BUREAU OF SUGAR EXPERIMENT STATIONS

QUEENSLAND, AUSTRALIA

FINAL REPORT

SRDC PROJECT BS98S

FACTORS AFFECTING THE RESIDUAL VALUE OF LIME

by
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SD97002

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1. EXECUTIVE SUMMARY

This project was initiated to:

(a) determine the relative significance of soil acidity and soil calcium status for predicting response of sugarcane to lime in southern Queensland, where recommendations developed for tropical soils had not been tested previously,

(b) understand the influence of soil properties on the residual value of lime;

(c) study the negative interaction between cane yield response to lime and ccs, and

(d) develop and extend improved management guidelines for the necessity and frequency of lime applications.

The major findings of this project were:

- Measurement of soil calcium was confirmed as a robust basis for recommending application of lime to sugarcane. Critical levels of soil calcium are relevant to both tropical and sub-tropical soils.
- Response to both lime and gypsum shows that response of sugarcane to lime is related more to calcium nutrition than soil acidity *per se*. High levels of soil and leaf manganese did not appear phyto-toxic.
- There are good prospects for modelling the residual value of lime with functions incorporating initial soil calcium status, consumption of bases by soil acidity and export of bases in harvested cane.
- The project provided the first series of soil pH buffer curves for a range of southern caneland soils. This information will allow soil to be limed to target pH for rotation crops and avoid higher soil pH which is implicated in enhanced degradation of chlorpyrifos.
- Commercial rates of lime will do little to ameliorate acidity and calcium deficiency of sub-soil in the gley and yellow podzolic soils which are a major soil resource for the sugar industry in southern districts.
- The depression in ccs, which is often seen when sugarcane responds to lime, was associated with elevated ratios of calcium to other nutrients, particularly the calcium / magnesium ratio in leaf tissue.
- The project enjoyed a high extension profile and was a value adding resource for another SRDC project and a PhD activity.

To address the project objectives four field trials were established in the Moreton area in 1992. Surface soil at the yellow podzolic, gleyed podzolic and humus podzol soil sites was deficient in calcium. The latter site also demonstrated magnesium deficiency. The strongly acidic humic gley soil site had adequate calcium and magnesium for sugarcane growth. Sites not deficient in magnesium were treated with rates of calcitic limestone to 8 t/ha, while treatments at yellow podzolic and humic gley sites also included a single rate of gypsum and a lime plus gypsum. Impact of treatments was monitored through analysis of soil, leaf and biomass components in addition to measurement of cane and sugar yield.

Yield responses to lime at 4 t/ha, in plant cane, were obtained at yellow podzolic and humus podzol sites; but responses were not significantly greater than those obtained from lime at 1 t/ha.. Yield responses at the gleyed podzolic site were precluded by adequate levels of calcium (1.97 cmol(+)/kg) in the sub-soil. The humic gley site was un-responsive. Response to gypsum at two sites confirmed previous conclusions that yield response of sugarcane on acidic soil was associated more with correction of calcium deficiency than amelioration of effects of low pH *per se*.

Interpretation of soil analysis and yield data with a Mitscherlich function confirmed the robust nature of liming advice to the sugar industry based on soil calcium. We found that yield response to application of calcium was unlikely if soil calcium status was greater than 1 to 1.5 cmol(+)/kg. Ninety percent of maximum yield was obtained at 0.44 cmol(+)/kg of soil calcium in the 0 to 25 cm layer. This agrees closely with the current industry critical value of 0.55 cmol(+)/kg.

A value of 0.175 % calcium in leaf tissue was the critical value for 90% yield in these experiments`. The generally lower values of leaf calcium in Q110 and absence of yield response at the fertile humic gley site was interpreted as need to assess specific leaf norms for different varieties.

Despite high values of manganese in soil and leaf tissue (306 mg/kg) we concluded that manganese was not toxic to sugarcane at these sites.

Removal of nutrients in the sugarcane biomass at project sites was similar to regional values obtained from BSES Soil Fertility Monitoring Sites. Use of nutrient content of cane stalks and cane yield should provide a reliable method of estimating export of bases from canefields.

