ALUMINIUM AND SILICA RELATIONSHIPS IN GROWTH FAILURE AREAS

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Introduction

In 1962 an investigation was conducted to measure the reduction in hydrogen ion concentration of a weak acid (0.02N H_2SO_4) after it had been in contact with different soils. The acid-soil mixture was shaken, filtered and an aliquot titrated against 0.02N NaOH to neutrality. Of some 2,000 soils treated in this way, four were characterised by the formation of a clear gelatinous precipitate (considered to be some compound of Al) when the solutions were rendered alkaline. Subsequently they were found to belong to the Inanda soil series, and all were associated with growth failure areas. With the recent extension of cane cultivation into the Natal midlands, the likelihood of cane being grown on soils of the Clovelly series has increased. The fact that these soils are also high in Al (Skeen and Sumner 1965) increases the urgency of an investigation into the relationship between soil soluble Al and cane growth.

Since Ayres (1966) reported significant yield responses of cane to Si applications on soils with high concentrations of soluble Al, the Si status of crops and soils is included in the present study.

1. A SURVEY OF TWO SOIL SERIES

In the present survey, the extent of which is described by Alexander (1967), two soil series were considered:

(i) Inanda. Derived from a laterite formed on the sandstone and characterised by a high organic matter content (approximately 10%) and low pH value (4.70). It is located in the inland higher altitude, plateau or mistbelt areas. Texturally it is a clay loam.

(ii) Cartref. Derived directly from the sandstone and has a lower organic content (approximately 1%) and higher pH values (approximately 5.50). Texturally it is a loamy sand.

Method

(A) *Soil*

Ayres (1966) used 0.5N ammonium acetate adjusted to pH 4.8 and a solution to soil ratio of 20:1 to extract soluble Si. This procedure was adopted except that in place of shaking end over end for one hour at 13 rpm, leaching 2.5g of soil with 10 x 5ml aliquots of extractant was used. This solution was analysed for Al and Si. For exchangeable Al determinations, the method of Skeen and Sumner (1965) was used.

For determining the concentration of Al in the soil extract the method of Frink and Peech (1962) employing 8-hydroxyquinoline was followed.

Ammonium molybdate reagent was used for Si determinations (Vogel 1958) with tartaric acid to eliminate phosphate interference and stannous chloride as reducing agent. All solutions were stored in plastic containers.

(B) *Third Leaf Blade*

For Al, an adaptation of the method for soils was employed.

Following the wet digestion of leaf material with sulphuric acid, a white precipitate remained, which was considered to be almost exclusively dehydrated Si. This material was filtered, ashed and weighed and will be referred to as "acid insoluble residue" (AIR).

Results

A summary of Al and Si contents of samples taken over a wide area from sites on the Inanda and Cartref series is presented in Table I.

As expected, the amounts of soluble Al in the Inanda series (of lower pH value) are considerably higher than in the Cartref series. Areas of poor growth were generally associated with soils high in organic matter (greater than 10%) and soluble Al (in

TABLE I

Soluble Al and Si contents (ppm) of soils and leaves from two soil series

	Inanda				Cartref			
	Soil		Leaf		Soil		Leaf	
	Al	Si	Al	% AIR	Al	Si	Al	% AIR
Lowest concentration	88	7	31	0.408	2	6	39	0.572
Highest concentration	724	44	151	1.504	270	102	147	1.995
Number of sites	50	50	50	50	70	70	70	70
Mean	320	21	70	0.911	73	23	98	1.095

excess of 400 ppm). High Al was often, but not always, associated with low pH and exchangeable Ca values. From observation, the crops at 17 of the sites on the Inanda series were considered to be below average, and of these, the cane at three was severely stunted and was associated with the only soils where the soluble Al content exceeded 550 ppm. The condition of the crop at 10 of the remaining sites was described as fair, poor or patchy, and was associated with soils containing between 400 and 550 ppm soluble Al. Crops growing on soils with contents less than 400 ppm were generally good.

