

A BRIEF REVIEW OF THE METHODS CURRENTLY IN USE FOR ESTIMATING THE LIME REQUIREMENT OF ACID SOILS IN THE R S A

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Abstract

The assessment of lime requirement in South Africa and in the U S A is a controversial subject. The merits of the various methods used are discussed and the legitimacy of some of these procedures is questioned. The need for rationalization on the methods currently in use in the R S A is emphasized.

Introduction

Lime requirement predictions are at present confused by ideas that, on the one hand, nutrient availability is maximized at near neutral pH values (Truog, 1946; Mc Lean, 1970) and on the other, that A1 is the primary cause of acid soil infertility (Kamprath, 1970b). A chart relating pH to plant nutrient availability was first presented by Pettinger in 1935 for seven nutrient elements. In 1946 Truog added another four elements and presented the "pH - nutrient availability" chart as we know it today. He emphasized, however, that "the chart represents a generalized presentation, which is tentative in certain respects and because of lack of adequate and precise data relating to certain aspects of the subject, some assumptions had to be made in the preparation of the chart, and this has undoubtedly led to certain inaccuracies in it". The chart indicates pH 6,5 as the most favourable pH as regard the availability of all the elements shown, and therefore "... acid soils should be limed to this pH". He adds however, "... of course, for control of potato scab and other plant diseases, and for certain other plants which require a lower pH, this chart may not be feasible or advisable".

Although litmus was first used as an indication of acidity in 1865, it had no general application for lime recommendation until many years later. Veitch (1902) proposed treating the soil with enough lime water ($\text{Ca}(\text{OH})_2$) to make the soil solution alkaline to phenolphthalein. He observed that the quantities of lime required according to this method far exceeded the amount of lime necessary for good crop performance in the field. However, the basic concept of Veitch's method has since been used by many workers with various modifications. Prior to 1923, the method in vogue in South Africa for estimating lime requirement was one based on the total lime content of the soil by acid (HCl) extraction Hall (1923). This procedure overestimated the actual lime needs of most of the soils tested, particularly where maize was grown in the Transvaal, Orange Free State and Natal. Possibly the first work done on dif-

ferent methods for determining lime requirement in South Africa was when Hall (1923) compared the old acid extract method with the Veitch method. He reported that the latter gave a more realistic estimate for the 245 soils tested. Hall (1923) felt that more attention should be given to the tolerance of different crops to acid soil conditions. He concluded that although liming could be profitable for such crops as lucern and tobacco, it may not be so in the case of barley or maize, all grown on the same soil. When H ion activity and its relation to acid soils came under intensive study between 1915 and 1920, and with the introduction of electronic methods for determining pH circa 1930, the quantity of lime water required to bring an acid soil to a $\text{pH}(\text{H}_2\text{O})$ value of 7,0 was substituted for the old indicator procedure. The precision of measuring the pH value of soils was improved further by Schofield and Taylor (1955), who measured the soil pH in 0,01 M CaCl_2 to eliminate the salt effect (and later the suspension effect) on soil pH measurements.

Methods currently in use for estimating lime requirement in the R S A

Recommendations for lime are often based only on pH and soil texture (Möhr, 1977). Because of the buffering action of various soil constituents such as organic matter and amorphous hydroxy sesquioxides however, this procedure does not provide sufficient information for an accurate, reliable estimate of the amount of lime that should be applied to the soil.

Mehlich (1938) used a buffer solution (pH 8,2) consisting of triethanolamine acetate (TEA-OAc) and $\text{Ba}(\text{OH})_2$ to estimate the lime requirement of acid soils. This method indicates accurately the lime requirement for unlimed soils, but *overestimates* that for previously limed soils.

Woodruff (1948) introduced the procedure of mixing the soil with a solution buffered at pH 7,0 (paranitrophenol plus $\text{Ca}(\text{OAc})_2$ in which the depression in pH of the buffer solution by the added soil was taken as an estimate of the lime requirement. This method was initially calibrated with strongly buffered soils from Missouri, U S A and was an improvement on the Mehlich method. The Woodruff buffer rapidly neutralizes any soil acidity and the buffer curve is linear between pH 6 and 7. The buffer is adjusted to pH 7,0 and each 0,02 me of H added (from the soil) causes the pH to drop 0,1 pH unit in that range. The amount that the pH of the soil-buffer mixture drops below 7,0 indicates the amount of lime required by the soil. The soil is limed to

pH 6,5. It was found later however, that this method *underestimated* the actual need for lime in certain U S A soils by as much as 50% (Weeks and Lathwell, 1967). Studies were then conducted to determine why certain test methods fail to indicate the actual lime requirement of various acid soils.

