SOME CHEMICAL METHODS OF DETERMINING THE LIME REQUIREMENT OF SOILS

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A research worker in soil chemistry accustomed to conditions in England is soon conscious in New Zealand of many anomalies in the position that liming occupies in local farming practice. In the majority of districts in Great Britain the periodical application of lime is an establish& practice, and when this practice is neglected the failure of crops or of pasture is quickly noticeable. Moreover, it is a simple matter in these districts to detect by laboratory methods the symptoms indicating a need for lime. New Zealand soils, however, frequently give reactions which, in England, would be considered as indicating high requirements for lime and yet when lime is applied, no marked increase in crop yield is exhibited.

The methods for the detection of lime requirement may be briefly explained.

1. DETERMINATION OF CALCIUM CARBONATE.

The earliest method of determining the lime requirement of soils consisted in the estimation of the calcium carbonate already present in the soil. Hall[1], states that "the application of lime to clays and sands containing less than 1% of calcium carbonate produces very pronounced results." 'This method was found to he of limited application since in many soils under certain systems of farming, the above statement is not true. The method is quite inapplicable to New Zealand soils which appear to be singularly lacking in calcium carbonate. Soil samples from many important farming districts have been examined at the College, and in no case under normal farming conditions, has any calcium carbonate been detected, even in soils, derived from limestone. Samples taken from experimental plots recently and heavily limed have constituted the only exceptions. There are, however, considerable variations in the response to liming exhibited by soils from the various districts, in many cases absolutely no visible improvement in plant growth being evident.

2. TREATMENT OF SOILS WITH CALCIUM BICARBONATE SOLUTION.

This method, proposed by Hutchinson and MacLennan[2], consists in treating the soil with excess of lime in the form of calcium bicarbonate solution (the form to which added'lime is eventually converted in the soil solution) and estimating the amount of lime removed by the soil from the solution. The method has been used to a considerable extent for survey and advisory purposes, although it suffers from some serious limitations.

(a) The method presumes that it is necessary, or at least desirable, that soils should be neutral for the optimum growth of crops. This presumption is now known to be erroneous.

(b) Lime is removed from the solution by the soil colloids in excess of that required to neutralise acidity. The physical texture of the soil, therefore, influences the results quite apart from the acidity. The quantities of lime required, as indicated by the results obtained by this method, are frequently considerably in excess of the maximum profitable applications.

Wild[3] has shown that this method gives very high values with New Zealand soils.

3. METHODS INVOLVING THE DETERMINATION pH OF SOILS.

Following the development of physico-chemical conceptions of acidity has come the introduction of comparatively simple methods of estimating hydrogen - ion concentration in soils. This concentration is expressed conveniently by the pH scale. A higher pH value signifies a less acid condition and a lower pH value a higher degree of acidity.

The pH of a soil really expresses the INTENSITY of acidity as opposed to the AMOUNT of acidity, An analogy may be drawn in the case of the measurement ot the DEPTH of water in a reservoir as opposed to the VOLUME of water. It is possible to be drowned in a well containing only a few hundred gallons of water, and yet to be quite happy paddling 'in a shallow lake containing a volume of water many times greater. In the' same way it is possible for a degree of intensity of acidity to exist in a soil sufficient to check the growth of plants, and yet the total acidity (as estimated by the method of Hutchinson and MacLennan) to be comparatively small. Conversely,' and this more frequently is the case, a total amount of acidity giving a high figure for lime requirement, may occur in conjunction with a low intensity of acidity (i.e. high pH) and, therefore, not detrimental to crop yields.

It was hoped that this new conception of soil acidity would throw an illuminating light on the problems of tolerance of plants to acid conditions. Research workers have attempted to ascribe to various crops optimum ranges of pH. The results of different workers are widely divergent owing to the effects of other factors such as temperature and food supply, but the experiments have at least exploded the theory that a neutral medium is preferred by all plants. Neutrality is represented by pH 7.0 and yet Arrhenius[4] gives pH ranges for optimum growth as follows:-

Lucerne	pH 7.0 to 7.5
Barley	6.6 to 7.5
Wheat	6.0 to 7.5
Red Clover	5.8 to 7.0
Turnips	5.5 to 7.0
Oats	4.7 to 6.7
Swedes	4.7 to 5.5
Potatoes	4.8 to 5.7

Hoagland[5], using water cultures found barley not seriously affected at pH 5.1, but quite unable to grow at pH 3.6. Experiments involving water cultures are, however, subject to criticism on the grounds that the plant can effect considerable changes in pH of the nutrient solution within a few hours.

