CHANGES OF THE SOIL NUTRIENT STATUS

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SUMMARY

The factors governing the alterations of the soil nutrient status, can be distinguished as easily, and hardly or not changeable, ones. To the first group is reckoned the fertilization and the initial nutrient level. Their effects were investigated in experiments with interference, using the magnesium content of sandy soils as an example. A supposed relationship between these factors and the changes of the magnesium content was laid down in a mathematically formulated model, which after testing on the experimental data appeared to be adequate. The values of the parameters of the formula are considered as characteristics for the fields concerned.

Subsequently the parameter values of the various experiments, that formed together an experiment without interference, were brought into relation with the corresponding organic matter and pH values according to a model that is discussed. These two factors were chosen since they govern the adsorption capacity to a certain extent and consequently the leaching. In doing so, at least the influence of one of the hardly or not changeable factors on the changes of the nutrient level is estimated.

The presented formulas and the values found for the various parameters make it possible to outline a fertilization policy.

INTRODUCTION

In fertilization planning the nutrient status of the soil plays an important role. For most nutrients it can be determined by soil analysis. The figures found serve as a guide in the first growing season after sampling the soil. In the following years they lose their value if the nutrient level changes substantially in the meantime. Soil-fertility specialists should therefore provide knowledge about the alterations to be expected.

Alterations are brought about by fertilization, rainfall, disintegration of soil components and upward movement from the subsoil which are all supplying factors, and by depleting factors such as drainage, fixation, uptake by the crop and volatilization. Apart from these the size of the change may depend on the initial nutrient level. Only the fertilization, the initial nutrient level and to a certain extent the uptake by the crop can be changed. Their effects therefore can, as contrasted with those of the other factors, be examined in experiments with interference. An example relating to changes in the magnesium content of sandy soils in the Netherlands is given in the next paragraph. The other factors mentioned are hardly or not changeable, but in principle it is still possible to determine their effects by means of an experiment without interference. This may consist of a series of experiments

with interference laid out on well chosen fields differing by nature from each other in the factors concerned. By relating the results of the separate experiments to those factors, their influences can be estimated. The principle is demonstrated in the second following paragraph.

EXPERIMENTS WITH INTERFERENCE

The nutrient content of the soil in a certain year can be considered as the sum of the content in the preceding year and the change in the intermediate period. Among other factors the absolute size of the change depends on the initial nutrient level and on the amount of fertilizer applied in the meantime. Presumably the fertilizer influence varies with different initial levels. We therefore use experiments in which different dressings are combined with a desired wide range of initial levels. This can be realized on long-term experimental fields, where a certain fertilizer dressing is not given each year to the same plots. An example of an adequate scheme is given in Table 1. The influence of 0 kg of MgO, for instance, could be investigated in 1961 on plots that were dressed in previous years with 0, 150 and 450 kg of MgO (treatments 1, 6 and 8 respectively), so the magnesium level at the beginning of 1961 could be expected to be rather divergent.

TABLE 1

MgO kg per ha (as kieserite $= MgSO_4 . H_2O$) on treatments 1-9

Years	1	2	3	4	5	6	7	8	9
1954–57–60	0	50	150	0	0	50	50	150	150
1955–58–61	0	50	150	50	150	0	150	0	50
1956–59–62	0	50	150	50	150	0	150	0	50

According to the scheme of Table 1 eleven experiments were laid out. The magnesium content of the soil (extraction with 0·5N NaCl; the figures are expressed as mg of MgO per kg of dry soil) was determined each year between the harvest and the new fertilization in spring. On studying the course of the contents over the whole period and having in mind earlier experience, certain rules in the alterations were noticed, expressed in the following tripartite hypothesis:

> 1. If no fertilizer magnesium is applied, the content sooner or later decreases to an equilibrium level that need not be zero. It is indicated by $x_{eq.0}$, in which 0 stands for no fertilizer magnesium.
> 2. The amount of soil magnesium present exceeding $x_{eq.0}$ is in a one-year period reduced by a factor a_1, the size of which does not depend on the initial amount.
> 3. A spring application of fertilizer magnesium raises the autumn magnesium content proportional to the amount applied. The multiplication factor is called a_2.

