SHORT TERM EFFECTS OF SURFACE APPLIED AMENDMENTS ON TWO ACID SANDY LOAM SOILS IN THE EASTERN TRANSVAAL HIGHVELD*

(Met opsomming in Afrikaans)

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Abstract

The short term effects of surface applied amendments on certain chemical properties of two acid sandy loam soils in the Eastern Transvaal Highveld were measured. The soils were a red, sandy loam (Hutton series) and a yellow brown sandy loam (Ruston series).

On both soils leaching of calcium from applied lime and gypsum into subsoil horizons occurred but was limited under practical field conditions. The surface applied amendments had no marked effect on subsoil pH and exchangeable aluminium index (EAI) values.

The relationship between EAI and pH measured in H_2O, $CaCl_2$ and KCl was found to be logarithmic, but different for the two soils. Similarly, different but significant logarithmic relationships were found between exchangeable Ca and EAI, and exchangeable Ca + Mg + K and EAI for the two soils.

Penetration of maize roots into the acid subsoils was also examined in excavation pits and evaluated according to different treatments.

Introduction

The adverse effects of soluble aluminium in acid mineral soils on the growth of a variety of crops have been reported by many investigators (Brown, et al. 1950; Reeve, 1970; Kamprath, 1970; Rios and Pearson, 1964; Lee, 1971; Hutchinson and Hunter, 1970; Armiger, et al. 1968). Toxic levels of aluminium are often manifested by severely restricted root growth (Adams and Lund, 1966; Flemming and Fov, 1968; Armiger, et al. 1968; Sumner, 1970).

In order to eliminate or reduce toxic levels of aluminium in subsoils various workers have investigated the possibility of applying soluble calcium salts as acid soil ameliorants. Sumner (1970) found that leaching an acid sandy subsoil from the Makatini flats with a saturated gypsum solution in pots was reasonably effective in removing exchangeable aluminium. Similar results were obtained by Fouche (1968) who leached acid soils in pots with $CaCl_2$. In simulated soil profiles in leaching tubes, Reeve (1970) found that Ca from surface incorporated gypsum moved rapidly through the entire profile but at the expense of exchangeable Mg. There is, however, not sufficient conclusive evidence that the same results will be obtained when a soluble Ca salt is applied as an ameliorant under field conditions. Surface applied gypsum on Maputa soil decreased exchangeable aluminium index (EAI) values and increased pH and exchangeable Ca in the upper layers of the soil after 39 months (Sumner, 1970). Actually, EAI increased below 45 cm depth. Sumner suggested that given sufficient time and sufficient water for leaching, gypsum additions are a feasible means of ameliorating this soil. McCart and Kamprath (1965) on the other hand, found that the additions of a soluble source of Ca cannot overcome the adverse effects of Al in acid, low CEC soils. Gypsum added to acid soils with high aluminium saturation tended to increase aluminium and decrease pH. Brown et al (1950) reported that gypsum applied at rates of 1000–4000 lb/acre on an acid soil high in exchangeable aluminium, Mn and Cu, did not affect the growth of several crops.

The object of this study was to measure the short term effects of surface applied amendments on soil pH, base status, EAI and root development on two acid soils in the Middelburg district of the Eastern Transvaal Highveld.

Materials and methods

Description of soils

1 *Hutton series.* This is a deep red, well-drained and medium textured soil. Detailed profile description is presented in Appendix 1. Some selected properties are given in Table 1.

Exchangeable Ca values decline steadily with increase in depth. Base saturation also declines with depth – from 30 per cent in the topsoil to less than 10 per cent at depth. EAI values remain fairly constant throughout the profile except for the 0–40 cm depth, where EAI values have been reduced by lime applications in the past. Kaolinite is the domestic clay mineral.

2 *Ruston series.* This soil is a member of the Avalon form. Profile description is presented in Appendix 2. Morphologically this soil differs from the Hutton in that it exhibits hydromorphism, manifested by a prominent yellow brown B horizon overlying a soft plinthic layer at 80+ cm. Selected properties are presented in Table 2.

pH values, especially $pH(H_2O)$, are slightly higher in the Ruston than the Hutton. EAI values are essentially the same for the two soils but is lower in the plinthite layer of the

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TABLE 1a Selected properties of the Hutton series: pH and cation exchange properties (me %)