The exchangeable Al in the Inanda series ranged from 0.01 to 3.40 me/100g soil with a mean of 1.05. Although the areas of poor growth were generally characterised by high exchangeable Al contents, soils with relatively high exchangeable Al did in some cases support good crops.

The Si content of the soil, and the AIR and Al content of the leaves were apparently not related to the condition of the crop. In fact, soils of high Al content tended to remain the highest amounts of soluble Si indicating that a deficiency of the latter element is not responsible for the poor cane growth.

In the Cartref series the exchangeable Al content ranges from zero to 0.27 me/100g of soil. In this series none of the factors studied were correlated with crop yield.

2. EFFECTS OF FILTER CAKE AND LIME

Applications of filter cake (FC) are now known to give significant yield increases in the problem areas. Mr. H. E. H. Garnett has successfully converted regions of growth failure on his farm into areas of high productivity by applying heavy dressings of FC. In an experiment conducted on a problem area (mean yield of control plots was 29.3 tons cane per acre) at Doornkop (Allsopp) a significant increase of over 15 tons cane per acre was obtained by top dressing ratoon cane with 10 tons of FC per acre following normal dressings of N, P and K. The soluble Al (423 ppm) at this site is just above the critical level, and organic matter content (12.83%) is in excess of 10%. To indicate whether FC reduces the level of soluble Al, comprehensive plot by plot analyses were made but no changes in soil composition could be detected. However, since FC is rich in P, Ca and Si, it was considered that sampling errors must have obscured any changes in soil composition. Tests in the laboratory were therefore conducted.

To 2.5g of the Inanda soil increasing amounts of oven-dry FC were added. The mixtures were twice puddled with water, dried at 40°C and then the soluble Al, Si and Ca contents determined.

TABLE II

Effects of FC on the soluble Al, Si and Ca content of an Inanda soil series

	Grams of FC mixed with 2.5g of soil					
	Nil	0.1	0.2	0.3	0.4	0.5
Al (ppm) ..	411	205	111	16	0	0
Si (ppm) ..	34	50	68	78	85	175
Ca (ppm) ..	16	60	100	105	125	155

FC drastically reduced the soluble Al content and increased the soluble Si and Ca content of the soil.

Further investigation indicated that the high concentration of easily soluble P in FC is responsible for precipitating out Al and thus rendering it insoluble. The concentrations of Al and P in the extracting solution after leaching FC and FC plus soil (one wetting and drying cycle) are presented in Table III.

Although 959.3 ppm of P was in the leachate from 0.4g of FC, less than 1 ppm was present when the same amount of FC was mixed with 2.5 g of soil.

If the observed reductions in yield are caused by Al toxicity, the application of agricultural lime was considered to be the most suitable way of reducing the level of Al in the soil. The effects of different levels of agricultural lime on the soluble Al and Si contents of two soil series are presented in Table IV.

TABLE III

Concentrations of Al and P in extract of O.5N ammonium acetate (pH 4.8)

Treatment	Grams of FC mixed with 2.5g soil						
	Nil	0.025	0.05	0.1	0.2	0.3	0.4
Al (ppm) Soil + FC	21.1	20.4	17.2	14.1	10.6	9.7	8.2
P (ppm) Soil + FC	0.1	0.0	0.3	0.2	0.2	0.4	0.8
P (ppm) FC alone	—	203.4	274.6	394.4	807.0	945.5	959.3

The amounts of Al decreased almost linearly (significant at the 1% level) with increasing amounts of lime applied. Soluble Si content increased significantly with increasing lime application. Concentrations of Al and AIR in the third leaf blade did not reflect the changes in soluble Al and Si content of the soil.

The above experiments are on soils which are relatively low in soluble Al and, as expected, there was no increase in yield due to the application of lime. However, even in observation plots with soils of a high Al content poor yields were not improved by the application of lime. Since liming does reduce Al content it would appear that the cause of poor growth is not high levels of Al but some factor, or factors, associated with it.

