

## LIMING PROBLEMS ON LIGHT SOILS IN THE NETHERLANDS

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THE lime status of the soil is of importance for all crops and on all types of soil; it requires special attention and care on light soils, i.e. sandy soils, and peat-sand mixtures called 'moor-colonial' or reclaimed moorland soils, which form a large part of the arable land in the Netherlands. The pH of these soils has to be adjusted within narrow limits—say, within 0.5—to ensure good and reliable yields. pH-determinations form an integral part of soil investigations in these regions; extensive pH surveys have been made and others are in hand.

When liming the soil, the aim is not—as it is with manures like nitrogen, potash, and, to a large extent, phosphate—to provide for the requirements of the next crop; one aims at reaching, either in one dressing or in the course of a few years, an optimal lime status. Soil analysis therefore has to determine two properties: the actual state of the soil (for which purpose the pH in an aqueous suspension is used in our country), and the amount of lime necessary to reach another (the desired) state. For the latter purpose we determine the 'lime factor' of the soil, by which is meant the amount of lime, expressed as kilograms of  $\text{CaCO}_3$  per hectare, needed to increase the pH by 0.1 in a layer 10 cm. deep, when all the lime is taken up by the humus.

For determining the lime factor of the soil the following method has been adopted, after several trials and extensive preparatory investigations [1]. Twenty grammes of air-dry soil are mixed carefully with 400 mg. of fine, precipitated calcium carbonate in a 150–200 c.c. wide-necked flask; the mixture is stirred to a paste with some water, left standing overnight at room-temperature, stirred again, and then dried in an oven at about 100° C. The bicarbonate formed is thereby decomposed and the  $\text{CO}_2$  removed. The unchanged carbonate is then determined with hydrochloric acid, using the Scheibler method, the volume of  $\text{CO}_2$  being compared with the amount evolved from a known quantity of pure calcium carbonate at the same room-temperature and atmospheric pressure. This gives the amount of base, in milli-equivalents per 100 gm. of soil [2], necessary to saturate the clay and the humus in contact with a surplus of calcium carbonate under the chosen conditions. From this T-S figure, and from the S-figure, determined by treating the soil with 0.1 N. hydrochloric acid, the base saturation T (in milli-equivalents per 100 gm. soil) and the degree of base saturation V are calculated. For acid sandy and peaty soils ( $\text{pH} < 6$ ) 0.1 in pH corresponds with 2 per cent in V. The lime factor [1] is then found from the formula: lime factor = 10 T  $\times$  volume weight of soil.

It was found that this method of determining the lime requirement, based on conditions naturally existent in the soil (saturation in moist condition in contact with  $\text{CaCO}_3$ ) gives on the average (when seasonal variations are eliminated) satisfactory results, provided that the calculated amount of lime can be properly and evenly mixed with the soil, and there is no loss by leaching. In ordinary cases, e.g. in experiments on

small plots or in tanks without bottoms, as well as in experimental fields and agricultural practice, the desired pH is often not reached and rather large deficiencies, amounting to 0.5 pH or more, may occur.

Many data about differences between laboratory measurements and results in field experiments are to be found in the literature. Christensen and Tovborg Jensen called the ratio of these two the 'liming factor' [3] and, using their  $\text{Ca}(\text{OH})_2$  titration method [4], found a value of about 3 for this factor on different types of soil. Tovborg Jensen found the same factor for a soil with a very high humus-content, whilst in the surface-layer of this soil only a third of the lime applied could be recovered as exchangeable  $\text{CaO}$  and only traces of  $\text{CaCO}_3$  were left [5]. He hinted at great losses by leaching. In a later publication losses of lime from the surface-layer of the soil, some years after liming, were calculated from the results of some experimental plots, based upon extractions with 20 per cent.  $\text{HCl}$  [6]. E. M. Crowther made the hypothesis of losses by leaching more plausible by showing the effect of liming upon deep layers, up to 36 in. below the soil surface [7].

