effect of fertilizers on the lime requirement of the soil

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One of the factors to be taken into account when characterizing a fertilizer is its influence on the lime requirement of the soil. The acidifying property of some products is often regarded as unfavourable because their application requires addition of bases to maintain a good pH level.

This paper deals with the question of the quantity of bases which should be added to compensate the effect of a certain amount of fertilizer. This old question again became of topical interest in the Netherlands with the increasing use of compound (mixed) fertilizers. From literature supplemented with data from Dutch experiments we derived a formula to be used for calculating the effect of any fertilizer (Sluijsmans 1961). We believe that the formula is unknown to many agronomists. Therefore we were pleased to comply with the request of the editors of this journal to give an explanation of it.

The way of calculating the effect will seem familiar to those who know the work of Pierre (1928, 1933) on the subject. As a matter of fact he already used a formula, which he does not mention explicitly, but which can easily be derived from one of his papers (1933). Our own work consisted in fact in comparing his conclusions with Dutch experience.

Approach to the problem

The effect of fertilizer on the base status of the soil can be conceived as the sum of the effects of its components. For sodium nitrate for instance it consists of the effect of sodium plus that of nitrate. Each of these can be expressed in equivalent terms of kgs of CaO. By doing so the result of the addition gives a direct answer to the question about the change in lime requirement.

Cations and anions applied to the soil reduce and raise the lime requirement respectively with chemical equivalent amounts of CaO, provided that they remain unchanged. On this condition neutral salts will naturally have no influence. However, in the soil several processes take place which may lead to a final excess of cations or anions.

Amongst them are microbiological factors, leaching, change from ionic into molecular form and uptake of ions by the plant. What we are interested in is the result of all these processes.

The result seems well established for many of the non-nitrogenous fertilizers. From that knowledge we are able to make conclusions about the effects of their separate components. For nitrogenous fertilizers, however, experimental results reported in literature show a wide variation. In our opinion it was therefore desirable to pay renewed attention to the principles underlying the effect of the nitrogen components. In doing so we followed in the main the train of thought of Allison (1931).

After having established the effects of the separate components, it is merely a question of addition to calculate the effect of any fertilizer, either a well known or an entirely new one.

Non-nitrogenous components

1. With Pierre (1933) and also in accordance with Dutch experience, we take it for granted that the common potassium fertilizers, such as muriate and sulfate of potassium, have no residual effect on soil reaction. To this group we also add calcium and magnesium sulfate and sodium chloride. They do not influence the lime requirement of the soil. Apparently the alkaline effect of their cations is quantitatively compensated by the acid effect of the anions. It appears therefore justifiable to convert the effects of the ions involved into CaO on the simple basis of chemical equivalence.

Since one kg of K_2O is equivalent to 0.6 kg of CaO, 100 kg of a fertilizer with k % K_2O will, on behalf of the potash component, reduce the lime requirement by 0.6 x k kg of CaO. Similarly, multiplication factors can be calculated for the Na_2O-, CaO-, MgO-, Cl- and SO_3- components. They are in this sequence : 0.9, 1.0, 1.4, —0.8 and —0.7.

2. Pierre's statement that monocalcium phosphate in general has no permanent effect on soil acidity can be confirmed for Dutch circumstances. Since on this product one mol of P_2O_5 faces only one mol of CaO, the acidifying effect of one kg of P_2O_5 apparently corresponds in the agricultural practice to the basic effect of 0.4 kg of CaO. So 100 kg of a fertilizer with p % of P_2O_5 will, on behalf of the phosphate component, raise the lime requirement by 0.4 x p kg of CaO. This holds good for soils with a pH between about 4 and 6. For soils with a higher pH, the factor should be somewhat higher.

3. The carbonate, silicate and hydroxide ions of fertilizers can be left out of account, as they do not offer a noticeable contribution to the amounts of these ions already present in the soil. They will be converted from the ionic into the molecular form. For that reason, for instance, the effect of 100 kg of $CaCO_3$ equals that of 56 kgs of CaO.

Nitrogenous components

At first we shall deal with the effect of nitrate ions and next with that of ammonium ions.