Thus, while FC and lime both reduce Al level, one improves the condition of the crop while the other does not. The two materials must, therefore, be affecting the soil in different ways. The effects of a basic material (which affects soil reaction in a similar way to lime) and FC on soil pH are presented in Table V.

TABLE IV

Effect of agricultural lime on the soluble Al and Si content (ppm) of two soil series

INANDA SERIES

lb fertilizer applied/acre; 4-1-6(31)	Lime applied (lb/acre)							
	Nil		2000		4000		Means	
	Al	Si	Al	Si	Al	Si	Al	Si
Nil	133	18	60	22	29	31	74	24
1000	144	26	75	23	45	33	78	27
2000	126	22	52	28	24	40	67	30
Means	124	22	62	24	33	35		

	5% level	1% level
LSD's of Al due to fertilizer; lime	46;56	61;85
LSD's of Si due to fertilizer; lime	17;6	26;8

WALDENE SERIES

lb fertilizer applied/acre; 4-1-6(31)	Lime applied (lb/acre)							
	Nil		4000		8000		Means	
	Al	Si	Al	Si	Al	Si	Al	Si
Nil	41	16	18	23	13	35	24	25
1000	53	16	23	23	8	40	28	26
2000	43	18	21	25	12	31	25	25
Means	46	17	21	24	11	35		

	5% level	1% level
LSD's of Al due to fertilizer; lime	20;18	30;27
LSD's of Si due to fertilizer; lime	8;6	13;8

TABLE V

Effects of FC and basic Si slag on soil pH

Treatment	Grams of FC and basic Si slag mixed with 2.5g soil						
	Nil	0.025	0.05	0.1	0.2	0.3	0.4
FC alone	6.20						
FC + soil	5.35	5.35	5.38	5.33	5.39	5.38	5.35
Slag alone	11.00						
Slag + soil	5.35	5.67	5.73	5.93	6.20	6.37	6.40

The basic material has increased the pH of the soil while the FC has not. It is possible, therefore, that the difference in yield response between lime and FC is due to their effects on soil pH.

That the correlation between high Al and poor yield is a characteristic of the Inanda series is indicated by a four-months-old trial on the Clovelly series (579 ppm Al) in the Natal midlands. Here