We have also made extensive investigations to clear up these discrepancies between laboratory and field results, and found the following to be the principal causes:

- (a) Oscillations in pH in the field, generally termed seasonal variations;
- (b) Losses of lime by leaching and drainage in the first months after liming, which on light soils were found to be much larger than hitherto supposed.

#### *Seasonal Variations in the pH of the Soil*

These have been studied from many sides [8]. In a communication from one of us [9], different causes of this phenomenon have been discussed; we shall not go fully into this subject here but consider only the nature and the magnitude of the variations in pH as determined in 1:5 aqueous suspension measured with the quinhydrone electrode.

Fig. 1 illustrates the nature of this phenomenon by figures obtained on two plots of an experimental field which had been manured during a series of years, the one by sodium nitrate and basic slag, the other by sulphate of ammonia and superphosphate, whilst both received the same potassium dressing.

As Fig. 1 shows, pH is raised by the one, lowered by the other type of manure; but it shows oscillations around the general trend, and these oscillations have in the main the same direction for both types of manure. It is possible to calculate the standard error for these deviations from the distances of the points to the average trend. Using the formula

$$\sigma = \sqrt{\frac{\sum d^2}{n}},$$

we found from an experimental material obtained from 29 experimental fields and relating to 942 observations, a standard error of 0.17 pH. The error of sampling on these experimental plots (size  $\frac{1}{2}-1$  acre; 12

borings per plot), and the error of analysis when analysing in duplicate, were known to be 0.065 pH. The total standard error of a pH figure for a soil sample from an experimental field is therefore 0.18 pH on the average [10]. This means that, when comparing pH figures for one plot, found in two yearly samples, in 5 per cent. of the number of cases a difference greater than 0.5 pH, and in 25 per cent. of the cases a difference greater than 0.3 pH may be ascribed to the unavoidable errors and not to the effect of lime or other factors. This is a rather large figure.

When studying the changes in pH brought about by a certain amount of lime, it is therefore better to put the question in this way: how far is

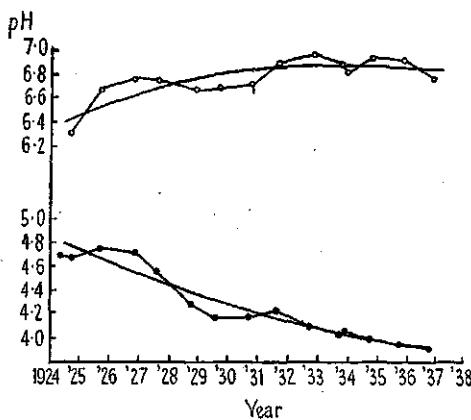


FIG. 1. Example of yearly variations in pH of the soil. Samples taken after the harvest of each year. Every point is the average of the figures of four parallel plots. The smooth lines indicate the average trend, eliminating the yearly variations: above for alkaline manure (nitrate of soda and basic slag), below for an acid combination (sulphate of ammonia and superphosphate).

it possible to raise, by liming, the pH of a plot by a given amount above the pH of an unlimed plot in the same field? Some of our investigations of this kind are described in the following pages.

#### *Losses of Lime by Leaching and Drainage shortly after Liming the Soil*

We estimated the losses of lime in our experiments by determining the base-content by one extraction with 0.1 N. hydrochloric acid (in the ratio of 20 liquid to 1 soil) and titrating the free acid, using phenolphthalein as indicator. A comparison between the figures for the limed and the unlimed plot shows the percentage of the added lime that has been retained. When one also determines the amount of unchanged  $\text{CaCO}_3$ , it is possible to calculate the amount of the added lime that was bound by the humus.

It was in the first place necessary to determine how far the above-described extraction with hydrochloric acid gives a correct indication of the amount of lime that had been added. In experiments with 15 different types of soil, to which different amounts of chemically pure calcium carbonate had been added in a porcelain dish, so that no losses

could occur, we found practically complete recovery (on the average 97 per cent.). Furthermore, it was found that up to pH 6.5 the lime was practically all bound by the humus, whilst with larger quantities of added calcium carbonate part remained unchanged.

