THE EFFECT OF LIME REACTIVITY ON THE DETERMINATION OF LIME REQUIREMENT OF THREE ACID SOILS

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Introduction

Much has been said on lime requirement criteria for maize (Farina, Summer, Plank & Letzsch, 1980; Fox, 1979). The general trend is that the importance of Al in acid soils is recognised, but there is a certain persistence to use soil pH as criterion. Methods for determining lime requirement of acid soils exist therefore based on obtaining either specific soil pH levels (eg. Shoemaker, McLean & Pratt, 1961) or specific acid or Al saturation levels in the soil (eg. Fox, 1979).

The accuracy of lime recommendation based on whatever method used is, however, dependent on the reactivity of the lime used in practice. It is therefore essential that the reactivity of the specific lime used be taken into account to ensure that the amount of lime recommended actually leads to the desired acidity level in the soil.

The purpose of this paper is to investigate the effect of reactivity of a commercially available dolomitic and calcitic lime on lime recommendations based on two methods.

Materials and methods

Data of liming trials conducted from 1979 to 1983 on a Clovelly Mossdale, a Hutton Msinga and a Hutton Clansthal (MacVicar, De Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen & Harmse, 1977) situated in the Heidelberg, Randfontein and Klerksdorp Magisterial districts, respectively, were used in this study. Selected properties of these soils are given in Tables 1, 2 and 3.

TABLE 1. Soil properties of the Clovelly Mossdale soil and average rainfall at the site chosen in the Heidelberg Magisterial district.*

	Horizon	
	Orthic A	Yellow Apedal 821
Depth (mm)	0 - 365	365 - 570
Effective depth (mm)	1 200	
CEC ($cmol(+)kg^{-1}$)**	3,58	2,86
pH (H_2O)	4,5	4,4
pH (KCl)	3,8	3,9
Ca ($cmol(+)kg^{-1}$)	0,67	0,31
Mg ($cmol(+)kg^{-1}$)	0,12	0,13
K ($cmol(+)kg^{-1}$)	0,10	0,05
Exch. acidity ($cmol(+)kg^{-1}$)	0,92	0,84
Exch. Al ($cmol(+)kg^{-1}$)	0,72	–
P ppm (Bray 2)	12,7	2,0
% acid saturation	50,8	63,2
% Al saturation	44,7	–
Colour (Munsell)	7,5 YR 4/2	7,5 YR 5/6
% Clay	11,80	14,40
% Silt	1,95	5,10
% Sand	86,25	80,50
S/kg clay (cmol(+))	7,63	3,47

(i) Longitude and Latitude: 28°15'E 26°32'S
(ii) Average annual rainfall: 692,5 mm
(iii) Geology:
Witwatersrand quartzite, shale, grit and conglomerate of the Basement Complex

* According to MacVicar, *et al* (1977)
** $cmol(+)kg^{-1}$ = me/100 g.

TABLE 2. Soil properties of the Hutton Msinga soil and average rainfall at the site chosen in the Randfontein Magisterial district.*

	Horizon	
	Orthic A	Red Apedal B21
Depth (mm)	0 - 400	400 - 550
Effective depth (mm)	1 200	
CEC ($cmol(+)kg^{-1}$)**	3,48	2,97
pH (H_2O)	4,8	5,1
pH (KCl)	3,8	4,2
Ca ($cmol(+)kg^{-1}$)	0,31	0,55
Mg ($cmol(+)kg^{-1}$)	0,17	0,45
K ($cmol(+)kg^{-1}$)	0,17	0,17
Exch. acidity ($cmol(+)kg^{-1}$)	0,73	0,53
Exch. Al ($cmol(+)kg^{-1}$)	0,50	–
P mg/kg (Bray 2)	13,7	3,6
% acid saturation	52,9	31,2
% Al saturation	43,5	–
Colour (Munsell)	2,5 YR 3/6	2,5 YR 4/6
% Clay	15,3	23,5
% Silt	3,4	6,8
% Sand	81,3	69,7
S/kg clay (cmol(+))	4,31	5,02

(i) Longitude and Latitude: 27°35'E 26°11'S
(ii) Average annual rainfall: 732 mm
(iii) Geology:
Witwatersrand quartzite, shale, grit and conglomerate

* According to MacVicar, *et al* (1977)
** $cmol(+)kg^{-1}$ = me/100 g.