In these three points the effects of fertilization and initial level are included. No attention is given to the magnesium uptake by the crop, though this has been described in the introduction as a third changeable factor. Its influence on the magnesium content of the soil has not been studied so far.

The above-mentioned hypothesis can be formulated mathematically. If the magnesium content in the autumn of year t is called x_t, that in the next autumn x_{t+1} and the amount of fertilizer applied in the intermediate spring F, the formula runs:

$$x_{t+1} - x_{eq.0} = a_1 (x_t - x_{eq.0}) + a_2 F$$

or
$$x_{t+1} = a_1 x_t + a_2 F + x_{eq.0} (1 - a_1) \qquad (1)$$

In a two-dimensional graph with x_t on the abscissae and x_{t+1} on the ordinates, this formula is represented by parallel straight lines, having a slope a_1 and each holding for another fertilizer dressing. The vertical distances from the
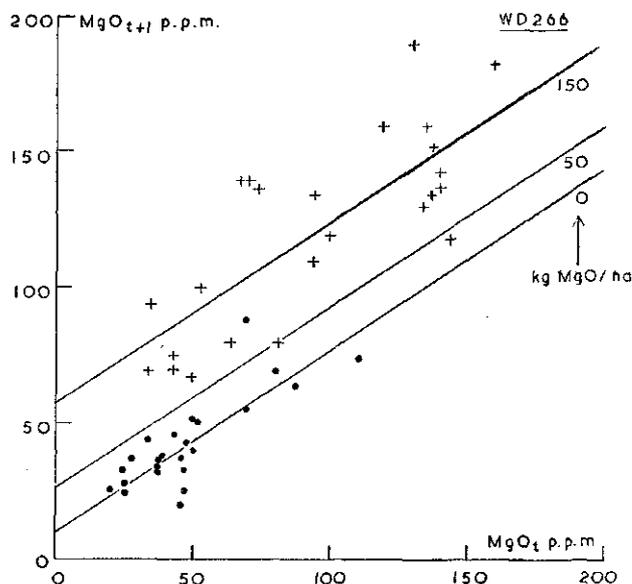

FIG. 1. Relation between the Mg contents in succeeding years in dependence on the Mg fertilization.

lines to the line for no fertilizer are proportional to the applied amount F. The line for $F = 0$ intersects the ordinate at $x_{eq.0} (1 - a_1)$. This value may, for a given field, be treated as a characteristic just as well as a_1 and a_2, if one has in mind the average for a range of years.

The first point of the hypothesis needs no further comment. To test the second point the eleven experiments already mentioned were used. The results of one of these are shown in Fig. 1. The magnesium contents of each year (x_{t+1}) are plotted against those of the preceding year (x_t). All plots dressed with an equal magnesium amount in spring between two succeeding

sampling dates are grouped together. For the sake of clarity the single data
for 50 kg of MgO have been omitted.

Now, if point two of the hypothesis is applicable, the relation between
ordinate and abscissa values should be a straight line. Moreover, the slopes
of the lines for different fertilizer amounts should be equal. The figure shows
that there is no reason to represent the relation other than by a straight
line, which was confirmed statistically. The slopes of the separately calculated
regression lines are 0·64, 0·65 and 0·68 for 0, 50 and 150 kg of MgO per ha
respectively. As an average of the eleven experiments we found 0·64, 0·58
and 0·55 which are approximately equal values. So point two is quite
acceptable.

The third part of the hypothesis was investigated in the same and in other
experiments. If it is true, the vertical distances between the lines of Fig. 1
according to formula (1) should be proportional to the intervals of the fertilizer
amounts. The ordinate axis (the lines are practically parallel) is intersected
at 12·7, 25·8 and 57·4 p.p.m. respectively. As an average of the eleven experi-
ments we found, based on parallel lines, 10·0, 21·2 and 41·8 respectively.
These results agree satisfactorily with the hypothesis.

Since each of the three points of the hypothesis appears to be acceptable,
formula (1) represents a suitable model to describe the course of the magnesium
content in dependence on the preceding contents and the amounts of fertilizer
applied.