Similar figures were obtained in a laboratory experiment with a soil to which increasing amounts of lime had been added; the same sandy soil (humus 14 per cent., pH 4.3) was used in a further experiment (VPr 19) on small plots (800 × 80 cm.) in the open, separated by wooden partitions. A layer of 20 to 25 cm. of the sandy soil was placed on a layer of coarse white subsoil sand, infertile and poor in humus. To this upper layer different amounts of a local marl (98 per cent.  $\text{CaCO}_3$  with about 80 per cent. passing a 0.17 mm. sieve), were added on July 29, 1930. The pH was found to be:

	Amount of lime added in mg. equiv. per 100 gm. soil			
	0	6.1	10.2	12.3
Nov. 7, 1930 . . .	4.7	5.1	5.7	5.9
Oct. 1, 1931 . . .	4.2	4.8	5.35	5.5

The frames were planted with spinach on Aug. 15, 1930, and in 1931 different legumes were grown. The loss of lime was 26 per cent. on the average in Nov. 1930, and 32 per cent. in Oct. 1931. These figures are so much larger than the errors of determination in the laboratory experiments that the losses are unquestionable. It may be remarked that all of the lime had already been bound by the humus on the first sampling date (Nov. 1930, 3 months after liming).

On Nov. 17, 1931, further portions of lime (3.0, 6.5, and 8.9 mg. equiv. per 100 gm.) were added, this time in the form of powdery slaked lime, which was stirred as well as possible into the upper layer. They gave, on Feb. 24, 1932, a pH of 4.3 (unlimed), 5.4, 6.2, and 6.7 respectively. The loss of lime was 14 per cent. after this second addition.

In the above experiments the percentage loss by leaching is nearly the same, i.e. is independent of the amount of added lime.

A loss of 26 per cent. in 3 months means for the largest application of marl used in this experiment a loss of 3,000 kg.  $\text{CaCO}_3$  per hectare. The questions arise: in which form is this large amount of lime removed and is it possible that this amount leaves the top soil layer in the form of bicarbonate? The reaction between humus and added  $\text{CaCO}_3$  produces  $\text{CO}_2$ , which may convert part of the calcium carbonate into calcium bicarbonate; at low concentrations of  $\text{Ca}(\text{HCO}_3)_2$  practically only one gram-molecule of  $\text{CO}_2$  is needed to convert one gram-molecule of  $\text{CaCO}_3$  into bicarbonate, but at higher concentrations the amount of free  $\text{CO}_2$ , that must be present, is larger. The data of Schlösing [11] and Kurris [12] show that, at a  $\text{CO}_2$ -pressure of about one-third of one atmosphere, twice as much  $\text{CO}_2$  is needed as the quantity necessary for the formation of bicarbonate from carbonate.

If the  $\text{CO}_2$ -pressure from the reaction between humus and  $\text{CaCO}_3$  reaches the value of one-third of an atmosphere, the amount of  $\text{CO}_2$

evolved from three-quarters of the calcium carbonate present would be necessary to maintain one-quarter in the form of bicarbonate. In our case the loss after 3 months is 26 per cent. of the amount added.

The total rainfall from July 29 till Nov. 7, 1930, measured in the garden of our Experimental Station, was 370 mm. or 3,700,000 litres of water per hectare. As one litre of water at an assumed  $\text{CO}_2$ -pressure of one-third atmosphere can dissolve at the most 725 mg. of calcium carbonate, this amount of water would be able to remove in solution at total saturation 2,700 kg. of calcium carbonate. The actual figure would, of course, be much smaller (due to evaporation of rain-water<sup>1</sup>, only partial saturation by calcium bicarbonate, &c.), so that the loss of 3,000 kg. calcium carbonate, calculated from the analytical figures in the example given above, could, in the assumed circumstances, only have taken place in part in the form of bicarbonate dissolved in the drainage water; the rest should have left the upper layer in another form.