TABLE 3. Soil properties of the Hutton Clansthal soil and average rainfall at the site chosen in the Klerksdorp Magisterial district.*

	Horizon	
	Orthic A	Red Apedal B21
Depth (mm)	0 - 320	320 - 500
Effective depth (mm)	1 200	
CEC (cmol(+)kg^{-1})**	2,32	2,29
pH (H_2O)	4,9	5,1
pH (KCl)	4,0	4,1
Ca (cmol(+)kg^{-1})	0,35	0,53
Mg (cmol(+)kg^{-1})	0,18	0,25
K (cmol(+)kg^{-1})	0,14	0,13
Exch. acidity (cmol(+)kg^{-1})	0,41	0,32
Exch. Al (cmol(+)kg^{-1})	0,31	–
P mg/kg (Bray 2)	38,4	6,7
% acid saturation	38,0	26,0
% Al saturation	31,6	–
Colour (Munsell)		
% Clay	8,60	11,25
% Silt	3,05	3,50
% Sand	88,35	85,25
S/kg clay (cmol(+))	7,91	8,18

(i) Longitude and Latitude: 26°41'E 26°49'S
(ii) Average annual rainfall: 580 mm
(iii) Geology:
Witwatersrand quartzite and shale

* According to MacVicar, *et al* (1977)
** cmol(+)kg^{-1} = me/100 g.

Values for pH and percentage acid saturation indicate that all three soils are excessively acid and would require liming for successful production of most crops. Dolomitic and calcitic lime were applied to the soil at rates of 0, 2, 4, 8 and 16 tons per hectare in August 1979

TABLE 4. Chemical and physical properties of the Dolomitic and Calcitic lime used in the incubation study and in the field trials.

	Dolomitic lime	Calcitic lime
Ca (as % $CaCo_3$)	39,45	72,03
Mg (as % $MgCO_3$)	45,84	7,38
CCE* (% $CaCO_3$)	90,63	78,50
% < 10 mesh	99,07	99,51
% < 60 mesh	40,68	50,70
Fe mg kg^{-1}	799	1 370
Zn mg kg^{-1}	8	7
Mn mg kg^{-1}	53	940
Cu mg kg^{-1}	5	6
A1 mg kg^{-1}	1 225	1 013

* Calcium Carbonate Equivalent

in combination with 0, 30 + 30 and 60 + 60 kg P per hectare. The effect of the latter will not be dealt with in this paper. Analyses of the limes are given in Table 4.

Both limes exceed the minimum stipulations given in Act 36 of 1947[1)]

The field trials were planted to maize (cultivar Pioneer 432) in all four seasons.

A laboratory incubation trial was also conducted using the Clovelly Mossdale soil. Zero, 2, 4, 6, 8, 10 and 16 tons per hectare equivalent of precipitated $CaCO_3$ (AR), the abovementioned dolomitic and calcitic lime were applied unreplicated to 750 g samples of the Mossdale in glass bottles. Incubation was conducted in the dark at 30°C and field moisture capacity for four months. The soils were allowed to dry after incubation, crushed to pass a 2 mm standard sieve and analysed.

Lime requirement for the soils were determined by a slightly modified SMP (Shoemaker, McLean & Pratt, 1961) method used in the Highveld Region soil analysis laboratory (modification given by Haumann & Volschenk, 1979) aimed at obtaining a soil pH (H_2O) of 6,0. The other method used was aimed at obtaining an acid saturation of 25 per cent as used in the Natal Region (method given by Haumann, 1980).