Shoemaker, McLean and Pratt (1961) realized that underestimation of lime requirement using such strong buffers as employed in the Mehlich and Woodruff methods, was due to the major portion of active or soluble hydroxy - Al in the soil being *trapped* by a coating of insoluble Al (OH)₃ formed on contact with the buffer. Reaction with lime in the field or during incubation of the soil with CaCO₃ is a slow process with a gradual increase in pH. Consequently a far greater amount of Al is neutralised. For this reason therefore the SMP method employs a weaker buffer mixture (paranitrophenol and TEA-OAc in CaCl₂) than the Mehlich or Woodruff buffers. The SMP buffer mixture gives a "... near linear depression in pH with the degree of acidity of the soils as determined by CaCO₃ incubation" (Shoemaker, *et al*, 1961) and the soil is limed to pH 6,5. The buffer curve is linear between pH 3,5 and 7,5. Although this method is claimed to work better than previous buffer methods on soils containing appreciable amounts of hydroxy Al (Coleman and Thomas, 1967), lime requirements of as high as 27 to 35 tons lime/hectare have been measured for some acid clay soils (Woodruff, 1967). Such high rates far exceed practical limits for liming and could induce nutrient and micro element imbalances in the soil. Research in the U S A has shown that liming to high levels as indicated by the SMP buffer method to bring the soil to neutrality, gave no advantage in the field (Woodruff, 1967).

The work of Evans and Kamprath (1970), Kamprath (1970a) and Reeve & Sumner (1970), has demonstrated the importance of Al in leached acid soils, and maximum yields have been reported at pH values well below neutrality (Woodruff, 1967; Peters, 1978). According to Pearson (1975) lime requirement recommendations in the humid tropics should be based on exchangeable Al in the soil rather than on pH as such. Marked reductions in exchangeable Mg in soils at near neutral pH levels have been reported by Färina, Sumner, Plank & Letzsch (1979) and Sumner, Farina and Hurst (1979). Recent work by Färina & Sumner (1979) has shown that near neutral pH levels are not required for maximum maize production and that liming the soil to such pH levels, could in fact be detrimental to plant growth (Kamprath, 1971). Maximum maize yields were obtained on two Natal soils (Balmoral and Avalon) at pH(KCl) values of 4,2 to 4,3 by the former workers. They conclude that if maize is dependent upon legume supplied N, near neutral pH levels may indeed be necessary. The reason for this could be due to increased availability of Mo at near neutral pH and possibly the higher Ca requirement necessary for initiation of nodulation of the legume (Kamprath, 1970b). But in the maize

industry in the R S A, this situation does not apply and therefore liming to pH (H₂O) levels of 6,0 to 6,5 is not only unnecessary for maximum growth, but could result in yield depressions due to increased (lime induced) Al toxicity on some highly weathered soils which contain KCl extractable Al (exchangeable Al) (Färina & Sumner, 1979; Färina, Sumner, Letzsch & Plank, 1979); most of the buffering in leached acid soils is primarily due to exchangeable Al in the pH(H₂O) range 4,5 to 5,4 (Kamprath, 1970) and due to non-exchangeable hydroxy Al and Fe (and organic matter) above pH 5,4 (Coleman & Thomas, 1967). Kamprath (1970a) found that "... maximum growth occurs after a certain amount of the exchangeable Al has been neutralized". He concludes therefore that acid soils should be limed to reduce the *exchangeable Al saturation* to a low level, tolerable to the particular crop, rather than to bring the soil to a uniform pH. The exchangeable Al saturation (or Al saturation) is the exchangeable Al expressed in terms of the effective CEC, which is the sum of exchangeable Al plus exchangeable Ca and Mg:

$$\% \text{ exchangeable Al saturation} = \frac{\text{exchangeable Al}}{(\text{ex Ca} \& \text{Mg}) + (\text{ex Al})} \times 100$$

Natal Region of the Department of Agric. Tech. Service at Cedara, who base lime recommendations on exchangeable Al measurements after the work of Reeve and Sumner (1970), now feel that liming to eliminate exchangeable Al is a doubtful practice, and therefore suggest liming only to reduce the exchangeable Al saturation (% Al saturation) below a critical level, depending on the particular crop (Färina & Sumner, 1979). Various tolerance factors are used for different crops: for example, 25% for maize; zero for lucern.