At higher  $\text{CO}_2$ -pressures than were assumed above, the solubility of calcium carbonate is greater. In such circumstances, however, part of the carbon dioxide must have been produced by microbiological destruction of humus. It is clear that analysis of the drainage water should supply more accurate figures, particularly for the anions. Some of the kations will undoubtedly occur in the drainage water in the form of sulphate or nitrate derived from mineral salts added as a manure (the spinach was manured on Aug. 9, 1930, with sulphate of ammonia, superphosphate, and potassium magnesium sulphate at the rates of 200 kg. N, 100 kg.  $\text{P}_2\text{O}_5$ , and 200 kg.  $\text{K}_2\text{O}$  per hectare respectively), or formed by bacterial decomposition of humus and plant residues, &c.

A further possibility is the removal of calcium carbonate in a purely mechanical way, such as was assumed by de Vries and Hetterschij for part of the displacement of phosphates in a sandy soil [13].

The figures of the above experiment show that the loss of calcium carbonate is much larger in the first 3 months than in the following 11 months, 26 as against 6 per cent. This may imply a larger leakage when unchanged calcium carbonate is present than when the calcium is taken up by humus in the latter period; but it seems probable that the  $\text{CO}_2$  developed during the first months by the reaction between humus and carbonate is the factor mainly responsible. In this connexion it may be pointed out that the second amount of lime, applied on Nov. 17, 1931, underwent a loss of only 14 per cent. in the following 3 months, and this loss is much lower than that of calcium carbonate from the first amount of lime, applied on July 29, 1930. This fact gives an indication of the possible influence of the type of lime on the losses by drainage shortly after liming the soil. It should be noted, however, that the rainfall in the 3 months after the second application was much lower than that after the first application (157 mm. and 370 mm. respectively).

<sup>1</sup> In a lysimeter experiment made at our Institute, J. G. Maschhaupt used a layer of untilled light clay soil 1 m. thick. He found the average drainage loss to be 50 per cent. of the rainfall in the months August–October 1934–7. In our experiments the soil layer was 20 to 25 cm. thick, so that a somewhat greater part of the rain-water will have passed the limed layer of the soil and brought calcium carbonate from it into solution.

To study this point further, data derived from an experiment in Mitscherlich pots, containing the same humic sandy soil as above, were used to investigate the velocity of the reaction between humus and different forms of liming materials. The pots were set up in the garden and left unplanted. The results, obtained at different times after applying the lime, are given in Fig. 2. The figures for different amounts of lime (6.3, 12.7, and 21.1 mg. equiv. per 100 gm. soil, respectively) have been averaged, because the percentage loss is the same for smaller and

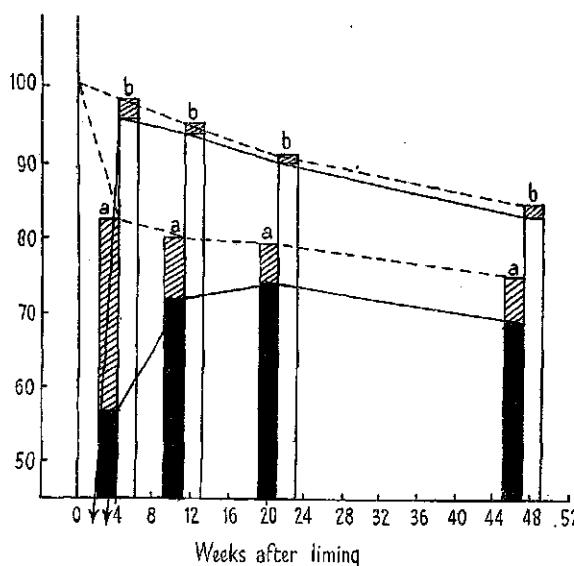


FIG. 2. Percentage amounts of calcium carbonate recovered from the soil (black columns for the calcium bound to the humus and hatched columns for the unchanged carbonate) at different dates after liming, and when using marl (a) and slaked lime (b) respectively. For marl, each point is the average from nine pots with three different quantities; for slaked lime from three. The full lines give the changes in percentage of lime taken up by the humus, the interrupted lines the total percentage of lime still present in the soil.