There are good prospects for modelling the residual value of lime based on an initial soil test, knowledge of applied calcium product and consumption of calcium by soil acidity and base export in cane.

Lime and gypsum increased soil calcium status of the 0-25 cm layer, but as expected gypsum had no effect on soil pH. Results from these experiments provide the first field data on soil pH buffer curves for southern caneland soils. This information is relevant to situations where alternate crops in sugar areas require liming to a target pH and will allow improved management of soil pH to minimise effects of elevated soil pH in enhancing degradation of chlorpyrifos. We show that application of lime at 1 t/ha will elevate soil pH in the 0 to 10 cm zone by 0.36, 0.19, 0.17 and 0.09 units for humus podzol, yellow podzolic, gley podzolic and humic gley soils respectively.

Soil pH to 40 cm was increased by a lime application of 8 t/ha at the yellow podzolic site 38 months after lime application, whereas lime at 2 t/ha had no effect on sub-soil pH. That an application of lime at 2 t/ha plus 3.75 t/ha of gypsum had a similar effect on soil calcium to 40 cm depth was attributed to the greater solubility of calcium from gypsum. Surface applied calcium products had no effect on soil chemical properties below 20 cm depth at humic gley and gleyed podzolic sites. The sandy humus podzol site demonstrated 0.1 to 0.3 units pH increase in the 30 to 50 and 50 to 70 cm zones after liming, but there was no evidence of associated calcium leaching or accumulation at these depths.

The phenomenon of depression in ccs associated with response to lime was noted at the humus podzol site. The strongest predictor of ccs depression was a cane yield response of more than 30% to liming products and there were strong associations between depression of ccs and elevated calcium levels in leaf tissue, as reflected by ratio of calcium to other nutrients. The ratio of calcium to magnesium in leaf dry matter was the strongest nutrient index of ccs depression. Higher levels of leaf or stalk nitrogen could not be associated with depression of ccs from a lime response.

SRDC agreed to re-fund this project to enable evaluation of the residual value of lime on a similar time scale to canegrower decisions about re-application of lime at the end of each crop cycle (intervals of five to seven years). The continuing project BS155 (*Factors affecting the residual value of lime*) will further develop the model of the residual value of lime, allow for re-treatment with lime and explore the physiological basis of the effect of lime response on ccs.

The project enjoyed a high extension profile with work being featured at grower, agri-business and international soil science symposium field days, in conference poster papers and in a technical paper to the Australian Society of Sugar Cane Technologists. The work has enhanced collaboration between partner agencies and allowed value adding to SRDC project CSC21S (*Measuring N in cane at the mill*), and a University of Queensland PhD project (*Nitrogen metabolism in sugarcane*).

2. PREFACE

This report should be regarded as an interim report in terms of achievement of project objectives. The initial project (BS98S) was funded by SRDC for three years commencing in July 1993. In 1996 SRDC provided funding for a further four years (Project BS155) in the recognition that monitoring for more than three years would be needed to model the residual value of amendments on acidic canelands.

A final report encompassing results and recommendations arising from both projects will be submitted at the completion of BS155

3. INTRODUCTION

Almost 90% of canegrowing soils are acidic. The sugar industry currently applies in excess of $3.5 million worth of lime per year to about 10,000 ha of cane land, but some 40,000 ha should be treated annually. In the longer-term, most of the 360,000 ha of cane growing soil may need lime applications. Recent surveys (Reghenzani 1993) showed that 67% of soil samples from north Queensland are calcium deficient. Similar results (Kingston and Linedale 1987) were obtained in the Moreton area, and soils in other areas yet to be surveyed are expected to show calcium deficiencies also. Response to lime can raise cane yields by 15-40 t/ha in moderately to very deficient areas , thus improved use of lime would offer the industry considerable productivity benefits. The benefit of liming caneland was demonstrated from BSES trials in the high rainfall areas of north Queensland (Hurney 1971, Haysom *et al.* 1986, Ridge *et al.* 1980) but there has been less trial work on the cane soils of southern Queensland. Adopters of liming in the region have sought information on the longevity of response to lime and the most economic rate and frequency of retreatment.