1. Nitrate ions applied to and remaining unchanged in the soil, will neutralize an equivalent amount of bases. On this condition one kg of nitrogen would raise the lime requirement by 2 kg of CaO, this being the maximum possible effect.

Several processes are responsible for a reduction of the amount mentioned. The most important one is probably the effect of the plant. If the nitrate application would give rise to an increased nitrogen uptake without influencing the uptake of other cations and anions, only the nitrogen not taken up could cause acidification. According to the results of Dutch experiments, about 70 % of the fertilizer nitrogen is taken up by the harvested crop on grassland, and about 50 % on arable land ; so 30 % and 50 % respectively will remain in the soil. The acidifying effect of this residual nitrogen corresponds to a loss of 0.6 and 1.0 kg of CaO per kg of fertilizer nitrogen respectively.

It is known, however, that increasing nitrogen uptake usually is attended by a change in the uptake of other cations and anions. From a series of experiments on grassland we calculated that, as a result of this change, the lime requirement of the soil will increase by an amount equivalent to 14 % of the increase of nitrogen uptake. Data from literature indicate that the change on arable land is of the same magnitude. The figure is an average of widely diverging results. It will be evident from the above that on behalf of the factors so far involved, one kg of nitrate nitrogen will raise the lime requirement of grassland by 0.6 + $0.14\frac{1}{2} \times 0.70 \times 2 = 0.8$ kg of CaO, and that of arable land by 1.0 + $0.14\frac{1}{2} \times 0.50 \times 2 = 1.1$ kg of CaO.

Besides the influence of the plant there are some other processes that might influence the amount of residual nitrogen and, through that, the acidifying effect of the fertilizer. In this category, the volatilization of nitrogen during denitrification can be of importance. As it is naturally not attended by a simultaneous loss of cations, the process will diminish the acidification brought about by the nitrate. Uptake of nitrates by microbes and in soil organic matter works in the same direction, but these processes can be left out of consideration if we take the view that the microbic population and the organic matter content are at an equilibrium level. It might be thought also that leaching of nitrogen reduces the acidification. This is not true, however, because the leaching nitrate ions in general will be accompanied by an equivalent amount of bases. Only in the case where nitrate leaches as nitric acid, has it a similar effect to volatilization. Leaching of the pure acid will occur only in extremely acid soils.

It is not well known what amount of nitrogen can be taken as an average for the loss by way of volatilization. Therefore we shall call this amount, expressed as kg of CaO per kg of fertilizer nitrogen, X_1. Later on we shall reconsider this value.

2. The behaviour of ammonium ions with respect to the lime requirement is more complicated, because these ions are subjected to nitrification and through that process change from the cationic into the anionic form. If ammonium would be nitrified before uptake by the plant, and leaching and volatilization take place, its influence would be essentially the same as that of nitrate.

As far as plant uptake is concerned, again two aspects are interesting. It should be known first what amount of nitrogen is taken up per kg of fertilizer nitrogen, and secondly to what extent the uptake of other cations and anions is influenced by the increased uptake of nitrogen. With regard to the first point, we take it for granted that there is not much difference between nitrate and ammonium. That means an uptake of about 70 % of fertilizer nitrogen on grassland and 50 % on arable land, so the amounts left in the soil may be 30 % and 50 % respectively. With regard to the second aspect, our experimental results on grassland show that fertilization with ammonium brings about a relatively higher uptake of anions than nitrate does (if nitrogen is not included in the calculation), but the difference is not important for the purpose for which we use it. Assuming that this is also true for arable land, and furthermore that all of the residual ammonium nitrogen will be nitrified, the effect of one kg of ammonium nitrogen will be equal to that of one kg of nitrate nitrogen.

As was explained in a preceding paragraph, leaching of nitrates generally does not influence the lime requirement of the soil. Leaching of the ammonium ion however does. The leaching as such is not important in this connection, but since ammonium ions disappearing in this way escape nitrification their potential acidifying power is lost. Of course, if they are nitrified in deeper soil layers, they will again have an acidifying effect. Leaching to a depth beneath the root zone is probably negligible.