larger dressings. It will be seen that the amount recovered after different intervals (given by total height of the columns) decreases much more quickly for the marl than for the slaked lime. After 4 weeks about 20 per cent. of the lime given as marl had disappeared, whilst the soil to which slaked lime had been applied showed practically no loss; after about a year the losses were 25 and 15 per cent. respectively. It is very remarkable how quickly the loss takes place in the marled pots; later, the losses are much slower. We observed a similar course in other pot experiments with marl. From these observations it appears probable that the large amount of  $\text{CO}_2$  produced by the reaction between humus and calcium carbonate plays an important role.

Fig. 2 further shows that the amount bound to the humus is lower at first for the marled pots than for those with slaked lime. The reaction between  $\text{CaCO}_3$  and acid humus proceeds gradually and reaches a

maximum after 20 weeks, whilst with slaked lime nearly all the lime is bound in 4 days, and afterwards the amount of exchangeable calcium decreases. (The calcium hydroxide, not bound by humus, quickly changes into calcium carbonate and can be determined as such.)

It may be emphasized that the above conclusions about rate of loss and the different behaviours of marl and slaked lime, drawn from a pot and a small plot experiment, should not be generalized, and need not hold for the reactions in the field. In our field observations we sometimes found the losses of lime to be very large in the first year and

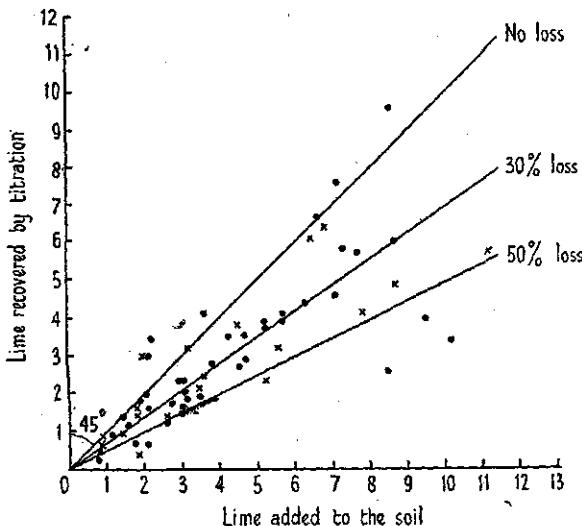


FIG. 3. Amounts of lime recovered after about a year, against the amount applied, for 60 plots on 25 different experimental fields on various types of soil and under varying local conditions. Average loss about 30%, average for extreme cases about 50%. Dots: limed with marl; crosses: slaked lime.

smaller in later years, but in other cases the losses in lime are relatively small and sometimes continued for a period of years. It may also be said that in general the application of lime as hydroxide does not cause smaller losses than the carbonate.

We investigated the results of 25 field experiments with lime, including in all 60 treatments each on 2 to 5 parallel plots. The experiments were carried out in different parts of the country, on different types of soil, and under different local circumstances. It is self-evident that the figures for loss of lime from the top soil will show a larger experimental error for the field data than for those from experiments in pots or bottomless frames. In pots the layer of top soil is measured accurately or even weighed, whilst in the field one has a roughly estimated thickness of the top layer, and an uncertain volume-weight, even if one takes volume-weight and thickness always for the settled top soil as it is after the harvest in a grain stubble. Nevertheless, when studying a large number of such cases, one gets an interesting picture (Fig. 3) giving the relation

between amount of  $\text{CaCO}_3$  added and amount recovered about a year after the application, investigated by the method of analysis described above and always in comparison with the unlimed plot. The dots relate to marl and the crosses to slaked lime: a difference in behaviour between the two is not apparent. There are certain cases falling in the neighbourhood of the  $45^\circ$ -line, in which therefore practically no loss of lime had occurred. The average of all points is roughly represented by the line for 30 per cent. loss. We have also drawn a line for 50 per cent. loss, which just about averages the extreme cases. The average loss on these