To enable determination of the reactivity of the dolomitic and calcitic limes and the effect on the accuracy of the two lime requirement methods the following data were used:

- Maize yield tons per hectare
- Soil pH (H_2O and KC1) in 1 : 2,5 soil to water and 1 molKCldm^{-3} solution, respectively (Jackson, 1958)
- Percentage acid and Al saturation (Fox, 1979)

Results and discussion

Lime requirements determined by the modified SMP method and the method used in the Natal Region for the Mossdale, Msinga and Clansthal soils are given in Table 5.

TABLE 5. Lime requirement of a Mossdale, Msinga and Clansthal soil as determined by the modified SMP method (SMP mod.) and the 'Natal method' (NM 25%)

Soil type	Lime Requirement (kg/ha 200 mm)	
	SMP mod.	N.M. 25%
Mossdale	8 267	2 805
Msinga	6 133	2 310
Clansthal	3 733	840

TABLE 6. Interpolated maize yield at lime rates indicated by the modified SMP and Natal methods on the Mossdale, Msinga and Clansthal soils.

Soil	Method	Lime Type	Yield 1979/80	1980/81	1981/82	1982/83	Average
			t/ha				
Mossdale	1*	Dol	3,8062 a[1)]	6,0408 b	1,0286 c	0,8187 b	2,9236 b
		Cal	3,9593 a	5,4863 ab	0,7663 bc	1,0293 c	2,8103 ab
	2**	Dol	3,4947 a	5,3360 ab	0,3936 a	0,3844 a	2,4022 ab
		Cal	3,1414 a	4,7984 a	0,4598 ab	0,3677 a	2,1918 a
		Lsd	1,6900	1,2370	0,3120	0,2100	0,6582
Msinga	1	Dol	3,6890 a	2,9560 b	0,9650 b	2,4761 c	2,5215 b
		Cal	3,4890 a	2,8969 ab	0,8230 ab	2,0790 bc	2,3220 b
	2	Dol	3,5192 a	2,7060 ab	0,8841 b	1,4767 ab	2,1465 ab
		Cal	3,1717 a	2,1193 a	0,5839 a	1,3233 a	1,7996 a
		Lsd	1,4910	0,7920	0,2595	0,6140	0,4510
Clansthal	1	Dol	4,4626 a	3,4142 bc	3,4454 a	1,5657 c	3,2220 ab
		Cal	4,7074 a	3,6505 c	3,6159 a	1,5368 bc	3,3799 b
	2	Dol	4,5116 a	2,4623 a	2,8398 a	0,9203 a	2,6835 a
		Cal	4,7071 a	2,7136 ab	2,9881 a	1,0271 ab	2,8590 ab
		Lsd	1,7227	0,7883	0,9777	0,5308	0,6299

* Modified SMP (Haumann & Volschenk, 1979)
** To obtain 25% acid saturation
1) Yield values with the same letter within a season and within a soil type are statistically the same

The modified SMP method indicated more than double the amount of lime indicated by the method used in the Natal Region.

Maize yields obtained at the different lime application rates given in Table 5 were determined by means of interpolation of yield data obtained in the field trials and given in Table 6.

Higher maize yields were obtained when liming according to the modified SMP method compared to the method used in the Natal Region. These differences were statistically significant when comparing yields obtained using dolomitic lime to yields obtained using calcitic lime. Higher yields being obtained using dolomitic lime on the Mossdale and Msinga.

The reverse was true on the Clansthal. The reason for this was probably due to the maize being able to exploit subsoil reserves of Mg in the case of the Clansthal which was not possible on the Mossdale and Msinga due to excessive subsoil acidity and low reserves of subsoil Mg (Data not given).