TABLE VI

Yields and analytical data from a Zn:Mo trial on an Inanda series

Treatment	Plot No.	T.C.P.A.		Soil analyses				Leaf analyses			
		Plant	1st R	Sol Al (ppm)	Sol Si (ppm)	Exch Ca (ppm)	pH water	Zn (ppm)	Al (ppm)	AlR %	Ca %
Control	2	36.3	34.7	513	38	230	5.20	17	79	1.10	0.22
	10	29.1	35.4	715	56	180	5.05	10	65	1.08	0.30
	18	33.8	50.1	541	78	180	5.10	11	120	0.98	0.22
	19	32.6	43.3	508	82	200	5.05	10	66	0.97	0.22
	27	26.3	46.7	643	85	160	5.10	9	137	1.27	0.25
	35	14.4	23.8	742	63	100	4.95	10	187	1.30	0.18
Means		28.8	39.0	610	67	175	5.08	11	109	1.12	0.23
0.5 lb/ac sodium molybdate	1	21.9	26.9	688	54	180	5.05	12	127	1.28	0.25
	9	36.6	43.1	652	55	180	5.10	14	134	1.24	0.22
	17	23.3	40.5	706	61	160	5.05	10	138	1.26	0.22
	22	30.0	42.8	597	54	200	5.10	10	113	1.04	0.22
	26	35.9	49.3	593	78	240	5.20	10	166	1.06	0.22
	36	17.4	23.9	768	69	120	5.00	10	232	1.31	0.25
Means		27.5	37.8	667	62	180	5.08	11	152	1.20	0.23
25 lb/ac zinc sulphate	5	41.2	32.6	661	78	220	5.00	14	71	1.24	0.14
	8	35.8	31.1	760	73	180	4.95	16	191	1.20	0.18
	16	43.4	50.5	570	68	220	5.05	13	89	1.22	0.22
	21	36.8	47.4	636	67	140	4.85	15	124	1.25	0.18
	30	34.3	41.1	656	66	160	5.05	14	263	1.05	0.10
	31	29.5	32.7	562	71	130	5.00	13	97	1.30	0.14
Means		36.8	39.2	656	71	175	4.98	14	139	1.21	0.16
25 lb/ac zinc sulphate + 0.5 lb/ac sodium molybdate	6	48.6	47.0	582	33	160	5.10	15	162	1.19	0.18
	7	38.1	32.1	643	37	160	5.05	16	87	0.98	0.14
	15	41.3	49.4	542	54	200	5.15	15	87	1.05	0.14
	20	40.2	46.8	652	69	140	4.85	15	125	1.05	0.10
	29	36.0	46.9	563	62	200	5.15	15	166	0.95	0.25
	34	18.8	25.6	605	59	100	4.85	16	120	1.24	0.14
Means		37.2	41.3	598	52	160	5.03	15	125	1.08	0.16
50 lb/ac zinc sulphate	3	58.9	54.7	429	96	300	5.25	17	127	1.06	0.18
	11	35.2	48.8	509	77	120	5.00	17	102	1.10	0.18
	13	33.3	34.9	589	51	140	5.05	16	56	1.07	0.18
	24	30.6	50.6	450	55	240	5.20	20	186	1.07	0.25
	28	21.2	36.5	634	74	120	5.00	17	170	1.34	0.18
	32	29.7	33.4	634	70	120	4.95	20	269	1.17	0.18
Means		34.8	43.2	541	71	173	5.08	17	152	1.14	0.19
50 lb/ac zinc sulphate + 0.5 lb/ac sodium molybdate	4	39.8	32.0	679	82	150	4.95	19	170	1.25	0.25
	12	45.3	45.7	508	67	140	4.95	19	120	1.04	0.22
	14	31.6	35.3	585	77	120	4.90	17	96	1.08	0.22
	23	34.5	39.3	626	65	160	5.10	16	110	1.10	0.22
	25	21.0	37.5	637	45	120	4.85	13	76	0.83	0.18
	33	33.6	40.6	572	61	90	4.70	14	253	1.08	0.22
Means		34.3	38.4	601	66	130	5.08	16	138	1.06	0.22
Correlations for yield of plant crop..				−0.54	0.04	−0.56	0.32	0.44	−0.12	−0.43	−0.18
Correlations for yield of 1st ratoon..				0.68		−0.52	0.40				

Levels of significance .. .. 5%=0.33, 1%=0.42, 0.1%=0.52.

	Plant	1st R	Sol Al	Sol Si	Exch Ca	pH	Zn	Al	AlR	Ca
LSD 5% level	8.40	8.0	89	36	57	0.38	2	41	0.15	0.05
LSD 1% level	11.5	10.9	122	45	78	0.52	3	56	0.21	0.07

crops receiving only N, P and K are growing well and are, in fact, superior to those receiving FC (30 tons/ac.) N and K.

3. CORRELATIONS WITH CROP YIELDS

High levels of Al in the soil are generally associated with highly leached infertile areas. Excellent yield responses to applications of N, P and K occur on most of the soils of the Inanda series and it is likely that in the problem areas one or more of the other essential plant nutrients are also deficient. Apart from FC the only other material to improve yield has been zinc sulphate (du Toit 1962). An experiment with different levels of Zn and Mo was laid down in 1962 on an Inanda series on the farm of H. E. H. Garnett in the Kearsney area. Although a statistical significant yield response was obtained to Zn, the experiment was characterised by marked fluctuations in yield irrespective of treatment applied. A comprehensive plot by plot analysis of soil (after plant crop) and leaf (from plant crop) samples was conducted so that if the factor causing poor growth was nutritional it might be detected. The more interesting of these results are presented in Table VI.

Yield is significantly correlated with soluble Al, AIR, exchangeable Ca and pH.

The soluble Al results again indicate that at levels in excess of approximately 400 ppm cane yield is adversely affected.