Clover is frequently stated to be intolerant of acid conditions and yet, to quote one example, a soil from a peat swamp in the Waikato district with pH 4.5 was able to support a luxuriant growth of red clover. Soils much less acid in other districts would require lime before a satisfactory growth of clover could be obtained. For instance, a soil from the property of Mr. D.H,Paterson, Temuka, South Canterbury, a sample of which was supplied by the Fields Division of the Department of Agriculture from an experimental hay plot has pH 5.45 and yet Hudson and Montgomery[6] report that this soil failed to show satisfactory growth of red clover even after application of superphosphate. Dressings of lime, on the other hand, produced ,an extraordinary increase in the growth of red clover.

The pH alone of a soil is, therefore, not a reliable indication of lime response.

An important feature of soil is its buffer capacity i.e., its ability to resist a change in pH when subjected to treatments producing acid or alkali. This is, of particular importance-in connection with the use of sulphate of ammonia. The acidity produced in the soil as a result of applications of ammonium compounds may not show its effects in a highly buffered soil until the treatmenthas been continued for some years. Soils with a high colloid content - clay and humus - possess a high buffer capacity.

4. DETERMINATION OF EXCHANGEABLE BASES.

As 'a result of the work of Gedroiz[7] in Russia and of Hissink in Holland and others, the conception of the clay particle has been considerably modified in recent years. We now visualise the colloidal particle as a complex "molecule" consisting of a central "aniun" composed of an alumino - silicio acid radical and a series of cations on the surface consisting of the more common soil bases - calcium, magnesium, sodium and potassium.

These cations are easily interchangeable and when a soil is treated with an electrolyte, instantaneous ionic equilibrium is established between the exchange complex and the solution. Hissink[8] had proposed a method for determining the exchangeable bases,- and has shown that in Dutch clays and sands approximately 80 per cent of the exchangeable bases consist of Calcium. When a soil is subjected to the action of rain, the bases tend to be washed out and if there is no reserve of calcium carbonate in the soil their place is taken by hydrogen. In this way untreated soils tend to become more acid with the passage of time. The degree to which the hydrogen has entered the base exchange complex is known as the "Degree of unsaturation" of the soil.

It has been suggested by some that the amount of exchangeable calcium and by others that the degree of unsaturation may determine the lime requirement of a soil.

(a) EXCHANGEABLE CALCIUM - Robinson and Williams[9], working with soils from North Wales, have found the estimation of exchangeable calcium valuable for diagnostic purposes. These soils are devoid of calcium carbonate, have an acid reaction and give lime requirement figures, by the method of Hutchinson and MacLennan, of about 2 tons of limestone per acre. In practice,. the need for lime could not be correlated with the results obtained by these 3 methods. It was found, however, that those soils which failed to respond to liming contained appreciable quantities, as a rule 0.14 per cent or more, of exchangeable calcium. In a few cases where response to liming could be clearly demonstrated, the amount of exchangeable calcium was very low (usually less than 0.035 per cent.)

Results obtained with some North Island soils are somewhat similar. The following are given as examples:-

Sample No.	Locality	Soil Type	Lime Requirement (Hutchinsan & MacLennan) in tons of limestone per acre.	pH.	Exchangeable Calcium (Hissink) per cent.
W 17	Rangitikei	Heavy Brown. Loam.	2.5	5.9	0.33
W 10	Kairanga	Heavy Clay	2.0	5.5	0.23
C 61	Palmerston North	Greyish Clay	1.75	5.3	0.11
C 1	" "	Light Loam	1.25	5.6	0.18

In none of the above cases is liming found to give any striking results,

The exchange capacity of a soil is associated with the soil colloids which, in turn, determine the texture of a soil, and it is thus reasonable to expect that soils varying in texture will yield very different quantities of exchangeable calcium, Such quantities will be quite unrelated to the acid properties of the soil.

(b) DEGREE OF UNSATURATION.

Pierre" states that "It is now generally recognized that soils are acid because of the presence of exchangeable hydrogen in the exchange complex, Determinations of the total amount of exchangeable hydrogen cannot serve as a measure of plant response to liming because most plants can make optimum growth on soils that are not completely neutralised."

It is seen that there are objections to the diagnostic value for lime requirement purposes both of exchangeable calcium and of exchangeable hydrogen. It is, thought, however, that the ratio of these two values may be correlated with plant growth and response to liming. This ratio is expressed in one of two forms.

a. Degree of unsaturation, i.e. ratio of exchangeable hydrogen to total exchange capacity.
b. Percentage base saturation, i.e. ratio of exchangeable bases present to total exchange capacity.

Methods for determining these values are described by Parker[11].

Pierre quotes an example from an experiment with sorghum. One soil produced as good a growth a pH 4.75 as at any higher pH values. The percentage base saturation was 62 per cent. Other soils which did not permit good growth of sorghum at similar pH values had a much lower percentage base saturation - viz., ranging from 9 per cent to 32 per cent.

A few soils from the farm of the Massey Agricultural College, where no response to liming is obtained, so far examined have given percentage base saturation figures of from 60 per cent. to 70 per cent.