Depth cm	KCl pH	H_2O pH	$CaCl_2$ pH	EAl	(i) CEC	Net (ii) CEC	Ca	Mg	K
0–20	4,8	5,2	4,9	0,02	6,9	4,08	1,40	0,37	0,18
20–40	4,0	4,8	4,3	0,33	6,1	3,50	0,75	0,16	0,09
40–60	4,0	4,7	4,2	0,43	6,1	3,31	0,60	0,16	0,09
60–80	4,2	4,9	4,5	0,54	6,1	3,40	0,40	0,20	0,10
80–100	4,2	4,2	4,1	0,53	5,3	3,55	0,40	0,16	0,10
100–120	4,2	4,5	4,3	0,52	6,1	3,44	0,30	0,13	0,12
120–140	4,3	4,4	4,3	0,47	6,1	3,44	0,25	0,20	0,07

(i) N NH_4OAc leached

(ii) 0,2 N NH_4Cl leached (Reeve, 1970)

TABLE 1b Particle size distribution and dominant clay minerals

Depth cm	Sand %	Silt %	Clay %	dcm (iii)
0–20	76	7	17	Kaolinite
20–40	77	4	19	"
40–60	78	5	17	"
60–80	72	4	24	"
80–100	68	2	30	"
100–120	72	2	26	"
120–140	68	6	26	"

(iii) Dominant clay mineral

TABLE 2a Selected properties of the Ruston series: pH and cation exchange properties (me %)

Depth cm	pH			EAl	(i) CEC	net (ii) CEC	Ca	Mg	K
	KCl	H_2O	$CaCl_2$						
0–20	4,2	5,4	4,6	0,33	6,8	4,15	1,00	0,20	0,26
20–40	4,2	5,2	4,4	0,61	6,8	3,79	0,50	0,20	0,20
40–60	4,2	5,2	4,4	0,58	7,3	3,70	0,34	0,15	0,15
60–80	4,3	5,5	4,6	0,54	5,3	4,26	0,30	0,14	0,14
80–100	4,4	5,3	4,8	0,31	6,1	4,00	0,30	0,12	0,12
100–120	4,5	5,5	4,8	0,27	6,1	4,08	0,30	0,14	0,14
120–140	4,5	5,6	4,8	0,24	6,1	4,08	0,30	0,12	0,12

(i) N NH_4OAC Leached,

(ii) 0,2N NH_4Cl leached (Reeve, 1970)

TABLE 2b Particle size distribution and dominant clay minerals

Depth cm	Sand %	Silt %	Clay %	dcm(iii)
0–20	82	3	15	Kaolinite
20–40	79	3	18	"
40–60	74	2	24	"
60–80	71	4	25	"
80–100	67	5	28	"
100–120	67	5	28	"
120–140	69	7	24	"

(iii) Dominant clay mineral

Ruston than at corresponding depths in the Hutton series. Cumulative amounts of extractable Aluminium in six extracts with 0,2N NH_4Cl and a shaking period of 15 minutes per extraction are similar for the two soils viz. negligible in topsoils and 0,85–0,90 at depths greater than 40 cm. Exchangeable calcium values within the Ruston soil also decline with increasing depth whilst exchangeable magnesium remains fairly constant with depth. Base saturation is approximately the same as in the Hutton viz. 21% in the topsoil and decreasing to 10% at depth. Particle size distribution and dominant clay mineral (kaolinite) are essentially the same for the two soils.

It is perhaps interesting to compare the Hutton soil in this study with the one on which Reeve (1970) conducted his experiments. Large differences exist between EAI values and exchangeable Al in the two soils, both values being much lower in the Middelburg soil. The greatest difference is to be found in N NH_4OAc CEC. This value is >20 in the Natal soil, but only 6–7 in the Middelburg soil. In fact, N NH_4 OAc CEC of the Middelburg soil corresponds with 'field pH' CEC of the Natal soil. Net CEC values are approximately the same for the two soils. It can therefore be concluded that the Middelburg soil has a much lower pH-dependent CEC. One is also tempted to speculate that the Middelburg soil contains much less amorphous Al and Fe hydroxy compounds than the Natal soil.

Experimental Procedure

Prior to the commencement of the trials maize had been commercially cultivated for two seasons on the Ruston and for six seasons on the Hutton series. Growth and production of maize was generally unsatisfactory during this period. At the time it was assumed that poor growth was caused by harmful (possibly toxic) levels of aluminium in the subsoil and/or general infertility. Investigation of maize planted on the Hutton soil during the summer of 1969 revealed a total absence of maize roots in the layer below plough depth. On the transition between plough layer and subsoil maize roots were severely stunted. Top growth was also stunted and showed a high susceptibility to periodical droughts. Crop performance was generally better on the Ruston soil and it was assumed that soil acidity and associated factors viz. harmful levels of aluminium were a lesser problem on this soil. In order to determine NPK nutritional requirements of maize grown on these soils, two randomized NPK trials were laid down on selected sites (Möhr, 1972). Working on the assumption that toxic levels of aluminium might exist, a heavy liming programme was followed. Apart from the NPK treatments, the following additional treatments were applied.