The significant negative correlation between AIR and yield is probably due to differences in the physiological age of the leaf in position number 3. In stunted cane the leaf in this position has matured more than the leaf from a plant which is actively growing and Si had longer to accumulate. Other elements which have been shown to accumulate continuously in the leaf, thus increasing their concentration with time, are Ca, Mg and P (Bishop 1965). This is partly confirmed by the analysis of leaf samples from an experiment in which highly significant increases in yield were obtained from the application of mixed fertilizer. The mean yields in this experiment were 31.0, 53.2 and 63.3 tons of cane per acre while the mean leaf contents for AIR were 1.683, 1.204 and 1.178% respectively.

Since the threshold value for exchangeable Ca is 150 ppm and yield is significantly correlated with this measure, a deficiency of Ca in certain plots is indicated. Leaf analyses, however, indicate that only plots 20 and 30 have Ca levels below the threshold value (0.12%). The limitation of the third leaf blade as a diagnostic tissue for Ca (Bishop 1965), as explained for Si above, could be obscuring the presence of this deficiency, i.e. where Zn applications caused more normal growth, leaf Ca levels were significantly lower.

It is suggested, therefore, that the cane in the poorer plots of the above experiment was suffering from deficiencies of Ca and Zn. In such circumstances FC would improve yield by supplying both these elements (plus other essential nutrients) without seriously changing the pH value of the soil. Liming by changing the pH of the soil would aggravate the deficiency of Zn and not improve yield. In those areas known to be low in Ca and Zn (Alexander 1967) liming should be avoided. To supply Ca, FC or gypsum should be applied.

An experiment using FC, and gypsum and $ZnSO_4$ in combination is being designed to test whether only Ca and Zn (plus N. P and K) are at present limiting cane production in these areas.

Discussions and Conclusions

The fact that FC is reasonably rich in Si increased a suspicion that the beneficial effect of this material on crop yield may be due to the presence of this element. The following evidence tends to eliminate this possibility:

(i) The Si content of soils was generally highest in the areas of poor growth and

(ii) liming did not prove beneficial in these areas even though it increased the soluble Si status.

When the level of soluble Al in the Inanda series exceeds approximately 400 ppm a reduction in yield can be expected. High levels of Al are not thought to affect plant growth directly but are associated with some other growth-inhibiting factor. Evidence leading to this conclusion is as follows:

(i) applications of lime and superphosphate (which should also render Al insoluble) do not rectify problem areas, and

(ii) the experiment sited on the Clovelly series indicates that normal crops may be grown even if the soluble Al content approaches 600 ppm.

Although it has not been diagnosed conclusively what factors associated with Al are depressing yield, the combined deficiencies of Ca and Zn (and perhaps other trace elements) are one possibility. While the third leaf blade will reflect the deficiency of Zn, the effectiveness of this tissue detecting low levels of Ca is suspect. Soil analysis on the other hand only detects the Ca deficiency, and the use of lime should be avoided. Under these conditions lime will not improve yields as it reduces the availability of Zn and most other trace elements.

It is suggested, therefore, that a survey to ascertain the soluble Al, exchangeable Ca and organic matter contents of all fields on the Inanda series be undertaken. In this way the problem areas could be identified and used as a basis for determining where FC allocations should be applied for maximum economic return.

Summary

A survey of the Inanda and Cartref series indicated that in some areas the Inanda series contained high levels of soluble Al. These soils were associated with areas of poor growth.

Applications of lime were found to decrease the levels of soluble Al and increase the levels of soluble Si, but did not improve yield. Samples from field trials showed no significant effects of filter cake on the soluble Al or Si contents of the soil, but did increase yield. Laboratory tests showed, however, that filter cake significantly reduces Al and increases Si content of the soil.

An experiment conducted on another series indicated that levels of soluble Al of the order of 600 ppm are not toxic to sugarcane. Poor growth is apparently associated with high levels of Al but is not caused by it.

Deficiencies of Ca and Zn (and possibly other trace elements) occurring simultaneously are thought to be one possible cause of low yields.