It should be well realized that in Fig. 1 and in similar graphs of the other
experiments, the data of all experimental years are included, differing from
each other in weather conditions, kind and yield of the crop and date of
sampling. Consequently the regression lines represent average relationships
between the contents of two succeeding years and also average effects of the
fertilization. The scattering of the data is, apart from errors, due to differences
in supplying and depleting factors in the various years. It can be imagined
for instance that the data obtained after a wet year are located relatively low
in the graph and that simultaneously the mutual distances between the
regression lines should be small, because under those conditions more than
normal leaching occurs. For the same reasons $x_{eq.0}$ can not be regarded as
an indisputable constant. It is certainly possible that in some years magnesium
contents will be found lower than $x_{eq.0}$. So far, we did not attempt to analyse
this scattering quantitatively.

EXPERIMENT WITHOUT INTERFERENCE

Since a number of factors responsible for the alterations in the soil nutrient
status cannot be changed artificially, their influences must be investigated
in an experiment without interference. This may consist of a series of similar
experiments, such as the eleven experiments mentioned before.

The values a_1, a_2 and $x_{eq.0}$ can be considered as characteristics for the
separate fields concerned. They are presented in Table 2. In this table the
results of another series of seventeen experiments are added. On these only
two treatments were applied, viz. no magnesium and 150 kg of MgO per ha
in the first experimental year (1958). Afterwards, up to 1962, the fertilization
was left to the farmers. The only agreement was that they should dress all

plots uniformly. It is not exactly known to us, if the farmers did apply any magnesium after 1958. Therefore, it was not possible to calculate from these experiments the value $x_{eq.0}$. The values a_1 and a_2 were calculated from the annual differences between the magnesium contents of the two treatments according to a model derived from formula I. So in principle the same model was used for both series of experiments.

TABLE 2

Values a_1, a_2, $x_{eq.0}$, pH and organic-matter contents

No. exp.	a_1	a_2	$x_{eq.0}$ p.p.m.	pH	o.m. %	No. exp.	a_1	a_2	pH	o.m. %
1	0·67	0·32	31	4·2	7·4	15	0·46	0·60	4·9	10·0
2	0·45	0·18	37	4·4	5·4	16	0·55	0·18	4·7	4·7
3	0·72	0·17	39	6·1	3·7	17	0·58	0·31	4·7	8·1
4	0·52	0·31	37	5·8	3·8	18	0·64	0·28	5·7	3·9
5	0·43	0·21	26	4·2	4·2	19	0·43	0·35	4·2	6·8
6	0·70	0·13	30	5·5	2·7	20	0·88	0·13	4·5	4·7
7	0·43	0·19	15	3·8	4·5	21	0·64	0·21	5·1	4·1
8	0·84	0·12	21	4·2	3·3	22	0·72	0·15	5·6	5·0
9	0·87	0·16	17	4·2	4·5	23	0·74	0·16	5·3	5·5
10	0·39	0·31	19	4·4	2·2	24	0·80	0·25	5·5	3·2
11	0·38	0·25	15	4·3	3·6	25	0·58	0·37	4·8	4·8
						26	0·49	0·47	5·0	4·8
12	0·80	0·21	—	4·6	7·2	27	0·80	0·25	4·6	5·1
13	0·72	0·30	—	4·9	9·6	28	0·56	0·36	5·3	6·5
14	0·61	0·36	—	5·0	6·3					
Mean values			26				0·62	0·26	4·8	5·2

It appears from Table 2 that there are wide variations in each of the parameter values. Apart from errors they must be due to differences in supplying and depleting factors mentioned before. None of these was measured, however. The only available figures are the organic-matter (o.m.) content (calculated from the loss on ignition and expressed as g per 100 g of dry soil) and the pH (determined in a 1N KCl solution). These can be used to obtain an idea about the effect of leaching. For we suppose that the adsorption capacity (A), which on sandy soils is mainly governed by the o.m. content and the pH, plays an important role in the removal by leaching.