It would appear offhand that pH (H_2O) 6,0 is a superior criterion for determining lime requirement than an acid saturation of 25 percent. The soil analyses, however, show that neither lime requirement method succeeded in indicating the correct amount of lime required to obtain the desired pH (H_2O) or percentage acid saturation (See Table 7).

pH (H_2O) values ranging from 4,76 to 5,36, 4,91 to 5,33 and 4,88 to 5,34 for the Mossdale, Msinga and Clansthal, respectively, were obtained when liming according to the modified SMP method using dolomitic lime. Acid saturation values ranging from 42 to 58, 44 to 60 and 40 to 55 percent for the Mossdale, Msinga and Clansthal, respectively, were obtained when liming according to the Natal Region method using dolomitic lime.

Considering the results reported, it becomes apparant that either the methods used are inaccurate or the limes used have relatively low reactivities.

To enable determination of the calcium carbonate equivalent (CCE) of the dolomitic and calcitic lime under field conditions use was made of the incubation results. The amounts of $CaCO_3$, dolomitic and calcitic lime required to neutralise exchangeable acidity were determined and plotted in Figure 1.

Linear regression was applied with success to the data and r^2 values of 0,9855, 0,9926 and 0,9946 were obtained for the neutralisation lines for the $CaCO_3$, dolomitic and calcitic lime, respectively.

Similar regression analyses of change in pH (H_2O) due to liming resulted in r^2 values of 0,9977, 0,9970 and 0,9803 for the $CaCO_3$, dolomitic and calcitic lime, respectively (See Figure 2).

TABLE 7. pH(KCl), pH(H_2O), percentage acid and Al saturations at lime levels indicated by the modified SMP and the Natal lime requirement methods over four years, after liming three soils with dolomitic lime.

Season		1979/80		1980/81		1981/82		1982/83		Average	
Method		SMP	Natal	SMP	Natal	SMP	Natal	SMP	Natal	SMP	Natal
Mossdale	*1	4,21	3,98	4,41	3,99	4,49	3,99	4,43	3,93	4,39	3,97
	2	4,76	4,50	5,09	4,74	5,36	4,78	5,27	4,59	5,12	4,65
	3	26,44	58,30	18,36	44,95	22,46	49,80	14,97	42,01	20,56	48,77
	4	–	–	10,81	25,90	9,10	24,50	5,41	26,92	8,44	25,77
Msinga	1	4,10	3,96	4,51	4,12	4,38	4,09	4,37	4,09	4,34	4,07
	2	4,91	4,76	5,33	4,86	5,15	4,76	5,08	4,62	5,12	4,75
	3	36,40	44,32	22,34	44,63	31,40	56,06	33,93	60,65	31,02	51,42
	4	–	–	13,70	28,70	10,85	29,40	14,87	36,69	13,14	31,60
Clansthal	1	–	–	4,07	3,89	4,39	4,08	4,32	4,15	4,26	4,04
	2	–	–	4,88	4,65	5,34	4,96	5,17	4,98	5,13	4,86
	3	–	–	30,75	55,01	20,47	41,91	22,82	39,95	24,68	32,77
	4	–	–	24,83	42,30	5,69	22,15	9,90	25,38	13,47	29,94