4. PROJECT OBJECTIVES

The objectives of this project were to
(a) determine the relative significance of soil acidity and soil calcium status for predicting response of sugarcane to lime in southern Queensland,
(b) understand the influence of soil properties on the residual value of lime,
(c) study the negative interaction between cane yield response to lime and ccs, and
(d) develop and extend improved management guidelines for the necessity and frequency of lime applications.

To achieve these objectives four field trials were established in the Moreton area.

5. MATERIALS AND METHODS

5.1 Site selection and application of amendments

Four sites, in the Moreton region of southeast Queensland, were selected to give a range of soil organic carbon, clay content and chemical characteristics (Table 1). Other soil characteristics and GPS marks for each site are presented in Appendix 1.

Table 1. Selected properties of the surface soil (0-10 cm depth) at each site at the time of lime application in August 1992.

Site	Soil type[A]	pH_w	pH_{Ca}	Org. C	Clay	ECEC	Exch. Ca	Exch. Mg	Exch. Al
				(%)	(%)	cmol(+) /kg			
1 Bisinella	Yellow podzolic	4.78	3.92	-	27	3.96	0.46	0.34	2.86
2 Trevor	Humic gley	4.84	4.08	4.8	36	11.54	1.80	1.77	6.90
3 Savimaki	Humus podzol	5.15	4.17	1.1	8	1.72	0.08	0.04	1.32
4 Colley	Gleyed podzolic	4.74	4.05	1.4	28	3.06	0.48	0.32	1.67

[A] Stace et al. (1968)

At each site the treatments were set out as four randomised blocks. The number of treatments varied across sites but included a range of lime application rates at each site (Table 2). At Sites 1, 2 and 3 the treatments incorporated a provision for the reapplication of amendment for selected lime rates. Individual plots were 9m wide and 10m long at Sites 1, 2 and 3 and 18m wide and 10m long at Site 4 (to allow three rates of nitrogen to be applied within each lime rate). Amendments were applied in late August 1992 and cultivated into the 0-10 cm depth using rotary harrows (see Plates 1 and 2).

Table 2. Treatments at each of the four sites

Site number/producer			
1/ Bisinella	2/Trevor	3/Savimaki	4/Colley
Control	Control	Control	Control
Lime 1 t/ha	Lime 1 t/ha	MgO 0.072 t/ha	Lime 1 t/ha
[A]Lime 1 t/ha	[A]Lime 1 t/ha	Ca/Mg blend 0.5 t/ha	Lime 2 t/ha
Lime 2 t/ha	Lime 2 t/ha	Ca/Mg blend 1 t/ha	Lime 4 t/ha
[A]Lime 2 t/ha	[A]Lime 2 t/ha	[A]Ca/Mg blend 1 t/ha	Lime 8 t/ha
Lime 4 t/ha	Lime 4 t/ha	Ca/Mg blend 2 t/ha	
[A]Lime 4 t/ha	[A]Lime 4 t/ha	[A]Ca/Mg blend 2 t/ha	
Lime 8 t/ha	Lime 8 t/ha	Ca/Mg blend 4 t/ha	
Gypsum 3.75 t/ha	Gypsum 3.75 t/ha	Lime 1.13 t/ha	
Lime 2 t/ha + Gypsum 3.75 t/ha	Lime 2 t/ha + Gypsum 3.75 t/ha	Lime 4.5 t/ha	
		Gypsum 0.68 t/ha + MgO 0.23 t/ha (NV= Ca/Mg blend 0.5 t/ha)	
		MgO 0.23 t/ha (NV= Ca/Mg blend 0.5 t/ha)	
		Filter mud/ash (120 t/ha)	

[A] Established for reapplication of amendment at a later date

Plate 1. Treated plots at site 3 prior to amendment incorporation.

Plate 2. Amendments were incorporated into the 0-10 cm depth using rotary harrows.