(i) 3 tonnes calcitic lime/ha broadcast by lime spreader.

(ii) 1 tonne gypsum applied by hand on all plots. On the Hutton site 3 additional levels of gypsum were applied on 3 single unreplicated plots viz. 2, 3 and 4 tonnes of gypsum per ha.

Treatments (i) and (ii) were ploughed under during September 1971 to a depth of 40 cm.

(iii) Two weeks later a second broadcast application of 2 tonnes calcitic lime/ha was ploughed down to a depth of 30 cm.

(iv) In order to compensate for possible trace element deficiencies following the heavy liming programme, sufficient quantities of copper, zinc, boron and molybdenum were applied to all plots.

(v) In order to compensate for a possible magnesium deficiency, commercial Magnesium sulphate at a rate of 112 kg/ha was applied as an early side dressing to all plots.

Maize cultivar SSM 42 was planted on the 1st November 1971 at a planting density of 53 000 p/ha in 1 meter rows. A final plant population of 40 000–42 000 p/ha was obtained.

Sampling technique

When the plants had reached a hard dough stage of development (March 1972), excavation pits approximately 1 m wide x 2 m long x 1 m deep were dug for visual inspection of root proliferation. Samples were collected at 20 cm depths from the following treatments:

Hutton series

5 tonnes lime + 1 tonne gypsum .... 6 'samples'
i e 2 pits per each 3 replications
5 tonnes lime + 2 tonnes gypsum .... 1 sample
5 tonnes lime + 3 tonnes gypsum .... 1 sample
5 tonnes lime + 4 tonnes gypsum .... 1 sample
5 tonnes lime only(1) .... 3 samples
'control' (2) .... 1 sample

(1) Pits were dug between blocks where gypsum had not been applied.
(2) A pit was dug in a land immediately adjoining the trial site where 2 tonnes of calcitic lime had been applied the previous season, and ploughed down to a depth of 24 cm. No previous applications of lime had been made on this land.

All the '5 tonnes lime' treatments had received 2 tonnes of dolomitic lime and 2 tonnes of calcitic lime in the past. These treatments had, therefore, received a total of 9 tonnes of lime over a period of 6 years.

Ruston series

5 tonnes lime + 1 tonne gypsum .... 6 samples
5 tonnes lime only .... 3 samples
virgin soil (1) .... 1 sample
control (2) .... 1 sample

(1) virgin soil samples were obtained from a fairly broad strip of headland immediately adjoining the trial.

(2) These samples were obtained from a land immediately adjoining the trial. This land had received 2 tonnes of calcitic lime + 2 tonnes of dolomitic lime in the past.

Apart from the samples collected in excavation pits for pH and EAI determination, a different sampling technique was used on the Ruston soil. Composite samples in a zigzag pattern were collected from the above treatments by means of a Johnson soil auger in 20cm cores up to a depth of 140 cm.

The '5 tonnes lime' treatments had received 2 tonnes dolomitic lime + 2 tonnes calcitic lime during past seasons; therefore a total of 9 tonnes lime had been applied over a period of 3 years.

It should be obvious that the trials were not designed to measure the effects of lime and lime + gypsum treatments on soil properties *per se.* Statistical evaluations can therefore not be made. The authors are of the opinion however, that certain conclusions albeit tentatively, can be drawn from the results obtained. Detailed analysis results are presented in Appendix 3.

Analytical methods

Two methods were employed for measuring cation exchange capacity:

(a) 'Standard' procedure i e leaching with N NH_4OAc buffered at pH 7, and washing excess ammonia with absolute alcohol. Adsorbed NH_4^+ was determined by Kieldahl distillation in boric acid and titration with standard diluted H_2SO_4;

(b) by leaching with 0,2N NH_4Cl and subsequent washing with deionized water until soil is free of Cl^- (Reeve, 1970). Exchangeable bases were extracted with N NH_4 OAc. Ca and K were determined by means of a flame photometer and Mg colorimetrically. EAI was determined by the method suggested by Reeve and Sumner (1970). Clay minerals were identified by means of X-ray diffraction.

Results and discussion

Relationship between EAI and pH

In order to establish whether any relationship exists between pH measured in H_2O, 0,002M $CaCl_2$ and 0,1N KCl and EAI for the two soils, different transformations of the data from 150 samples were effected to obtain the best 'fit'.