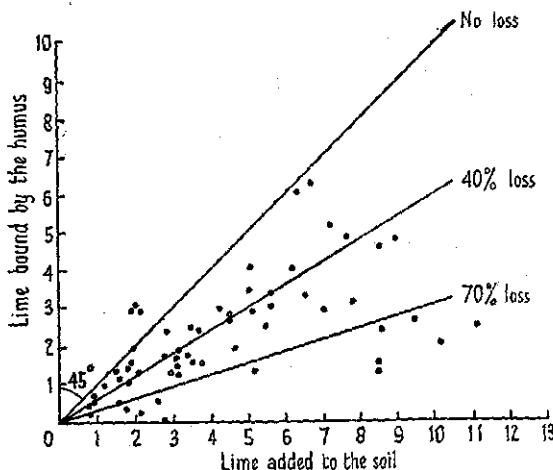


FIG. 4. Amount of lime (in milli-equivalents per 100 gm. of soil) bound to the humus in about a year, against amount of lime applied, for the same experimental material as in Fig. 3. Average of lime not bound about 40%, in extreme cases about 70%.

experimental fields was about 30 per cent. of the added lime in the course of a year.

Fig. 4 relating to the same experimental material as Fig. 3, gives the amount bound to the humus after a year, compared with the amount applied. The average figure is about 40 per cent.; the lower figures indicate a loss of about 70 per cent. By far the larger part of the lime lost must have disappeared into the lower soil layers. It may be safely assumed that in a year a maximal degree of binding by the humus has been reached. When 40 per cent. of the applied lime has not been bound by the humus in the course of a year, this means that one has to give about 1.7 times the amount calculated, to reach finally the desired lime status or pH. When there is a loss of 70 per cent., one has to give roughly three times the calculated amount and has therefore to use a 'liming factor' of 3. The conclusion from Fig. 4 is that there is no universal 'liming factor' for all types of soil and conditions: on the contrary, circumstances are found to be extremely divergent and different factors would have to be used in different cases. Moreover, it will be clear that the use of such a high factor as 3 would be very dangerous and uneconomic in the case of humic sandy soils; they are very pervious to water, and the losses by leaching

would probably be very large when such large amounts of lime were added, and especially so when the pH has to be raised a considerable amount and one has to apply correspondingly large amounts of lime. Moreover, such a very large amount of lime may temporarily cause a very high and perhaps harmful pH, leading to deficiency and other diseases. It is therefore better in practice to choose not too great an amount of lime, to determine after a suitable lapse of time the pH actually reached, and then to add a further amount of lime to reach the desired state.

### Conclusions

It will be clear from the above that, even though the laboratory method gives reliable and sufficiently accurate indications regarding the amount of lime that has to be bound by the humus to reach the desired rise in pH, there remains much uncertainty as to how much of this lime will actually form a calcium-humus compound. Moreover, the seasonal variations in pH may be so capricious that there may be considerable uncertainty as to the effect that has been reached. The behaviour and effect of lime may vary greatly with soil conditions, and the uncertainties in the determination of the lime status make it very difficult to predict the exact result of a given application of lime, or to prescribe the dose necessary for obtaining a certain effect. In liming prescriptions for experimental fields we generally add an extra allowance of one-fourth to one-third of the amount of lime calculated from the lime factor and the pH to be reached, to compensate for the lime that will rapidly disappear from the top soil or remain unused in the form of coarse and inactive particles. For actual practice, advice on amounts of lime to be applied can only be very approximate, more in the manner of a rule of conduct than as a definite indication. The directions have already been given above: they prescribe a moderate dose, to be followed by another dose after about a year, preferably calculated according to the effect actually reached by the first one.

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