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Discussion

Mr. Landsberg: To isolate a deficiency symptom the plant is grown in nutrient media and the element you are interested in is omitted or reduced considerably. Has this been done in respect of boron, zinc, aluminium and silica?

Mr. Bishop: We have tried to use Aspergillus niger to get an estimate of zinc deficiencies in these areas. The spores are grown in a solution and in about two weeks a dense mat forms on the surface and it is removed and weighed. However, this method is unsuitable for routine soil examinations.

Mr. Venn has put down pot trials in Swaziland with tomato and maize plants, omitting one nutrient, and he has been able to classify the soils on the basis of nutrient deficiency.

Mr. Gilfillan: Do growth failure areas develop a particular type of weed population? In Recent Sand we have noticed *Panicum maximum* coming in.

Mr. Bishop: Apparently filter press is often associated with growth of Panicum.

Mr. Moberley: When filter cake was applied at Town hill at thirty tons per acre the Panicum grew very well but the cane growth was poor.

It was suggested that cane grown adjacently with superphosphate thrived as the superphosphate was applied row only, whereas filter cake was broadcast, so in the initial stages the cane roots did not have immediate access to phosphate.

Mr. Lintner: It is difficult to grow maize on an untreated Clovelly Soil. Last year a research project was started which involved a blanket of agricultural gypsum, six thousand pounds, and fifty pounds of zinc sulphate per morgen. N, P_2O_5 and K_2O were calculated at presumed 100% efficiency levels on the basis of the whole plant requirement to produce a bag of maize. The two levels were then adjusted to produce seventy and a hundred and forty bags of grain per morgen. Last year, in spite of the drought, the top yield was 36 bags per morgen. This year the growth is such that, from field observation, it would appear that the maximum target could possibly be achieved. This soil will grow excellent potatoes, root crops and pasture.

Mr. du Toit: d'Hotman de Villiers in Mauritius applied a hundred tons per acre of crushed basalt to cane fields and he was the first to stress the importance of silica in cane nutrition.

We have a problem with our leached soils and we cannot always pinpoint the reasons for growth failure.

Mr. Bishop points out, in Table VI, that a lot of the values for calcium are below the threshold value of 150, but in Hawaii the threshold value is only 100 ppm.

On the basis of 100 the only low figure is 90 and that gave one of the best yields.

We need a microbiological examination into soil fertility in addition to these other investigations.

Filter cake plays a part in increased production that cannot easily be explaned from ordinary chemical analysis. The stimulation often affects one crop only and has no carry-over.

Organic manures have in the past rectified growth failure on the Inanda series.

I suggest that the survey being carried out at present on the Inanda series should be extended to the Clovelly and other acid soils in the new Midlands area.

Mr. Lintner: The only explanation I can give for the complete crop failure on the high nitrogen only plots on maize is stultification of the bacterial population of that soil, in addition to a very critical phosphate level.

Mr. Bishop: I do not feel the cause of poor growth is entirely due to a disease effect or a toxic bacteria in the soil.

Mr. Lintner: It has been shown that very heavy dressings of nitrogenous fertilizer initially can retard bacterial activity but the situation rectifies itself.

Mr. Bishop: If it is micro-biological, how can the areas defined in this experiment carry over from one year to the next and from one crop to the next without spreading?

The deficiencies, as mentioned by Mr. Alexander, are worse in cold, cloudy weather and improve as the weather gets warmer, which is not what you would expect if micro-organisms are involved.

Mr. Lintner: If a certain area of a field is pinpointed for the purpose of drawing soil samples for determining pH it will be observed that the pH varies quite considerably. Does not the available soil vary through a season?

Mr. Bishop: There is no evidence of that here. A growth analysis experiment which had six replications and was analysed every week for eighty-eight weeks showed no variation in exchangeable K content. In a laboratory you might get diurnal variations in "availability" due to different temperatures of the extraction solution but it should not affect availability in the field.

Mr. Lintner: It seems that it is the fluctuations in temperature in this country, that is largely responsible for poor maize yields.