The values and regression equations of the best fits are presented in Table 3(a) and the regression curves illustrated in Figure 1(a). From the data it appears that pH measured in

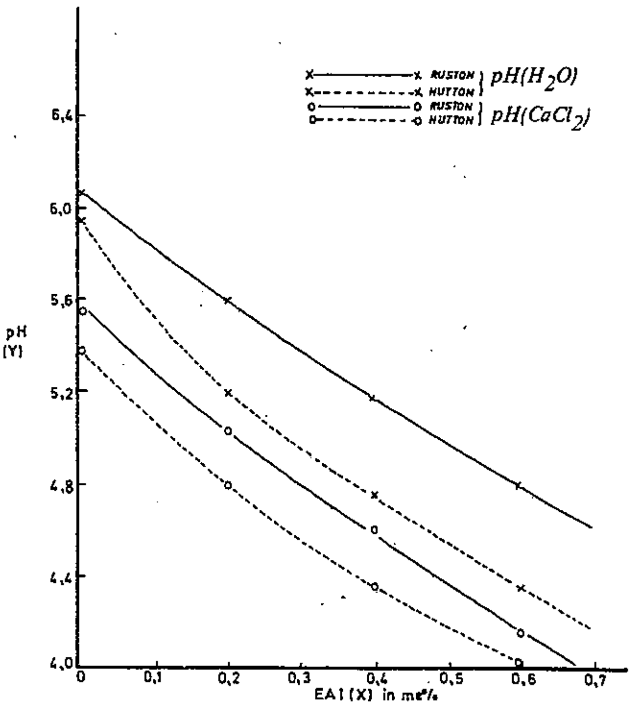

Fig 1(a) Relationship between pH and EAI: Ruston and Hutton series

TABLE 3a Relationship between soil pH values and EAI for Ruston and Hutton series

Soil Series	Factor(y)	r value	Regression equation
Ruston	pH(H_2O)	–0,751**	y = a–blog(x+2)
	pH(KCl)	–0,542*	log(y) = a–blog(x+2)
	pH($CaCl_2$)	–0,679**	y = a– blog(x+2)
Hutton	pH(H_2O)	–0,773**	log(y) = a–blog(x+2)
	pH(KCl)	–0,589*	log(y) = a–blog(x+2)
	pH($CaCl_2$)	–0,732**	log(y) = a–bx

** .... P = 0,01
* .... P = 0,05

TABLE 3b Relationship between base status (me%) and EAI for Ruston and Hutton series

Soil Series	Factor(y)	r value	Regression equation
Ruston	Ca	–0,591*	log(y+1) = a–blog(x+2)
	Ca+Mg+K	–0,582*	log(y+1) = a–blog(x+2)
Hutton	Ca	–0,732**	log(y+1) = a–blog(x+2)
	Ca+Mg+K	–0,772**	y = a–blog(x+2)

** .... P = 0,01
* .... P = 0,05

$CaCl_2$ and H_2O is better correlated with EAI than pH (KCl). The latter only reached significance at the 5% level. It is also significant that the regressions differ between the two soils, despite the fact that base exchange properties and particle size distribution (Tables 2 and 3, Appendix 3) for the two soils are fairly similar. Similar results were obtained by Avres, et al (1965) who found that extractability of Al increased rapidly and approximately linear with in pH below 5,8 but large differences in amounts extracted were found for different soils.

The relationship between EAI and exhangeable bases

This relationship was calculated in the same way as for EAI and pH. The best 'fits' are also described by logarithmic functions (Fig 5). The correlations are stronger in the Hutton than in the Ruston (Table 3b); the slope of the regression curves also differ between the two soils. The latter indicates that slightly higher levels of exchangeable Aluminium can be expected in the Ruston than the Hutton at the same Ca and Ca + Mg + K values.

The effect of surface incorporated amendments on pH, exchangeable bases and EAI

As could be expected, the heavy liming programme resulted in a sharp increase in pH values in the layer of incorporation (0—40 cm). Below 40 cm depth there is no consistent pattern in pH values with respect to different treatments (Figures 2a and 2b). It can be concluded that below 40 cm depth there is not a significant change in pH. It is striking that 1 tonne of gypsum in addition to 5 tonnes of lime on Ruston series markedly increased the pH in 0—40 cm depth. However, an additional application of 3 tonnes gypsum on Hutton series did not increase the pH above that attained by 5 tonnes of lime.

