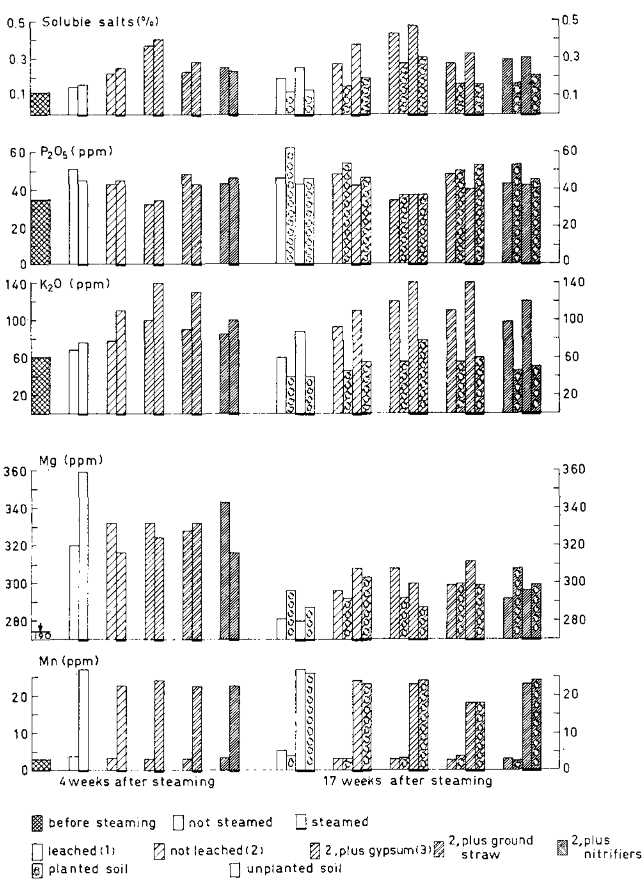

Fig. 2 Some chemical properties of steamed and not-steamed soil in course of the experiment. The influence of the plants is also shown

An increase after steaming is evident, the reducing effect of leaching is also clearly seen, and the addition of gypsum increased the soluble salts as could be expected. Very striking is the effect of the uptake of salts by plants, which was generally higher on steamed than on fresh soil. Such a higher uptake of different elements by plants grown on steamed soil was already observed by Darbyshire and Russell (1908), Russell and Petherbridge (1912), Millikan (1942), and Roll-Hansen (1952). Richter (1896) already noted an increased amount of salt, extractable with cold water from steamed soil. Lyon and Bizzel (1910) reported a 100–600% increase in soluble salts after steaming.

P_2O_5 (water-soluble). There was no clear influence of steaming on the amounts of water-soluble phosphates, and the effect of leaching was nil in steamed soil. The addition of gypsum reduced the solubility of the phosphate by increasing the amount of calcium ions in the soil solution. A similar effect, depending on possibly changed concentrations of cations forming insoluble phosphate compounds could be presumed for steaming. However, in most cases increased amounts of soluble phosphates are reported in the literature: Lyon and Bizzel (1910), Kelley and McGeorge (1915), Van Koot (1942), Malowany and Newton (1947), Roll-Hansen (1952), Lapensee (1959) and Simone-Sylvestre (1967). Baldwin (1922), using soils from various greenhouses, often found increases in acid-soluble phosphates, but sometimes the reverse effect was noticed. Russell and Petherbridge (1913) observed only minor differences in P_2O_5, soluble in 1% citric acid, between steamed and unsteamed soil. Decreased amounts of P_2O_5 after steaming are reported by Herzog (1939) and Sonneveld (1965).

Under the influence of the plant an increase in water-soluble phosphate (except in the case of gypsum addition) was observed. In the rhizosphere of the lettuce roots insoluble phosphates are solubilized, a fact already demonstrated by Gerretsen (1948) for other plants.

