INCIDENCE OF TOXIC ALUMINIUM IN SANDY SOILS

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Abstract

A summary of the information available on the incidence of toxic quantities of exchangeable aluminium in sandy soils is presented. Attention is focused on the widespread nature of this condition.

Introduction

Attention has recently been drawn to the importance of aluminium toxicity and the spectacular response to lime on some sandy Natal soils (Sumner[6]). Although the extent to which aluminium toxicity occurs on sandy soils in South Africa has not been fully investigated, a considerable number of sandy profiles have been analysed for labile aluminium. It is the aim of this paper to present a summary of the available information in order to focus attention on the importance and widespread occurrence of this condition.

Materials and methods

Sandy profiles representative of most of the soil forms containing series with less than 15% clay were sampled at various sites in the Natal Sugar Belt, Makatini Flats, Transvaal Highveld and northern Orange Free State. All samples were air dried and passed through a 2 mm sieve.

Exchangeable aluminium index (EAI) was determined according to the method of Reeve and Sumner[4] while pH was measured at a 1 : 2,5 soil : solution ratio using both water and 0,01 M $CaCl_2$.

Results and discussion

EAI and pH values for the various soil series are presented in Table I. Although there is considerable variation in EAI and pH values between and within soil series, the majority of samples had EAI values in excess of 0,05 me %, the level at which growth of sensitive plants is adversely affected. Sugarcane, however, is much more tolerant to the presence of aluminium and although exact threshold values are unknown at present for sandy soils, 0,20-0,30 me % is considered a reasonable estimate, applicable to most of the soil series.

With the exception of the Roodepoort series, which contained practically no labile aluminium, some members of all the other series contained toxic quantities of aluminium. The Roodepoort series is one of the less highly leached members of the Hutton form having a clay/total bases ratio of <7 in the upper B horizon and would therefore not be expected to contain labile aluminium. On the other hand the clay/total bases ratio for the other series is greater than 7 and in some cases exceeds 20, indicating that these soils are more highly leached.

Referring to the mean EAI values of series with more than 15 samples it seems likely that the incidence of Al toxicity decreases in the order:

Cartref > Fernwood > Clansthal > Glenrosa

The distribution of the EAI values in the topsoil of these series is shown in Figure 1 in order to support the above relationship. There appears to be, however, only a very small difference in the distribution between the Clansthal and Glenrosa series.

There is no consistent trend in EAI values down the profile although most series show a slight increase or no change with depth. In certain soil series considerable quantities of toxic aluminium are present in the subsoil horizons indicating that deep liming may be necessary to promote adequate root growth in these layers. Drought resistance is likely to be increased by this practice. Some preliminary results to support this statement have been obtained with lucerne on the Maputa series at Makatini (Table II).

There is a considerable increase in lucerne yield as a result of deep lime placement due to the more efficient utilisation of water deeper in the profile. This is supported by neutron moisture meter readings which show that the soil not receiving lime remained wetter at depth.

The occurrence of toxic quantities of aluminium in sandy soils appears to be largely unpredictable. For example, although all samples of the Maputa series came from a relatively small area on the Makatini Flats, where climatic conditions appear to be fairly uniform, some samples contained appreciable quantities of active aluminium while others contained negligible amounts. The reasons for the presence or absence of labile aluminium in a particular soil are not clearly understood.

One possible explanation was encountered during the sampling of some members of the Clansthal series at Tongaat. The growth of cane in this particular field was generally very poor with small patches of better growth occurring randomly within the field. Analysis of soil samples from areas of better cane growth revealed no labile aluminium, near neutral pH values, and localised fragments of sea shells. In the poor growth areas the soil was acid and had high EAI values.

Evidence for the presence of isolated patches of shell fragments in the Recent Sand deposits has been presented by Belderson[1] and McCarthy[2]. These sands are derived from the parent calcareous Bluff Sandstone beds which are remnants of former coastal dune deposits accumulated during Pliocene times. Their composition is extremely variable and the concentration of calcium carbonate is known to range from less than 30 per cent where the beds are

TABLE I

Exchangeable Aluminium Index (EAI) and pH values for profiles of various sandy soils series