The lime used had a neutralising value (NV) of 97.5, a Ca content of 39%, a Mg content of 0.3% and was 98% < 0.25 mm. Because of low soil Mg at Site 3, various rates of a commercially obtainable blend of $CaCO_3$ and MgO (neutralising value 110, 32% Ca, 8% Mg and 45% < 0.25 mm) was used. The gypsum used comprised 96% $CaSO_4.2H_2O$ and 4% $CaCO_3$ and was 80% < 0.15 mm.

The filter mud/ash used at Site 3 was obtained from the Moreton mill and had total concentrations of N, P, K, S, Ca and Mg of 1.11%, 0.65%, 0.32%, 0.11%, 1.64% and 0.45%, respectively. Based on the total Ca concentration, an application of 120 t of filter mud/ash supplied equivalent Ca to that in 1.25 t lime or 1.5 t of the $CaCO_3$/MgO blend. The filter mud/ash also contained trace elements (Cu, Zn, Fe and Mn).

5.2 Crop establishment

Sugarcane varieties, dates of crop initiation in 1992 and age at harvest are shown in Table 3. The 1993 harvest season at Nambour was disrupted by wet weather causing some 30% of the crop to be carried over to 1994 as standover. Plant cane at Sites 1, 2 and 4 was involved in the standover issue. No plant-standover data were available for Site 4 as hastily organised harvest after a run-away cane fire precluded re-location of the weighing truck to the site; second ratoon data from this site cannot be used as a heavy infestation of soldier fly was found in the trial area after harvest. First ratoon yield data must also be viewed with caution. Plant-standover yield data for Site 1 (data not shown) are also unreliable because the old Massey Ferguson harvester was under-powered to handle the heavy lodged crop; there was carry over of cane between plots in the harvester.

Table 3. Crop initiation and age data for experiments in BS98S in the Moreton area

Site	Variety	Plant cane		First ratoon		Second ratoon		Third ratoon	
		Plant	Age (mths)	Ratoon	Age (mths)	Ratoon	Age (mths)	Ratoon	Age (mths)
1	CP51-21	5/9/92	15*	27/7/94	12.5	19/8/95	12	28/9/96	-
2	Q110	10/9/92	24*	18/9/94	13	31/10/95	11.5	17/10/96	-
3	H56-752	20/9/92	14	19/12/93	11	16/11/94	11.5	5/10/95	13
4	Q110	2/10/92	24*	17/9/94	12.5	29/9/95	10	31/7/96	-

* Plant crop harvest deferred to 1994 as plant standover because of wet harvesting season in 1993

All experiments were planted by the host growers during planting of the commercial cane crop. Standard rates of fertiliser were applied by growers to all experiments except Site 4 where cane was planted with 250 kg/ha of di-ammonium phosphate and top dressed with 200 kg/ha of muriate of potash; three rates of nitrogen (from sulfate of ammonia) were applied within each lime rate to achieve 96, 146 and 196 kg N/ha in plant cane. A basal ratooning mixture of 415 kg/ha of CK33 was supplemented with sulfate of ammonia to achieve 75, 150 and 225 kgN/ha in ratoon crops.

5.3 Plant measurements

Leaf samples (20 cm sections of lamina only from 20 leaves per plot) were collected from the upper-most fully expanded leaf in each plot of the experiments in March each year for analysis of N, P, K, Ca, Mg, S, Cu, Zn, Mn, Fe and Al in leaf dry matter. Site 4 leaf material was also sampled at approximately five week intervals from December to July for determination of leaf nitrogen profiles in relation to rate of applied nitrogen and lime.

Stalk populations were determined in all treatments during May or June to allow post-harvest analysis of yield components associated with population or weight per stalk. Shoot populations were also determined eight weeks after planting at Site 3 where there was an obvious effect of treatment on crop establishment.

Cane yield data were obtained from a net area of 0.0045 ha (3 rows x 10 m) in each plot. A BSES weighing truck was used with a commercial harvester to obtain yield at Sites 1, 2 and 3, except that the sampling method of Hogarth and Skinner (1967) was used to obtain plant cane data at Site 1 in 1993. This sampling method was also used at Site 4 for first and second ratoon harvests.