K_2O (water-soluble). The solubility of potassium was enhanced by steaming. The effect of leaching is clearly visible, the addition of gypsum increased the amounts of potassium by exchange against calcium ions and the addition of ground straw also enhanced the amount of soluble potassium as the decomposing straw released potassium and other cations, which could be exchanged against potassium in the soil. The uptake of potassium by the plant decreased significantly the amount of water-soluble potassium in the soil.

Most investigators also mentioned increased amounts of soluble potassium due to steaming (Darbyshire and Russell, 1908; Lyon and Bizzel, 1910; Russell and Petherbridge, 1912; Millikan, 1942; Van Koot, 1942; Sonneveld, 1965; Simone-Sylvestre, 1967). Even increases up to harmful concentrations are noticed by Roll-Hansen (1952) for greenhouse soils in Norway. Small increases are mentioned by Kelley and McGeorge (1915), and only Lapensee (1959) found the potassium amounts unchanged after steaming.

Mg (soluble in buffer solution). The influence of steaming on the amounts of Mg in the different treatments was irregular. Comparing the amounts of P and Mg in this experiment, there seems to be a negative correlation. In all cases where the amount of Mg decreases as a result of steaming and treatment the amount of P increases; the reverse holds too. This only applies to the unplanted soil. The formation of insoluble $Mg\text{-}NH_4\text{-}PO_4$ compounds might be responsible for this phenomenon. The uptake by the plants was irregular in the differently treated samples. The very low content of Mg in the fresh soil before steaming must be considered to be determined incorrectly. An increase of water-soluble Mg due to steaming was reported by Kelley and McGeorge (1915), and by Lapensee (1959). Roll-Hansen (1952) observed that tomato plants grown in steamed soil showed a larger variation in their Mg contents than plants from fresh soil.

Mn (soluble in buffer solution). Steaming gave rise to an enormous increase of Mn. The amounts rose from 3–4 ppm in the extract of unsteamed soil to 22–24 ppm in the extract of steamed soil. Leaching of the soil brought about a further slight increase (Ozaki, 1959; Martin et al., 1963; Graven et al., 1965), by reduction during the prolonged wet condition during and after leaching. All other treatments had scarcely any effect. However, the treatment to which ground straw had been added had a lower content of soluble Mn 17 weeks after steaming. The influence of the plants on the soluble Mn content seemed to be insignificant. In a previous experiment the soil had a rather high Mn content (23–24 ppm), which increased by steaming to 33 ppm, and leaching caused a further rise to 46 ppm.

The observed increase of available manganese due to steaming, is a confirmation of earlier studies. Darbyshire and Russell (1908) observed already this fact, reported later by many other investigators. The amount of easily decomposable organic matter in the soil seems by reduction to contribute to the amount of available Mn during steaming, as is observed by McCool (1934) and Graven et al. (1965). The augmentation in available Mn is higher in soils steamed in a wet than in a dry condition (McCool, 1934; Walker and Thompson, 1949; Lapensee, 1959). According to McCool (1934) the amounts become higher, the higher the soil temperature is during steaming. Lapensee (1959) stated that available Mn increases with prolonged duration of steaming. The enormous rise in available Mn, which in acid soils may become harmful to plants (sterilization disease) can be prevented by raising the pH with $Ca(OH)_2$ or by liming (McCool, 1934; Walker and Thompson, 1949; Ozaki 1959; Graven et al., 1965).

Fe and Al (soluble in buffer solution). The amounts of both elements in the extract were only slightly increased by steaming of the soil, viz about 0.2 ppm. Roll-Hansen (1952) observed a small decrease of Fe in plants grown on steamed soil. Sonneveld (1965) reported a small gain in extractable Fe due to steaming. Kelley and McGeorge (1915) reported a rather small increase in soluble Al in steamed soil. Messing (1965b) showed that steamed soil had a higher content of extractable Al than fresh soil. Addition of $CaCO_3$ or superphosphate diminished the amount of extractable Al. The effect of liming and the addition of superphosphate on manganese toxicity in steamed soil was reported earlier by Messing (1965a). Both measures proved to be favourable for the crop production as both depressed total available Mn. It was shown, however, that another factor than Mn was active here in causing 'manganese toxity', as lettuce plants grown in sand culture with high Mn levels may show high Mn contents without symptoms of damage, while plants grown in steamed soil were severely damaged if they had the same Mn content. It was thought that aluminium was the toxic factor.