Form	Series	Depth cm	No. of Samples	pH $CaCl_2$ Av.	pH $CaCl_2$ High	pH $CaCl_2$ Low	pH H_2O Av.	pH H_2O High	pH H_2O Low	EAI me % Av.	EAI me % High	EAI me % Low	No. with EAI > 0,05 me %
Fernwood	Maputa	0,15	7	4,28	5,10	3,70	5,45	6,25	4,70	0,12	0,38	0,00	4
		15-30	3	4,32	4,75	4,00	5,30	6,05	5,15	0,16	0,31	0,00	2
		30-45	6	4,08	4,60	3,80	5,33	6,10	5,15	0,23	0,50	0,02	5
		45-60	4	4,16	4,50	3,90	5,36	6,05	4,40	0,33	0,54	0,03	2
		60-75	5	3,95	4,30	3,50	5,20	5,85	3,90	0,41	1,32	0,10	5
Fernwood	Fernwood	0-10	19	4,34	6,90	3,60	5,38	8,35	4,65	0,10	0,29	0,00	12
		10-20	12	4,52	6,85	3,60	5,55	8,30	4,45	0,14	0,39	0,00	7
		20-40	12	4,46	6,50	3,30	5,45	7,50	4,40	0,11	0,50	0,01	6
		40-70	11	4,43	6,20	3,75	5,54	7,55	4,85	0,10	0,32	0,01	6
		70-100	7	4,71	6,45	3,70	5,72	7,35	5,00	0,08	0,25	0,01	3
		100-150	4	4,68	6,00	3,80	5,79	7,30	5,85	0,13	0,41	0,05	2
Clovelly	Ofazi	0-15	4	4,00	4,05	3,90	5,26	5,40	5,00	0,83	1,07	0,65	4
		15-30	4	3,99	4,00	3,95	5,28	5,35	5,20	0,92	1,07	0,78	4
		30-45	4	4,01	4,05	4,00	5,40	5,50	5,30	0,96	1,10	0,71	4
		45-60	4	4,02	4,05	4,00	5,57	5,80	5,50	1,02	1,22	0,74	4
		60-75	1	4,05	4,05	4,05	5,65	5,65	5,65	1,17	1,17	1,17	1
Clovelly	Springfield	0-20	9	4,50	5,90	3,85	5,19	6,40	4,52	0,07	0,16	0,00	5
		20-40	9	4,51	5,50	3,92	5,07	5,84	4,35	0,08	0,18	0,00	5
		40-60	9	4,66	5,60	4,02	5,15	6,20	4,40	0,06	0,14	0,00	5
		60-80	9	4,83	5,90	4,08	5,32	6,40	4,75	0,06	0,14	0,00	5
		80-100	9	4,93	6,10	4,10	5,52	6,60	4,90	0,04	0,09	0,00	3
		100-120	8	5,04	6,15	4,50	5,67	6,75	5,00	0,02	0,07	0,00	1
Avalon	Leksand	0-15	4	4,64	5,25	3,90	5,52	6,10	4,90	0,06	0,19	0,00	1
		15-30	4	4,44	4,77	3,90	5,34	5,85	4,70	0,12	0,32	0,00	3
		30-45	4	4,54	4,85	3,90	5,31	5,65	4,60	0,20	0,64	0,00	2
		45-60	4	4,60	5,00	4,00	5,41	5,60	5,00	0,19	0,66	0,00	2
		60-75	4	4,77	5,20	4,80	5,57	6,10	4,75	0,04	0,11	0,00	1
		75-90	4	4.98	5,35	4,90	5,90	6,40	5,18	0,06	0,14	0,00	1
Avalon	Villiers	0-20	3	4,57	4,65	4,45	5,47	5,80	5,00	0,02	0,07	0,00	1
		20-40	3	4,60	4,92	4,30	5,43	5,95	5,15	0,02	0,07	0,00	1
		40-60	2	4,78	5,10	4,45	5,43	5,72	5,15	0,04	0,08	0,00	1
		60-80	2	5,15	5,20	5,10	5,99	6,20	5,78	0,00	0,00	0,00	0
		80-100	2	5,25	5,25	5,25	6,15	6,25	6,05	0,00	0,00	0,00	0
Hutton	Clansthal	0-15	44	4,41	6,75	3,70	5,41	7,70	4,60	0,09	0,60	0,00	22
		15-30	35	4,30	7,00	3,92	5,41	8,20	4,50	0,08	0,50	0,00	16
		30-45	35	4,81.	6,68	4,05	5,63	7,80	4,30	0,09	0,78	0,00	11
		45-60	35	4,94	7,00	4,00	5,78	8,25	4,30	0,08	0,95	0,00	9
Hutton	Roodepoort	0-20	3	4,41	4,60	4,22	5,53	5,55	5,50	0,05	0,12	0,00	1
		20-40	3	4,76	4.95	4,58	5,79	5,95	5,50	0,00	0,00	0,00	0
		40-60	3	5,02	5,20	4,85	6,07	6,22	6,00	0,00	0,00	0,00	0
		60-80	3	5,03	5,10	5,00	6,16	6,20	6,10	0,00	0,00	0,00	0
		80-100	3	5,03	5,08	5,00	6,15	6,22	6,02	0,00	0,00	0,00	0
		100-120	3	5,16	5,20	5,05	6,14	6,35	6,00	0,00	0,00	0,00	0
		120-140	3	5,09	5,18	5,05	6,01	6,32	5,80	0,00	0,00	0,00	0
Hutton	Kyalami	0-20	3	4,27	4,42	4,15	4,72	4,80	4,60	0,27	0,39	0,10	3
		20-40	3	4,23	4,40	4,10	4,77	4,88	4,58	0,31	0,44	0,09	3
		40-60	3	4,19	4,25	4,15	4,68	4,80	4,55	0,51	0,72	0,31	3
		60-80	3	4,31	4,40	4,15	4,80	5,10	4,50	0,37	0,42	0,33	3
		80-100	3	4,30	4,40	4,20	4,81	5,00	4,58	0,43	0,67	0,12	3
		100-120	2	4,34	4,48	4,20	4,85	5,00	4,70	0,30	0,49	0,10	2
		120-140	2	4,35	4,48	4,22	4,87	5,10	4,65	0,21	0,36	0,07	2