The effect of amendments on exchangeable Ca is shown graphically in Figure 3a and 3b. On the Hutton series little

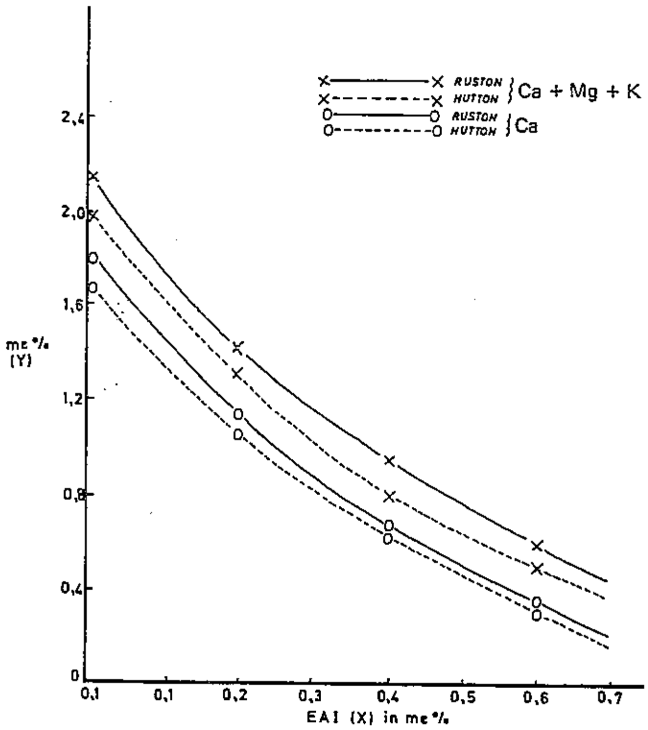

Fig 1b Relationship between base status and EAI: Ruston and Hutton series

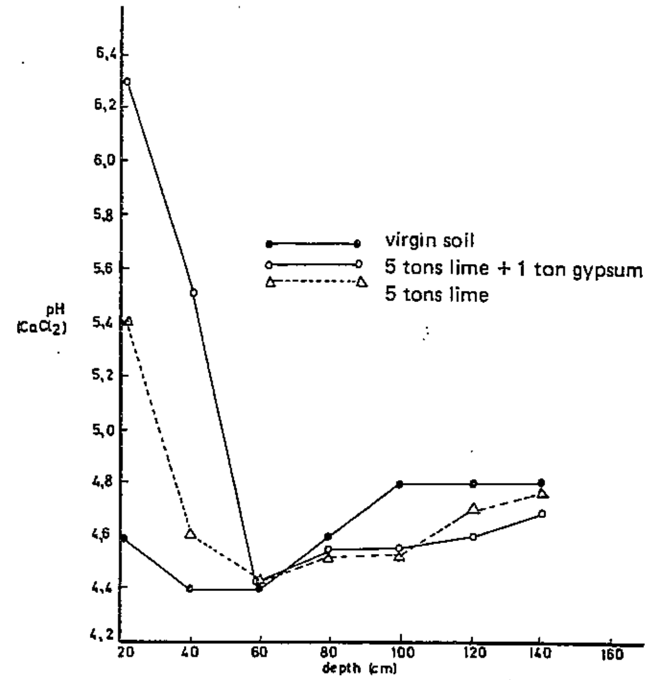

Fig 2b The effect of surface incorporated amendments on pH ($CaCl_2$) in Ruston series

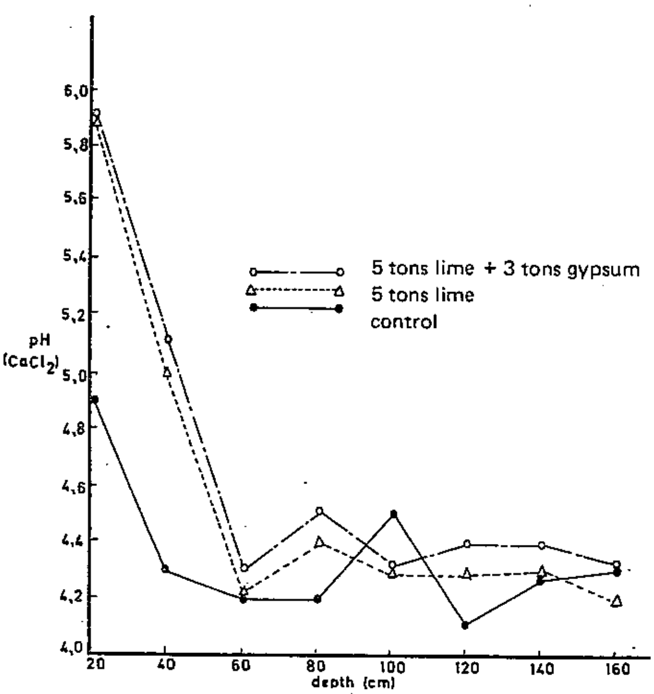

Fig 2a The effect of surface incorporated amendments on pH ($CaCl_2$) in Hutton series