Volatilization of nitrogen before nitrification takes place has a similar effect to leaching. On calcareous soils, ammonium can be turned into ammonia (NH_3) by the action of calcium carbonate. The loss of nitrogen due to this process can be reduced or even entirely prevented by working the fertilizer into the soil soon after its application. A second loss of gaseous nitrogen may occur during nitrification. There is lack of knowledge about the average amounts of nitrogen involved in this process.

We summarize the influences mentioned above, that of plant uptake excluded, in a term X_2 expressed in kg of CaO per kg of fertilizer

nitrogen. It will be evident that X_2 represents a decrease in lime requirement.

As soon as the ammonium ion has been nitrified, all processes that have been considered for nitrate can proceed. Apart from the effect of the plant, they result in the term X_1.

Discussion

From the preceding paragraphs it follows that the effect (E) of 100 kg of a fertilizer on the lime requirement of the soil, expressed as kg of CaO, can be calculated with the formula :

$$E = -1.0 \times CaO - 1.4 \times MgO - 0.6 \times K_2O - 0.9 \times Na_2O + 0.4 \times P_2O_5 + 0.7 \times SO_3 + 0.8 \times Cl + 0.8 \text{ (or } 1.1) \times N + X_1 \times N + X_2 \times N.$$

The factors CaO, MgO etc. represent the percentages of these constituents in the fertilizer. The coefficient 0.8 for nitrogen holds for grassland ; for arable land it should be 1.1.

The formula deviates only on a few points from the one used by Pierre. At first we introduced a coefficient for the effect of nitrogen on grassland, whilst Pierre only worked with arable crops. Secondly our nitrogen coefficient for arable land is 1.1. instead of 1.0 in his formula. At the end of our investigation we decided to adopt the value 1.0 for use in the Netherlands. This was done for several reasons, the most important one being the consideration that no differences should be introduced to literature if their existence has not been proved satisfactorily. Pierre concluded the value 1.0 on the base of experiments in which he actually checked on pH development. We on the other hand only studied the influence of plant interference and concluded from that the value 1.1. We might suggest that the difference is locked up in the terms $X_1 \times N$ and $X_2 \times N$. These terms are not present in Pierre's formula.

About the magnitude of X_1 and X_2 we have not enough information. These factors are negative. If volatilization of nitrogen does only occur to a small extent, the values of X_1 and X_2 will be small too. As suggested already, the acceptance of the nitrogen coefficient 1.0 instead of 1.1 for arable land may account for a part or the whole of $X_1 \times N$ and $X_2 \times N$. It seems therefore more or less justified to use the formula without paying attention to the terms with X_1 and X_2.

It must be pointed out that the result of the formula does not necessarily refer to the lime status of the surface layer only. Part of the loss or gain of bases can take place in deeper layers.

Another point that should be realized is the fact that the formula only gives the amount of lime needed to compensate the effect of 100 kg of