Other elements are also found to become more soluble due to steaming: boron (Naftel, 1938; Roll-Hansen, 1952), calcium (Russell and Petherbridge, 1912; Kelley and McGeorge, 1915; no change in calcium is reported by Simone-Sylvestre, 1967), silicon (Kelley and McGeorge, 1913), sodium (Lapensee, 1959), sulphur (Lapensee, 1959), sulphate (Malowany and Newton, 1947; Simone-Sylvestre, 1967) and copper (Roll-Hansen, 1952).

Besides the solubility of inorganic compounds, soil steaming enhances also the solubility of *organic material* (Pickering, 1908, and Lyon and Bizzel, 1910, who reported a 6 to 80 fold increase; Potter and Snijder, 1918; Walker and Thompson, 1949).

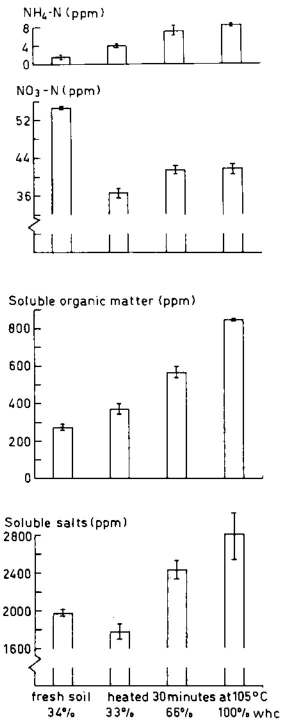

Fig. 3 Soluble salts, soluble organic matter, NO_3- and NH_4-N present in fresh soil and in soil autoclaved at different moisture contents

The degree of solubilization of different compounds depends too on the moisture content of the soil. Fig. 3 demonstrates the dependency of the solubility of total salts (residue after ignition of water extract), organic material (loss on ignition), and the amounts of NH_4-N and NO_3-N of the moisture content of the soil during steaming. The soil samples in this experiment were brought to the desired moisture content and autoclaved for half an hour at 105 °C, a treatment in many respects comparable with steaming. The amount of extractable NH_4-N and of organic compounds increased in proportion to the moisture content. However, the amount of soluble salts proved only higher than that in fresh soil, if autoclaved at high moisture contents. The amount of NO_3-N decreased in this soil, rich in nitrate before autoclaving. The reduction of nitrate in soil during steaming was already reported by Lyon and Bizzel (1910), Russell and Petherbridge (1912), Baldwin (1922), Herzog (1939), Simpson and Newton (1949), Roll-Hansen (1952) and Strømme (1962). Most of these investigators observed an increase of nitrite. This could be confirmed in our experiment.

The pH (water) of the soil at the start of the experiment and of steamed and unsteamed samples in course of time are presented in Table 2. The changes in the pH due to steaming were only small. This is in agreement with earlier observations (Millikan, 1942; Malowany and Newton, 1947; Walker and Thompson, 1949; Davies and Owen, 1953). The pH values measured in leached soil are about 0.1–0.2 units higher

Table 2 Changes in the pH-water in steamed and not-steamed soil during the experiment

	Unplanted			Planted (17 weeks after steaming)
	just before steaming	4 weeks after steaming	17 weeks after steaming	
not-steamed soil	7.1	6.9	6.7	6.9
steamed soil		7.1	6.7	6.8

than in the corresponding unleached soil. In planted soil the pH was 0.1–0.2 units higher than in unplanted soil.
The *waterholding capacity* of the soil may be reduced after steaming (Pickering, 1908a). But according to Malowany and Newton (1947) this reduction is small or even absent. Herzog (1939) observed a reduction of the water-holding capacity after steaming of alcaline soils; in other soils sometimes an increase was observed. She found the structure of heavy soils to be deteriorated if these were poor in humus. In general, the occasionally unfavourable influence of steaming on soil structure is small and can be overcome by a good soil management and addition of organic material.