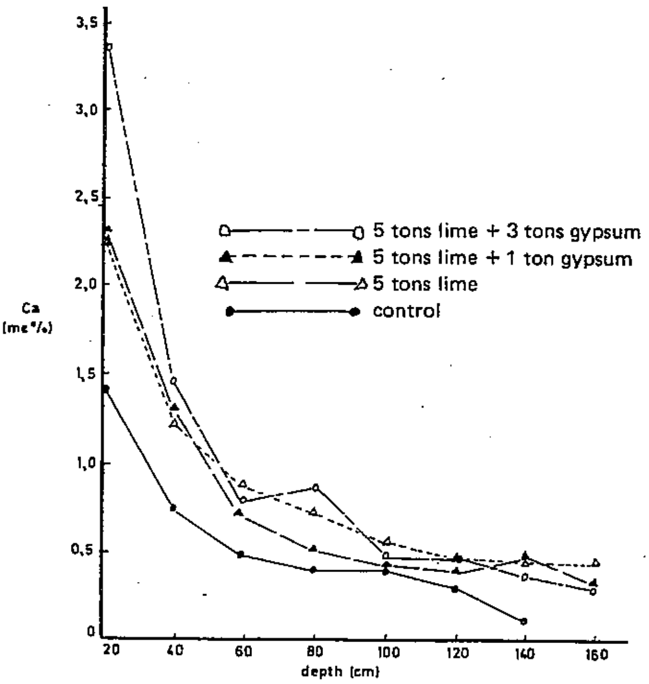

Fig 3a The effect of surface incorporated amendments on exchangeable Ca in Hutton series

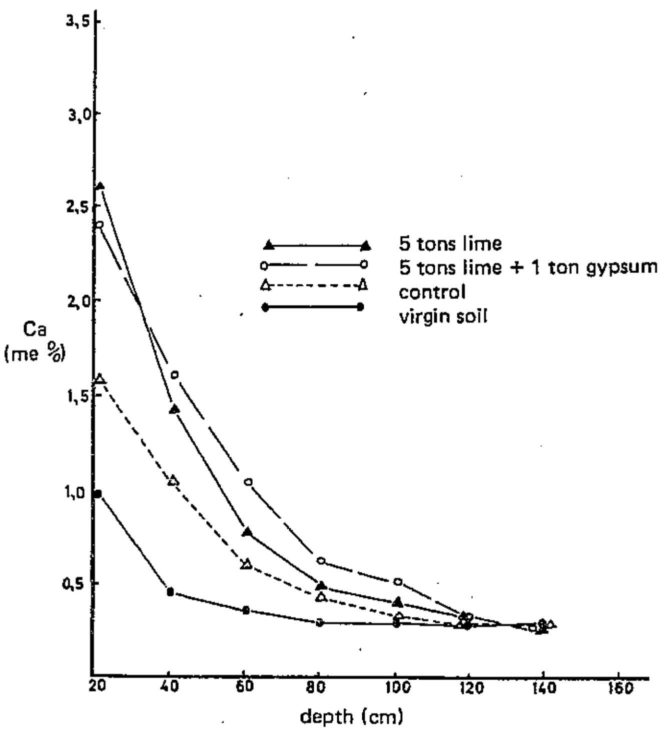

Fig 3b The effect of surface incorporated amendments on EAI in Hutton series

change had taken place in exchangeable Ca below 40 cm between 5 tonnes lime and 5 tonnes lime + 3 tonnes gypsum treatments. It is to be noted that the Ca values of gypsum treatments are consistently higher at depth than the 5 tonnes lime only treatment. Whether these small differences have any practical significance is, however, not a foregone conclusion. The same applies to the difference in Ca values between 5 tonnes lime and 5 tonnes lime + 1 tonnegypsum on the Ruston series, although the differences in the latter soil appear to be more in favour of gypsum than on the Hutton. If exchangeable Ca values in Ruston series for lime, lime + gypsum and control treatments, are compared with that of virgin soil, it can be inferred that Ca from lime applications in the past had in fact leached down the profile in significant quantities. The same pattern but not quite so apparent, also applies to the Hutton where the exchangeable Ca curve for the 'control' treatment lies well below the curves for the other treatments. Although Reeve (1970) found that downward leaching of calcium from applied lime is very limited in Natal oxisols, it is possible that lime can move more rapidly in soils with a small pH dependent negative charge.