CCS was determined for juice expressed by a laboratory mill from a sample of six stalks per plot in each experiment. All reported ccs values have been discounted by 1.5 units to more closely align laboratory mill ccs with commercial mill ccs values.

Samples of sugarcane biomass were fractionated into stalk, top, green leaf and trash, components at Site 4 in 1993, 1995 and 1996 to determine yield components on a dry matter basis and to quantify uptake and removal of nutrients from the soil. In 1993 the high and low rate of nitrogen was sampled in three replications of treatments receiving 0, 2 and 8 t/ha of lime, whereas in 1995 and 1996 all three nitrogen levels were sampled in three replications of lime applied at 0, 2, 4 and 8 t/ha.

Stalks from four replications of selected treatments at Site 3 were analysed for dry matter and content of N, P, K, Ca, Mg, S, Cu, Zn, Mn and Fe to quantify crop removal of nutrients and to study impact of moisture and N on ccs.

Sites 3 and 4 have also been sampled to provide data to CSC21S: *N at the mill* and Site 4 cane has also been sampled by Ian Biggs for his PhD project on N metabolism in cane.

5.4 Soil sampling and analysis

Soil samples were collected annually from each plot after the cane was harvested. The 0-10, 10-20 and 20-30 cm depths were sampled except in the case of treatments established for reapplication of amendment which were sampled to 10 cm only. Selected treatments at some sites were also sampled at depths of 30-50, 50-70 and 70-90 cm, with the depth of sampling increasing with time after amendment application. Eight cores (8 cm diameter) were collected from each plot and the respective depth intervals bulked, mixed and a subsample retained in a polyethylene bag. The soil from each plot and depth was air dried (40° C), sieved < 2 mm and mixed prior to analysis.

Separate samples of soil were used to measure soil pH (1:5 soil:solution) in each of water (pH_w) and 0.01M $CaCl_2$ (pH_{Ca}) after the suspensions had been equilibrated for 1 hour on an end-over-end shaker. Prior to the measurement of pH_w the electrical conductivity (EC) of the suspension was determined. Following pH measurement in $CaCl_2$, the suspensions were centrifuged, filtered, and the concentrations of Al and Mn in the filtrate determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). Calcium chloride extractable Al (Al_{Ca}) and Mn (Mn_{Ca}) levels are reported as mg/kg soil.

Each soil sample was also analysed for exchangeable Al and acidity (H plus Al) using a modification of the Yuan (1959) method in which the soil was extracted with 1M KCl (1:10 soil:solution) and the acidity and Al separately determined using a Metrohm autotitrator. Exchangeable bases Ca, Mg, K and Na were determined by ICP-AES following extraction with 1M NH_4Cl using the procedure (method 15A1) of Rayment and Higginson (1992). The effective cation exchange capacity (ECEC) was determined by the sum of exchangeable acidity and basic cations displaced with NH_4Cl. Aluminium saturation percent was calculated as 100 x exchangeable Al/ECEC and Ca saturation as 100 x exchangeable Ca/ECEC.

Soil solution was extracted from samples of unamended soil (control plots, 0-10, 10-20, 20-30 cm depths) and chemical characteristics (pH, EC) measured. The bioassay procedure of Aitken *et al.* (1990) was used to test for the presence of phytotoxic Al in soil solution.

5.5 Statistical analysis of data

Raw data were collated in Microsoft Excel spread sheets and exported to specialist statistical packages STATISTIX 3.0 and BSES ST001 for analysis of variance and regression analysis or to STATISTICA for fitting Mitscherlich curves to nutrient response data.

6. RESULTS AND DISCUSSION

6.1 Cane yield response

The yield of plant cane was significantly increased by lime application at two of the three sites at which plant cane data were obtained (Sites 1, and 3; Table 4). Plate 3 shows the effects of lime and the $CaCO_3$/MgO blend on the growth of plant cane at Site 3. Treatment effects at Site 3 were obvious from very early in the crop growth and there were significant effects on primary shoot counts, which were also reflected in the mature stalk population (Appendices 2a and b). At the other site (Site 1) at which significant treatment effects were recorded the responses were less obvious in the field (Plate 4).