Discussion

The increase in inorganic substances in soil due to steaming means an increased fertility as more nutrients become available for the plant. However, too high concentrations may become harmful towards the plant, therefore Connor (1922) advised to leach the soil in order to remove the excess of salts.
Roorda van Eysinga (1964) gives detailed information with regard to the mutual relations between initial salt content of the soil, the quantity of water supplied and the salt content of the soil after leaching. Wiebe (1958) considered the high osmotic pressure of the soil solution after steaming as the main cause of the 'sterilization disease'. He found negative correlations between the root growth of cucumber seedlings in 24-hour-tests and total soluble organic compounds, and NH_4-N, and the osmotic pressure of the soil extract, the latter being most spectacular. This holds only when no toxic compounds are present. The main substances responsible for the harmful effect of soil steaming on the growth of plants, mentioned in literature and partly also observed in the present investigation are: ammonium, manganese, nitrite, and some compounds formed and solubilized due to transformations of the organic matter of the soil. The concentration of NH_4-N rises often to very high levels, and it persists for many weeks. It is shown, that the amount of NH_4-N liberated by steaming rises in proportion to: soil organic-matter content (biomass), moisture content, temperature and duration of steaming, and the pH of the soil (Walker and Thompson, 1949; Davies and Owen, 1951; Roll-Hansen, 1952; Davies, 1953). Ammonium hydrogen carbonate, which may be available in the soil during the period of the enhanced microbial activity, was found to be injurious to some plant seedlings (Goss, 1960; Wallace et al., 1959).
The formation of available manganese during steaming proved to be influenced by the same factors and in the same way as was mentioned for ammonia with the exception of pH, as low pH levels enhance the availability of Mn (McCool, 1934; Walker and Thompson, 1949; Lapensee, 1959). Substances with chelating properties

liberated during steaming from soil organic matter may also be responsible for the enhanced availability of Mn and other heavy metals (some amino acids, hydroxy acids, phenolic acids).

The reduction of nitrate during steaming sometimes forms considerable amounts of nitrite, which is toxic to plants. It, consequently, might be advisable to steam a soil soon after the removal of a crop, avoiding nitrate accumulation and the formation of nitrite.

Large increases in soluble organic substances may occur during steaming. In this soluble organic matter compounds may be present showing phytotoxic properties (Pickering, 1908; Russell and Hutchinson, 1909; Lyon and Bizzel, 1913; Rovira and Bowen, 1966). These compounds also inhibit the nitrifying bacteria.

Lyon and Bizzel (1910, 1913) already stated that the toxicity of steamed soil disappears in course of time and that this happens faster when the steamed soil is inoculated with fresh soil. This may be due to the destruction of toxic organic compounds, but also to a sooner start of nitrification and to a reduction of the Mn excess, or most probably to a combination of these processes. The results of Rovira and Bowen (1966) merely point to a destruction of phytotoxic organic compounds by fungi and bacteria, as in their experiments excesses of NH_4-N and Mn did not occur.

The changes taking place in the soil during steaming not only depend on the technique of steaming (temperature, duration, moisture content) but also to a high degree on the soil composition, viz. on the properties of its mineral constituents and especially of the organic matter (amount of biomass, the quantity of reactive organic matter, its parent material, the transformations of that material, and its saturation with cations of different type). More studies are needed to get a better insight in the problems and possible relations, mentioned above.

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