*1 — pH(KCl)
2 — pH(H_2O)
3 — % acid saturation
4 — % Al saturation

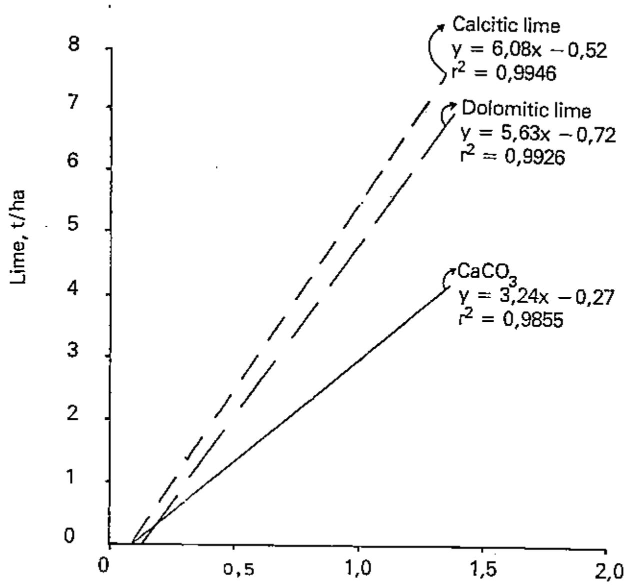

FIG 1. Neutralisation of exchangeable acidity due to incubation with different limes and application rates in a Mossdale soil.

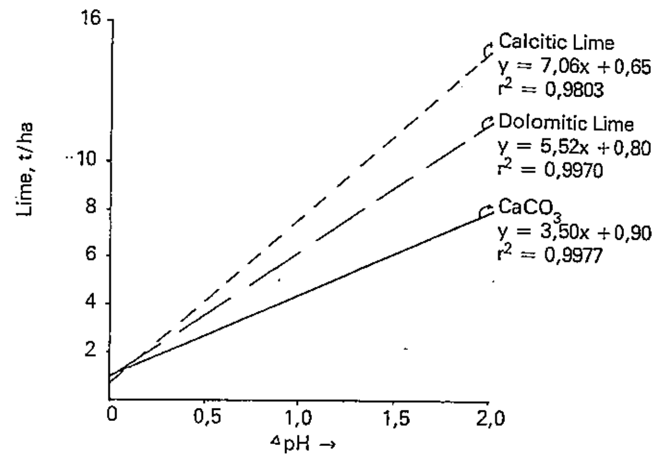

FIG 2. Changes in pH(H_2O) of a Mossdale soil due to incubation with $CaCO_3$, dolomitic and calcitic lime at different levels.

Based on the neutralisation of one cmol(+)/kg exchangeable acidity and unit increase in pH (H_2O), respectively, the effective CCE of the dolomitic lime was calculated to be 65 percent using both methods, and the effective CCE for the calcitic lime was 57 and 53 percent, respectively. These values being appreciably lower than the CCE values given in Table 4.

Evaluation of lime reaction CCE in the field was done using the regression equations in Figures 1 and 2, maximum neutralisation of exchangeable acidity and maximum increase in pH (H_2O) found under field conditions at the different lime application levels. The calculated CCE values for the dolomitic and calcitic limes are given in Table 8.

It was found that the CCE of the two limes drastically decreased with increased application rate. This was probably due to the soils not being acid enough to necessitate application of lime in excess of 8 tons per hectare and/or that effective incorporation of such large amounts of lime at one time was not obtained.

The calculated CCE values of the limes appear to follow a pattern according to the average annual rainfall.

TABLE 8. Maximum neutralisation of exchangeable acidity and increase in $pH(H_2O)$ at different application rates of dolomitic and calcitic lime for a Mossdale, Msinga and Clansthal soil.