In neither soil did Mg apparently leach out of the topsoil (Appendix 3); not even at the 3 tonne gypsum/ha level on the Hutton. This is further evidence by deduction that Ca from applied gypsum did not leach to the extent that might be expected. Under conditions where gypsum does leach into subsoil horizons viz. high levels applied to soils in leaching tubes, Reeve (1970) has shown that Mg is also rapidly lost from the topsoil.

EAl values are apparently unaffected on the Hutton series by addition of 3 tonnes gypsum (Fig 4a). Similar short term effects on EAl were obtained where large dressings of gypsum — as much as 14 000 kg/ha — hadbeen applied on an acid soil high in exchangeable Aluminium in the Amsterdam district (Gous, P.J. Personal communication of unpublished data). Gypsum appeared to have reduced EAl in appreciable quantities to a depth of 80 cm on Ruston series (Fig 4b), although the difference in EAl between lime + gypsum treatment and the virgin soil at this depth is only 0,06 me %.

Total rainfall from time of application to sampling was 650 mm which is slightly less than average seasonal rainfall. The apparent inability of gypsum to effectively reduce Al or markedly increase exchangeable Ca values in subsoils can perhaps be explained by insufficient downward movement of water under average rainfall conditions in the Eastern Transvaal Highveld.

The findings above are, in general, in agreement with those of Sumner (1970) with the exception that no evidence could be found in this study that leaching of exchangeable Aluminium into subsoils took place.

Effect of surface incorporated amendments on root development

Root development was inspected visually in a number of excavation pits on both soils during March 1972. Although no attempt was made to quantify root proliferation the observations were nevertheless interesting.