To obtain a suitable model for the determination of the influences of o.m. content and pH on the changes in magnesium content some assumptions were made. At first a rectilinear relation was assumed between the amount of magnesium recovered in autumn from a spring application of 1 kg of MgO per ha (the parameter a_2), and the adsorption capacity (A) of the soil. Further a rectilinear relationship was assumed between adsorption capacity and o.m. content. Finally it was assumed that the amount of magnesium adsorbed from a neutral salt solution per unit o.m. is rectilinearly related with the pH

in the range of pH values we have to do with. This is mathematically formulated:

$$a_2 = p_1 \times A + p_2 \quad \text{(first assumption)}$$
$$A = p_3 \times \text{o.m.} + p_4 \quad \text{(second assumption)}$$
$$\text{or } a_2 = q_1 \times \text{o.m.} + q_2$$
$$q_1 = r_1 \times \text{pH} + r_2 \quad \text{(third assumption)}$$

by substitution:

$$a_2 = r_1 \times \text{o.m.} \times \text{pH} + r_2 \times \text{o.m.} + q_2 \qquad (2)$$

The determination of the parameter values r_1, r_2 and q_2 from the data of Table 2, however, was disturbed by a high correlation between o.m. and o.m. $\times$ pH ($r = 0.96$). Therefore the formula was simplified to the following model:

$$a_2 = s_1 \times \text{o.m.} + s_2 \times \text{pH} + s_3 \qquad (3)$$

The relation between a_2 and o.m. content at different pH values is according to formula (2) a system of diverging straight lines, according to formula (3) a system of parallel straight lines. Though we realize that the first one is more logical we accept the last one as a useful approximation.

The same model has been used to determine the dependence of a_1 and $x_{\text{eq.0}}$ on o.m. content and pH. The results are reported in Table 3.

TABLE 3

Values of s_1, s_2 and s_3 in formula 3 for a_1, a_2 and $x_{\text{eq.0}}$ of formula (1)

	a_1	a_2	$x_{\text{eq.0}}$	
s_1	+0·000	+0·031**	+3·807**	**P < ·001
s_2	+0·062	+0·023	+11·038***	***P < 0·001
s_3	+0·32	−0·01	−41·03	rest P > 0·05

DISCUSSION OF RESULTS

From Table 3 it appears that a_1 does not depend at all on the o.m. content of the soil, which may look strange. To understand the phenomenon we must consider the saturation of the organic matter with magnesium. If two soils with H_1 and H_2 p.p.m. of organic matter have magnesium contents (beyond $x_{\text{eq.0}}$) of M_1 and M_2 p.p.m. respectively, the saturation of the organic matter with magnesium is M_1/H_1 and M_2/H_2 respectively. Since the o.m. content according to Table 3 has no influence on a_1, the saturation with magnesium after a one-year period will be $a_1 M_1/H_1$ and $a_1 M_2/H_2$ respectively. This implies that on two soils with an equal saturation of the organic matter (only the magnesium beyond $x_{\text{eq.0}}$ is meant) per unit of this material an equal amount of magnesium is lost, which is very acceptable.

The value of a_1 is positively related to the pH, though this relationship could not be established as significant, even if a one-sided test was used.

For the rest a positive influence is not surprising. It is generally recognized that an increase of pH hampers leaching.

The effect of the o.m. content on a_2 is highly significant. This means that the residue of a spring application is higher on soils richer in humus, which is of course due to the higher adsorption capacity of these soils. The positive, though not significant, influence of the pH must be caused by an improvement of the possibilities of cation exchange from the neutral magnesium salt.

Finally there appear to be positive effects of the o.m. content and the pH on $x_{eq.0}$, both being highly significant. The improvement of the adsorption capacity by an increase of these factors can be considered as responsible for these effects.

With regard to the size of the pH effects we point out that the reported figures are probably underestimated for soils high in organic-matter content and overestimated for soils low in this content, since we accepted in our model additive influences of organic matter and pH, though an interaction between both seemed more logical.

PERSPECTIVES

The formulas and the calculated parameter values make it possible to predict the course of the magnesium content of the soil over a period of years, taking into account the initial content, the magnesium dressings in that period (but only as far as applied as a soluble salt), the o.m. content and the pH of the soil. It is also possible to calculate what amount has to be applied to obtain a magnesium level fixed beforehand and which amounts are needed to maintain that level. By combining this knowledge with that about the magnesium requirement of the various crops a well founded fertilization policy for different crop rotations can be outlined. Of course the prediction is affected by a certain error, but there are still perspectives to reduce this error by taking other factors into account.