Soil	Maximum change in				Lime	Reacted				CCE in the field			
	cmol(+) exch acid/kg soil		$pH(H_2O)$		applied	Exch. acid		$pH(H_2O)$		Exch acid*		$pH(H_2O)$**	
	Dol.	Cal.	Dol.	Cal.	in field	Dol.	Cal.	Dol.	Cal.	Dol.	Cal.	Dol.	Cal.
						t/ha				%			
Mossdale	0,42	0,37	0,20	0,24	2	1,087	0,925	1,60	1,74	54,3	46,3	80,0	87,0
	0,53	0,44	0,70	0,40	4	1,444	1,152	3,35	2,30	36,1	28,8	83,8	57,5
	0,81	0,71	0,77	0,64	8	2,352	2,028	3,60	3,14	29,4	25,4	45,0	39,3
	1,36	1,36	1,74	1,47	16	4,136	4,136	6,99	6,05	25,9	25,9	43,7	37,8
Msinga	0,45	0,40	0,06	0,17	2	1,185	1,023	1,11	1,50	59,2	51,2	55,5	75,0
	0,58	0,63	0,07	0,33	4	1,606	1,769	1,15	2,06	40,1	44,2	28,8	51,5
	1,11	0,91	0,99	0,67	8	3,325	2,677	4,37	3,25	41,6	33,5	54,6	40,6
	1,14	1,01	1,76	1,34	16	3,422	3,001	7,06	5,59	21,4	18,8	44,1	34,9
Clansthal	0,29	0,36	0,27	0,47	2	0,666	0,893	1,85	2,55	33,3	44,7	92,5	>100
	0,49	0,58	0,74	0,53	4	1,315	1,606	3,49	2,76	32,9	40,1	87,3	69,0
	0,65	0,72	1,40	1,06	8	1,833	2,060	5,80	4,61	22,9	25,8	72,5	57,6
	0,71	0,80	2,23	2,10	16	2,028	2,320	8,71	8,25	12,7	14,5	54,4	51,6

* CCE of lime according to neutralisation of exchangeable acidity under field conditions.
** CCE of lime according to increase in $pH/H_2O)$ under field conditions.

Highest reaction at 2 tons per hectare of 59,2 percent on the Msinga (720 mm/year — see Tables 1 to 3), Mossdale 54,3 percent (680 mm/year) and 33 percent on the Clansthal (580 mm/year) for the dolomitic lime. Values for the calcitic lime were 51,2, 46,3 and 44,7 percent, respectively. The CCE values calculated according to increase in pH (H_2O) were on the whole higher than the CCE values calculated according to neutralisation of exchangeable acidity, but tended to be higher than the CCE values given in Table 4 which is highly improbable. Different buffer capacities and pH-dependent charges of the three soils are probably responsible for the apparent unreliability of CCE calculated by the increase in pH (H_2O) procedure.

It appears that the lime fraction finer than 60 mesh (250 micron) or at the most an additional 20 percent of the fraction just coarser than 250 micron will react with an acid soil under an average rainfall of 720 mm per year. The lower the average rainfall, the more important it appears to be that lime should be finer than 250 micron. It furthermore seems advisable to apply not more than 2 to 4 tons of lime at a time to obtain maximum lime reactivity.

Based on the data it appears that a liming correction factor (LCF) based on average annual rainfall, the fraction of lime finer than 250 micron and incubation-determined CCE (or a quicker method) should be used to enable liming to a desired soil acidity level. An approximation of LCF's based on the findings of this study is given in Table 9.

TABLE 9. Guidelines for determining liming correction factor using CCE and sieve analysis of lime.

	Average Rainfall (mm)		
	<600	600-700	>700
LCF*	$\frac{(1)}{(\% < 250\ \mu m/100)} \times 1{,}2 \times \frac{1}{CCE/100}$ **	$\frac{(1)}{(\% < 250\ \mu m/100)} \times 0{,}9 \times \frac{1}{CCE/100}$	$\frac{(1)}{(\% < 250\ \mu m/100} \times 0{,}8 \times \frac{1}{CCE/100}$

*LCF Liming correction factor.
**CCE Calcium carbonate equivalent determined by incubation.

Further testing of the LCF's given in Table 9 should, however, be conducted since only two limes were used in the study.

Conclusions

- The relatively low reactivity of the dolomitic and calcitic limes used was undoubtedly responsible for the inability of the two lime requirement methods to indicate the correct lime requirement.
- The stipulation that only 30 percent of a lime should pass a 250 micron standard sieve (Act 36 ot 1947), should be increased.
- The 0,5N HCl method for determining CCE overrates lime reactivity.
- Average annual rainfall apparantly plays an important role in lime reactivity.
- A liming correction factor based on the fractions of lime passing 250 micron standard sieve, average rainfall and incubation determined CCE should be used in lime recommendations.

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