The Eksteen method, which is useful for estimating the lime requirement of limed and unlimed soils in the Winter Rainfall Region, is expressed as follows (Eksteen, 1969):

$$x = \frac{RH - (Ca + Mg)}{R + 1}$$

where

- x = the lime requirement
- R = the ratio of exchangeable Ca and Mg to exchangeable acidity
- H = exchangeable acidity (K₂SO₄/KOAc extractable).

(Ca + Mg) = HCl extractable Ca and Mg.

The pH value of the soil is measured in 1 mol dm⁻³ KCl.

The method is attractive insofar that it compensates for any added lime remaining in the soil, by subtraction of HCl extractable (Ca + Mg) in the formula. On the other hand, however, Ca and Mg may have been added directly or indirectly to the soil in some form other than lime, for example as Ca(NO₃)₂ for bitterpit, or as MgSO₄, neither of

which cause an increase in the pH of the soil. In this case the Eksteen formula, by subtracting the (Ca + Mg), would underestimate the actual lime requirement of the soil if the amounts of Ca or Mg extracted by HCl were appreciable. Apart from this, the method is designed to "... raise the pH of the soil to a specific level", depending on the particular crop, a practice of doubtful credibility in the light of arguments mentioned previously (Kamprath, 1970a; Farina & Sumner, 1979).

Latest reports from the Western Cape are that the Fruit and Fruit Technology Research Institute intend replacing the Eksteen method for one which relies more on exchangeable Al (exchangeable acidity) and in which (Ca + Mg) are not subtracted in the formula for determining the lime requirement (Conradie, 1979).

Fouché (1979) compared the SMP buffer method with the exchangeable (KCl extractable) Al method and the Ca(OH)₂ incubation method, liming to pH 6,0. In most of the soils tested, lime requirement values by the SMP method were higher than those obtained by the other two methods. The difference in lime requirement values was most noticeable in the case of the Griffin soil (Table 1), where 10 times more lime was indicated by the SMP method than by the exchangeable Al method. The reason for such differences is

mainly due to the fact that the SMP buffer method measures exchangeable Al, H and non-exchangeable hydroxy Al (and Fe), whereas the KCl extraction method only measured exchangeable Al (and H), (Table 3). For the same reason Fouché (1979) points out that incorrect lime requirement estimates could be made with prolonged periods of standing or shaking with the SMP buffer.

The Ca(OH)₂ incubation method is a reliable method for estimating the lime requirement of soils and reflects fairly closely field conditions. The method is rather tedious, however, and can not be recommended for routine work.

Haumann and Volschenk (1979) investigated various buffer methods for estimating lime requirement. They point out that the buffer methods used all aim at raising the soil pH to a specific value (6,5), which may not necessarily be the optimum pH for a particular crop. According to these workers, the SMP and other buffer methods overestimate the actual lime requirement of the soil.

The various methods currently used in State laboratories and by other organisations throughout the country for determining the lime requirement and pH value of soils is presented in Table 2. The nature of the materials involved during the neutralization of soil acidity by different methods is shown in Table 3.

TABLE 1 Lime requirement (ton CaCO₃/ha), KCl extractable Al and percentage amorphous components of six Transvaal acid soils (Fouché, 1979)

Soil series	Locality	pH		Al (NKCl) me/100g	Percentage amorphous component	Lime requirement ton CaCO ₃ /ha (150 mm)		
		H ₂ O	KCl			SMP	Ca(OH) ₂	KCl-Al
Middelburg	Middelburg	4,4	4,1	0,80	14,1	1,4	1,9	2,4
Balmoral	Neishoogte	4,9	4,7	0,29	20,7	2,9	2,3	0,9
Griffin	Belfast	5,2	4,7	0,18	23,0	5,5	3,3	0,5
Farningham	Carolina	4,7	4,5	1,05	23,5	4,9	4,7	3,2
Appam	Panbult	4,8	4,6	0,53	19,5	2,6	2,0	1,6
Leksand	Hendrina	4,7	4,4	0,67	9,9	1,2	1,5	2,0