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Form	Series	Depth cm	No. of Samples	pH $CaCl_2$			pH H_2O			EAI me %			No. with EAI > 0,05 me %
				Av.	High	Low	Av.	High	Low	Av.	High	Low	
Hutton	Middleburg	0-20	3	4,89	5,52	4,02	5,54	6,08	4,70	0,10	0,29	0,00	1
		20-40	3	4,60	5,60	4,02	5,18	6,40	4,45	0,18	0,27	0,00	2
		40-60	3	4,21	4,35	4,10	4,71	5,00	4,38	0,32	0,56	0,10	3
		60-80	3	4,35	4,50	4,25	4,88	5,10	4,70	0,15	0,19	0,06	3
		80-100	3	4,42	4,58	4,25	5,06	5,22	4,95	0,09	0,15	0,00	2
		100-120	3	4,39	4,48	4,25	5,02	5,15	4,82	0,12	0,18	0,06	3
		120-140	2	4,36	4,38	4,35	4,81	4,82	4,80	0,26	0,33	0,19	2
Cartref	Cartref	0-15	52	4,17	5,65	3,65	5,00	6,30	4,25	0,29	1,55	0,01	36
		15-30	27	4,35	5,80	3,60	5,04	6,65	4,15	0,23	1,42	0,01	15
		30-45	27	4,33	5,80	3,70	5,07	6,45	4,55	0,22	1,21	0,01	18
		45-60	27	4,34	5,95	3,10	5,10	6,45	4,10	0,23	0,69	0,01	16
Gemvale	Glenrosa	0-25	25	4,39	5,80	3,65	5,38	6,89	4,40	0,125	1,65	0,01	11
		25-50	1	4,25	4,25	4,25	4,55	4,55	4,55	0,28	0,28	0,28	1
		50-75	1	3,90	3,90	3,90	4,20	4,20	4,20	1,10	1,10	1,10	1
		75-100	1	3,80	3,80	3,80	4,10	4,50	4,10	1,02	1,02	1,02	1
Total number of samples			539										301

poorly cemented to more than 60 per cent where cementation is good, or when the shells occurred in narrow but well defined strata. These sandstones weathered *in situ* by the solution and complete removal of $CaCO_3$ cement, while only partial removal of shell fragments occurred. This was followed by decomposition of feldspar and ferromagnesium minerals. Some reworking of the weathered material by wind subsequently took place. Thus the variable composition of the parent material is inherited to some extent by the derived soils.

TABLE II

Effect of deep lime placement on lucerne yield

Treatment	EAI† me %	YIELD (t/ha) 1st Cut	2nd Cut	3rd Cut	4th Cut	Total
No Lime	0,19-0,30	0,45	0,28	0,12	0,15	1,00
Lime 0-30 cm*	0,00-0,27	1,82	1,65	1,32	1,12	5,91
Lime 0-60 cm*	0,00-0,00	2,48	2,57	1,40	1,41	7,86

† range down the profile to 60 cm
* lime applied at the rate of 1,5 t $Ca(OH)_2$/ha 15 cm

Other post-depositional factors such as internal drainage, position in landscape, effective rainfall, movement of base rich waters into the profile could also account for some of the variation. Rhodes[5], considers the process of mechanical eluviation or the downward leaching of clay particles in the soil, controlled by factors such as slope, drainage and underlying parent material as being largely responsible for the difference between the resulting soil types.