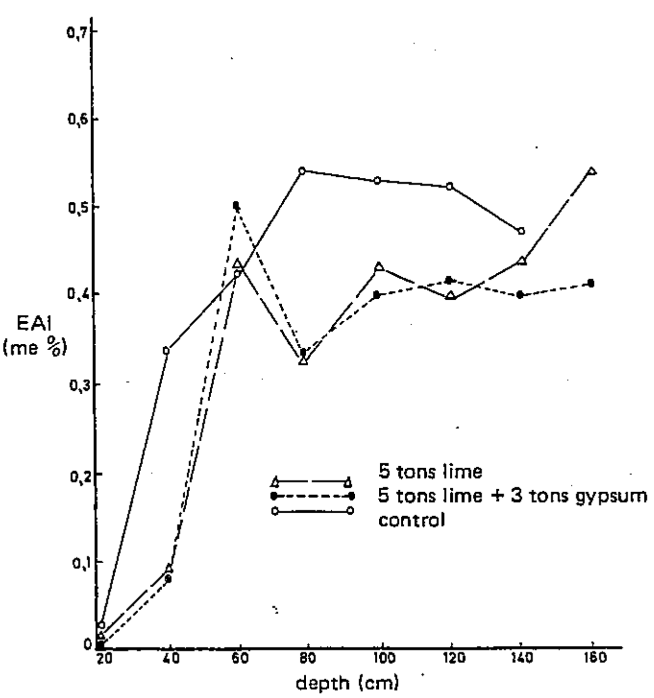

Fig 4a The effect of surface incorporated amendments on EAl in Hutton series

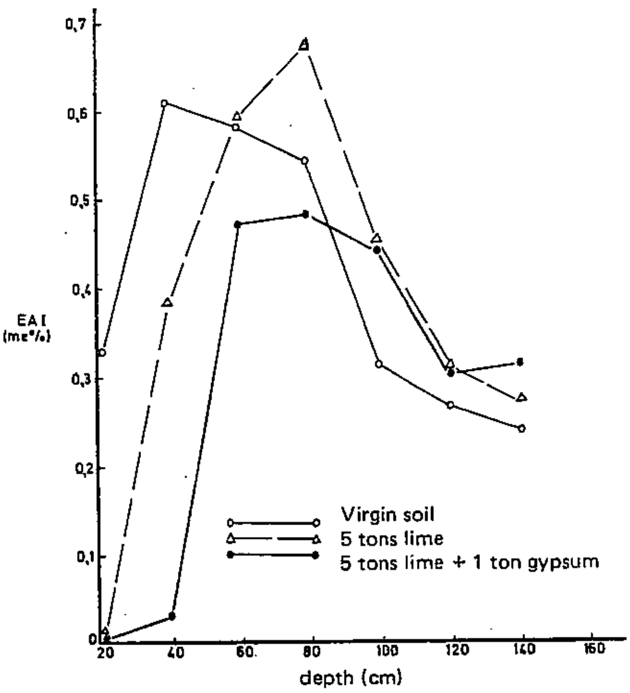

Fig 4b The effect of surface incorporated amendments on EAI in Ruston series

1 *Hutton series*

Under convertional farming practices immediately adjoining the trial site viz 20–25 cm depth of ploughing, nominal quantities of lime application at intermittent periods and NPK nutrient levels in the order of 50 kg N, 20 kg P and 15 kg K per/ha very little roots were found below plough depth. The roots that did penetrate into the subsoil were stunted, discoloured and a large percentage had already died by March. Top growth was similarly poor and showed a high susceptibility to periodical droughts. Yield of maize adjoining the trial site during the 1971–72 season was only 1700 kg seed/ha. In contrast, root growth was markedly better on all of the NPK treatments (even control treatments) in the trial area. Prolific root growth was observed on all 2x2x2 and 3x3x3 treatments down to a depth of 90 cm irrespective of gypsum levels. Below these depths little or no active root growth was observed. It is to be noted that control plots (with respect to NPK levels) yielded in excess of 4000 kg/ha in comparison with approximately 1700 kg/ha under conventional practice.[1]

It can be speculated that (a) a single large dressing of lime, (b) deep incorporation thereof or a combination of both could account for improvement in root growth and concommitant improval in top growth and yield. Depth of cultivation may be an important factor on acid loamy soils and in the authors' opinion it merits further investigation in the future.

(1) Yield data of these trials are obtainable from the Research Division FSSA, P O Box 1821, PRETORIA.

2 *Ruston series*

Although higher yields (2500 kg/ha more) were obtained on the Ruston trial, at the same optimum NPK levels than on the Hutton, roots did not develop to the same depth. Numerous and apparently healthy roots were found to a depth of 60 cm and very little beneath this depth. A possible explanation is that above normal rainfall during November and December 1971 caused temporary 'waterlogged' conditions at depth. In spite of the shallow rooting depth, top growth was better on the Ruston throughout the growing season indicating that depth of root penetration by itself is not necessarily any indication of so-called production potential. No obvious differences in rooting depth and root proliferation were observed with respect to gypsum and no gypsum treatments.

Conclusions

Maize growth and yields were not materially suppressed by relative high EAI values (0,4–0,7 me %) in the subsoils of the two soils studied. Therefore, limiting factor(s) other than Al toxicity were apparently responsible for the poor plant growth on the adjacent lands where only conventional farming practices were applied. This clearly indicates the need for evaluating the role of all possible limiting factors, singly or in combination(s), under conditions where plant growth is restricted on acid soils.

Although leaching of Ca from applied gypsum was small over the short term (one growing season) and under moderate rainfall conditions (650 mm/year), the cumulative leaching effect over a number of seasons might be large enough to increase Ca saturation considerably in the subsoil. There were also indications that over a period of several seasons leaching of Ca from applied lime did occur. This was especially apparent on the Ruston series where comparisons could be made with virgin soil. The leaching of Ca from applied lime sources might have been in part attributable to the low pH-dependent CEC values of the soils investigated.

Opsomming

KORTTERMYNEFFEKTE VAN OPPERVLAKTE-TOEGEDIENDE STOWWE OP TWEE SUUR SANDLEEM GRONDE VAN DIE OOS-TRANSVAALSE HOËVELD

Die korttermyneffek van oppervlakte-toegediende stowwe op sekere chemiese eienskappe van twee suur sandleem gronde in die Oos-Transvaalse hoëveld is gemeet. Die gronde was 'n rooi sandleem Hutton serie en 'n geelbruin sandleem Ruston serie.

By beide gronde het kalsium van toegediende kalk en gips tot in die ondergrondhorisonne geloog, maar loging was deur praktiese veldtoestande beperk. Hierdie toegediende stowwe het geen merkbare invloed op die ondergrondse pH en uitruilbare aluminium indeks (EAI) gehad nie.

Die verband tussen EAI en pH gemeet in H_2O, $CaCl_2$ en KCl is logaritmies, maar verskillend vir die twee gronde. Verskillende maar beduidende logaritmiese verwantskappe is ook gevind tussen Ca en AEI, en uitruilbare Ca + Mg + K en EAI vir die twee gronde.

Wortelpenetrasie tot in die ondergronde is ook ondersoek en ge-evalueer teen die verskillende behandelings.

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