TABLE 2 Methods currently in use in South Africa for estimating the lime requirement and measuring the pH value of soils

Method used for lime requirement	Institute, region, Organisation	Method used for pH value**
Soil texture & pH	O F S Region*	1
	Karoo Region*	3
	Fertilizer Society S A	2, 4
S M P buffer modif.	Transvaal Region*	2, 3
	Highveld Region*	2, 3
	Fertilizer Society S A	2, 4
	AgriLab	4
Exchangeable Al	Natal Region*	2
	Transvaal Region*	2, 3
	Fruit Research Inst*	3
	Fruit and Fruit Technology Research Institute*	1
	Fertilizer Society S A	2, 4
Eksteen	Winter Rain Region*	2
	Oenological and Viticultural Research Inst*	2
	Fruit and Fruit Technology Research Inst*	1
	Fertilizer Society S A	2, 4
Ca (OH) ₂ Extractable acidity and Al	Citrus Board	2, 4
R B A Harry method (KCl + KOH)	Summer Grain Centre	2
	E. Cape Region*	2, 3

* Department of Agricultural Technical Services

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1. 0,01 mol dm⁻³ CaCl₂ (1:25)
 2. 1 mol dm⁻³ KCl (1:2, 5)
 3. H₂O (1:1)
 4. H₂O (1:2, 5)

TABLE 3 Nature of acidity measured by different lime requirement methods

< 5,4	pH	> 5,4
exchangeable Al and H	non-exchangeable hydroxy Al (and Fe)	
extracted by 1 mol dm ⁻³ KCl	not extracted by 1 mol dm ⁻³ KCl	
extracted by buffered salt solutions (eg NH ₄ OAc)		
extracted/neutralized by SMP and other buffer solutions		

Conclusions

The problem of lime requirement measurement in soils is a rather complex one. Factors such as soil pH, exchangeable Al, non-exchangeable Al, toxicity or tolerance levels of Al (and other elements) to different crops, and element deficiencies and imbalances, are involved. The question exists whether lime should be applied to raise the soil pH to a prescribed value, or to reduce toxicities or deficiencies of different elements, or to select a crop compatible with the specific soil acidity condition. The difference in the quantity of lime recommended in each case could, in some instances, be quite considerable. Before this problem can be resolved satisfactorily, further research regarding the various factors mentioned, is essential.

Over one million tons of agricultural lime are being used annually by South African farmers and much more than this is claimed to be necessary. Such claims however, may well be based on current methods which overestimate the actual lime requirement of the soil. In view of the present fuel crisis and high labour costs, unnecessary applications of lime would have an adverse effect on farming economy and should be avoided. Apart from this, micronutrient imbalances, reduction in exchangeable Mg and increased Al toxicity may be induced by over liming some acid soils, even to near neutral pH values. Laboratory measurements for lime requirement estimation, whatever the method, should be supplemented by field trials with various crops. There is a need, however, for rationalization on the methods currently in use.

Opsomming

'N KORT OORSIG VAN DIE METODES TANS IN GEBRUIK VIR DIE BEPALING VAN DIE KALKBEHOEFTE VAN SUURGRONDE IN DIE R S A

In die R S A asook in die V S A is die bepaling van kalkbehoefte van suurgronde 'n omstrede onderwerp. Aan die een kant word grond pH as basis vir kalkaanbevelings beskou, terwyl aan die ander kant word kalk toegedien om uitruilbare suurheid te neutraliseer of uitruilbare aluminium in die grond tot 'n sekere vlak te verlaag.

Dit mag wees dat deur die gebruik van sekere metodes vir die bepaling van kalkbehoefte, onnodige of oormatige kalktoedienings gemaak kan word. Bo en behalwe die onwenslike ekonomiese aspek hiervan, kan dit ook 'n nadelige uitwerking in die grond teweegbring. Daar is dus 'n behoefte om die kalkbehoeftemetodes tans in gebruik, te rasionaliseer.

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