The main difficulty in applying any work of this nature to grassland lies in the problem of measuring the response to manurial treatment. Trials by observation may not be reliable, especially on the better class pastures where any improvements, unless very large, may not be apparent.

The evidence available at present does, however, appear to indicate that general advice to farmers to use lime in New Zealand, especially in the North Island, is not justified, unless trials in any given district on soils of a similar nature have shown a response to lime treatment.

The reasons given for recommending lime are numerous and may be summarised as follows:-

1. Improvement of physical texture of soils by the flocculation of the colloidal clay.

2. Reduction of acidity.

3. Maintenance of supplies of calcium which is an element essential to the growth of plants.

4. Improvement of the feeding value of pastures without necessarily increasing the yield of grass.

These will now be discussed.

1. The improvement of texture by liming is of little significance, in the North Island where such a small amount of cropping is carried out and where the humus content of the soil is high.

2. It has been shown that the reduction of acidity per se is not necessarily of prime importance in improving soils. An increase of pH may, however, have secondary effects in improving the conditions for beneficial microorganisms or in removing toxic aluminium ions from solution. Results of research on these factors are, however, extremely contradictory.

3. The use of lime is not necessarily the best method of supplying calcium to the plant. Rigg and Askew[12] state that on a dairying pasture in Nelson "lime, although applied at the rate of 1 ton per acre, has not markedly increased the percentage of lime in the pasture." Furthermore, their work shows that the highest figures for lime content were obtained in a sample of pasture mown from an unlimed plot receiving superphosphate, sulphate of potash and sulphate of ammonia. This is particularly striking in view of the fact that their experiments indicated that sulphate of ammonia tends to depress the lime content of the pasture.

The theory that liming is advisable in order to maintain supplies of calcium to stock by increasing the lime content of the pasture is not, therefore, by any means established.

Superphosphate contains abundant supplies of calcium soluble in water, and should be able to supply the plant with all the calcium it needs. Furthermore, if the main factor determining lime requirement is the percentage base saturation of the soil, it would be expected that any fertiliser, such as superphosphate, containing abundant calcium in a form readily absorbed by the base exchange complex, would improve the soil without further applications of lime. Cases are numerous in which the toxicity of acid soils has been reduced by dressings of superphosphate.

It is possible to explain by this theory the lack of response to lime of pastures on soils with a high percentage base saturation which have been liberally dressed with superphosphate - a state of affairs which appears to be common in the North Island - and there is no reason 'for assuming on this basis, that the need for liming in these cases will develop in the future. This theory does not explain, however, the results obtained in certain districts in the South Island where lime is found to be of paramount importance. In these cases no improvements are effected from the use of superphosphate until lime has been applied,

It is apparent, therefore, that much research and co-operation between laboratory and field workers is needed to explain these anomalies in order to be able to determine in the laboratory the probable response of soils to liming,

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REFERENCES:

1. Hall, Sir A.D. — "The Soil", Second, (Revised, Edition, 1928, p.2.61.
2. Hutchinson, H.B. and MacLennan, K. — "Studies on the Lime Requirements of Certain Soils", Journal of Agricultural Science, Vol.VII, 1915, p.75.
3. Wild, L.J. — "Some Soils of the Southern Island of New Zealand with special reference to their lime requirements." Journal of Agricultural Science, Volume VIII, 1916, p.154.
4. Arrhenius O. — "Kalkfrage, Bodenreaktion und Pflanzenwachstum". Akad.Verlag. Leipsig, 1926.
5. Hoagland, D.R. — "The Effect of Hydrogen and Hydroxylion concentration on the growth of Barley Seedlings". Soil Science, Vol.III, 1917, p.547.
6. Hudson, A.W., and Montgomery, A.Y. — "Pasture Topdressing in Canterbury". N.Z.Journal of Agriculture, Vol.42, No.1, Jan.1931, p.45.
7. Gedroiz K.K. — A summary of this work prepared by H.J.Page, appears in Transactions of the Second Commission of the International Society of Soil Science, Volume A, 1926, p.207.
8. Hissink, D.J. — "Base Exchange in Soils", Transactions of the Faraday Society, Vol.20, 1924, p.551.
9. Robinson G.W. & Williams, R. — "Base Exchange and the Problem of Soil Acidity", Transactions of the Faraday Society Vol.20, 1924, p.586.
10. Pierre W.H. — "Hydrogen ion concentration, aluminium concentration in the soil solution and percentage base saturation as factors affecting plant growth on acid soils." Soil Science Vol.31, 1931, p.18.
11. Parker, F.W. — "The Determination of Exchangeable Hydrogen in Soils" - Journal of the American Society of Agronomy, Vol.21, 1929, p.1030.
12. Rigg T. & Askew, H.O. — "Influence of Season and Fertiliser on the Yield and Composition of Typical Dairying Pasture." N.Z.Department of Scientific and Industrial Research,, Bulletin ~0.26, Pt.II, 1930.