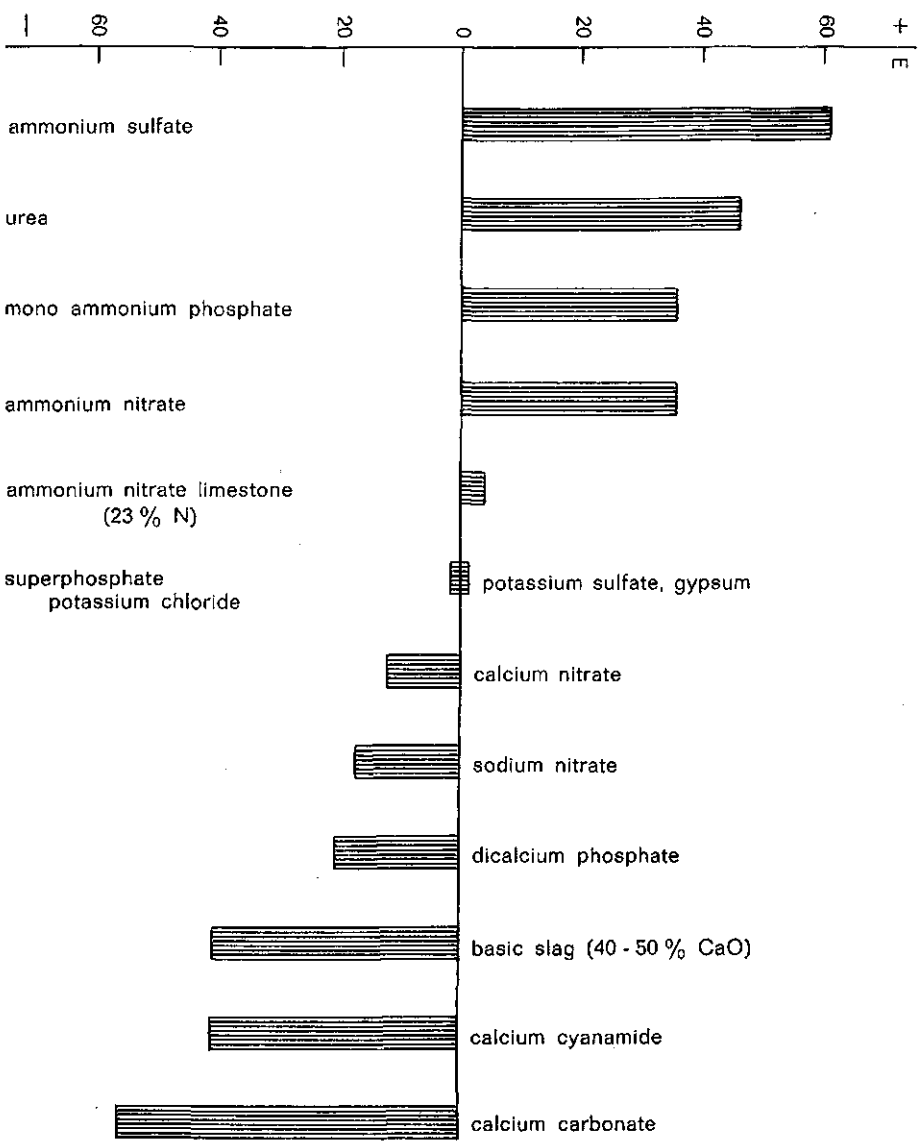

Fig. 1.
Effect (E) of some fertilizers on the lime requirement of the soil on arable land, expressed as kg of CaO per 100 kg of fertilizer.

fertilizer. This amount does not prevent a decrease in pH caused by the normal leaching of bicarbonates. We assumed for our calculations that the amounts of bases disappearing as bicarbonates are independent on the amounts of fertilizer used.

Formula.

The effect (E) of 100 kg of a fertilizer on the lime requirement of the soil, expressed as kg of CaO, consequently can be calculated as follows:

$$E = -1.0 \times CaO - 1.4 \times MgO - 0.6 \times K_2O - 0.9 \times NaO + 0.4 \times P_2O_5 + 0.7 \times SO_3 + 0.8 \times Cl + n \times N.$$

CaO, MgO etc. represent the percentages of these constituents in the fertilizer. The coefficient n for nitrogen amounts to 0.8 for grassland and to 1.0 for arable land. Under conditions where less than 50 % of the fertilizer nitrogen is taken up by the crop, n will lie somewhere between 1.0 and 2.0.

The result of the formula is represented in fig. 1 for a number of fertilizers.

Received October 1965.

Résumé : L'influence des engrais sur les besoins en chaux du sol — C.M.J. Sluijsmans

Pour calculer l'influence des engrais sur les besoins en chaux du sol, une formule est proposée et discutée. Ces recherches sont principalement basées sur les travaux de Pierre et consistent, en fait, à comparer ses conclusions avec l'expérience hollandaise.

Resumen : La influencia de los abonos en las necesidades de cal del suelo — C.M.J. Sluijsmans

Para calcular la influencia de los abonos en las necesidades de cal en el suelo, una formula es propuesta y discutida. Estas investigaciones están basadas principalmente sobre los trabajos de Pierre y consisten de hecho, en comparar sus conclusiones con la experiencia holandesa.

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