Management practices such as the use of physiologically acid fertilizers, "double carbonated" filter cake, and long continued cultivation could also be responsible for much of the variation in these poorly buffered soils.

Applicability of these results to the sugar industry

Reference was made earlier to the observation that on average the Cartref series contains more labile Al than either the Fernwood or Clansthal series. Because of the widespread occurrence of this series and its variants which cover nearly 74 000 hectares of the sugar industry, an attempt has been made to predict the incidence of Al toxicity on these soils.

As reported by Meyer *et al*[3], the results of a recent industry-wide survey of the areas under cane, showed that one in every four farms on the Cartref series in the coastal lowlands region contained fields with marginal to toxic levels of Al, indicating that approximately 18 500 hectares of land under cane require liming. As very few lime trials have been carried out on sandy soils in the cane belt it is difficult to predict the monetary benefits that would accrue to the industry if lime were to be used whenever it is considered necessary. However, by using breakeven analysis it is possible to estimate the yield response required to cover the costs of using three tons of limestone per hectare. This amounts to between four and five tons of cane per hectare.

depending on the location of the farm and various management factors. In arriving at this figure consideration was given to the cost of procuring the limestone, application costs incurred incorporating the limestone with topsoil and the extra costs of harvesting and hauling the additional sugarcane.

The potential benefits of limestone to the sugar industry are likely to be substantially greater when the lime requirements of other soil series are assessed for eliminating Al toxicities. It is also possible that many growers are unaware of Ca and Mg deficiencies in their soils. If these deficiencies are to be corrected still further amounts of limestone will have to be used in the industry.

Recently, on the evidence of soil profile data from pits located in 27 fields in the Richfond and Wewe areas of Tongaat, on Cartref series soils, lime amelioration recommendations were made for 60 per cent of the fields, 35 per cent to correct Ca and Mg deficiencies and the remaining 25 per cent to correct possible Al toxicity.

In conclusion, therefore, the occurrence of toxic quantities of aluminium in sandy South African soils is a widespread phenomenon and due cognisance should be taken in the management of these soils before crop yields can be maximised.

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Discussion

Mr. Harris: Concerning the calcareous deposits mentioned in the paper, could the shells have been preserved in the "sduli" because of their relatively higher clay content?

Professor Sumner: The shell fragments, comprising shells of various shellfish and mollusces, were spread over an area of three square metres and it is possible that shell fragments are preesrved in "sdulies".

Dr. Dick: Could the shells not have been deposited by humans? The strandlopers sometimes carried shells well away from the coast and are often included among the artifacts.

Dr. MacVicar: I support that because the sands have been resorted since they were laid down.

Mr. Meyer: There is geological evidence at various quarry sites and excavations that the Recent Sands contain isolated patches of partially weathered calcareous concretions, algae and shell fragments at depths up to 20 metres often associated with he upper boulder bed of the Red Sands. This predates any strandloper activity suggesting that in this case derivation is more likely related to incomplete weathering of the former calcareous Bluff Sandstone parent material.

Mr. Tucker: The cost of incorporating lime in the soil could be high. Professor Sumner used a concrete mixer in his experiment to get a good incorporation. How long will the EAI remain below the toxic level once the lime is incorporated?

Professor Sumner: Both the Experiment Station and ourselves have on occasions applied half the lime, rotavated it, turned it with a Nardi plough then applied the rest of the lime and then again rotavated and used the Nardi plough. This would probably cost R70 per hectare and should last for at least 20 years, although some further applications in the top soil might be necessary.

Mr. van der Riet: In the paper on the analysis of trace elements it was mentioned that calcium levels are often deficient in Cartref Series soils.

Could this not have some connection with aluminium toxicity?

Mr. Meyer: You generally find that high exchangeable A1 values are accompanied by low calcium and magnesium values, particularly in the heavier soils of the midlands mist belt region, which require limestone both to eliminate A1 toxicity and to supply Ca and Mg as nutrients. Sandy soils of the coast lowlands however, frequently contain non-toxic levels of A1 associated with deficient Ca and Mg values. For example, a recent analysis of sandy soil samples from about 40 sites in the Tongaat area showed that limestone was primarily required to supply the nutrients Ca and Mg while A1 toxicity was of secondary importance.

Dr. MacVicar: There will be more aluminium in midlands TMS than in a coastal TMS. I would like to ask the authors whereabouts the soil samples, representing the Cartref Series, were taken?

Mr. Meyer: The results in respect of the Cartref Series are based on the industry wide trace element survey samples, supplemented by analytical data of samples from the Richfond and We-We areas, comprising part of Tongaat's sugar estates.

Mr. van der Riet: Referring back to the shells, they are almost certainly derived from Bluff Sandstone sediments. Such finds can be found anywhere within a reworked sand where accumulations had been previously made in stream beds, followed by land surface changes due to erosion and weathering cycles.

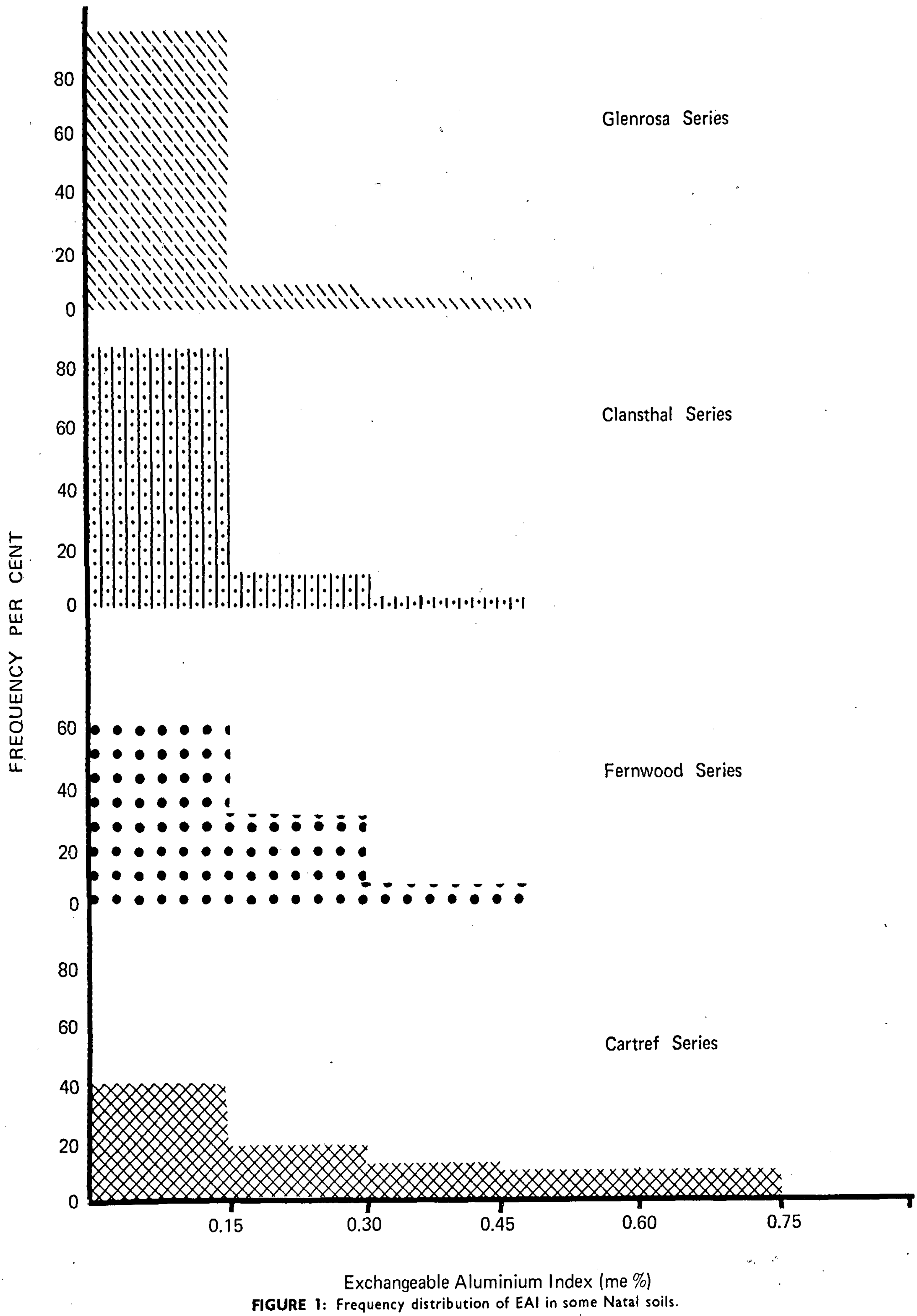

FIGURE 1: Frequency distribution of EAI in some Natal soils.