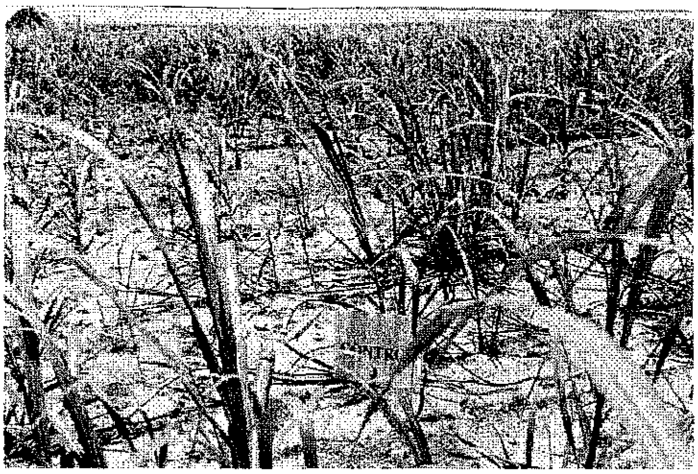

Plate 3a. The growth of the plant cane crop in unamended soil at site 3.

Plate 3b. Plant cane growth in soil amended with a $CaCO_3$/MgO blend (4 t/ha) at site 3.

Plate 3c. Plant cane growth in soil amended with lime (4.5 t/ha) at site 3.

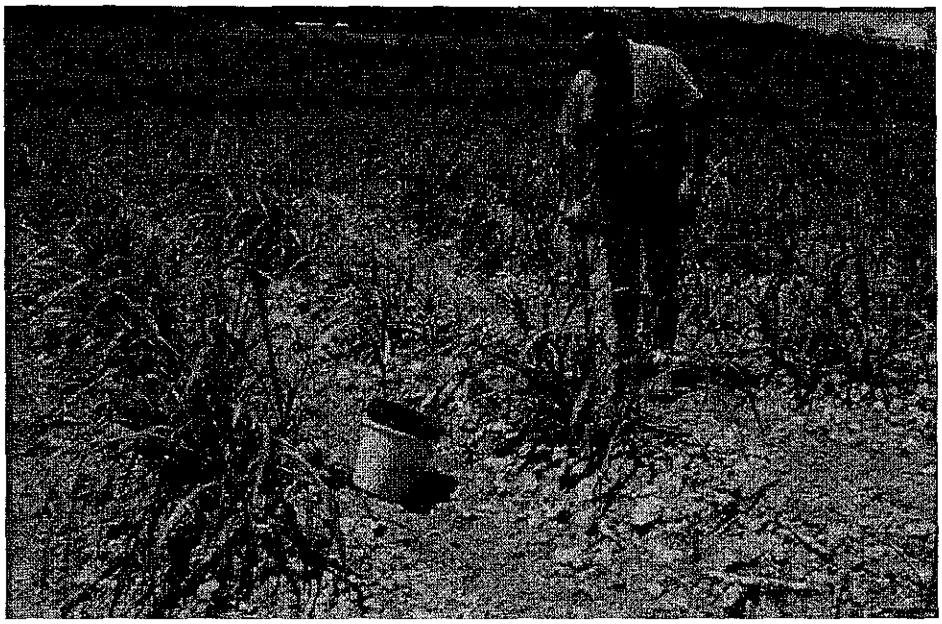

Plate 4a. Cane growth (1st ratoon) in unamended soil at site 1.

Plate 4b. Cane growth (1st ratoon) in soil amended with lime (2 t/ha) at site 1.

Cane and sugar yield increased up to application of 4 t/ha of liming material at Sites 1 and 3, but the increase above 1 t/ha was not statistically significant ($P<0.05$). Significant treatment effects in the plant cane crop at Site 1 were not maintained in the subsequent ratoon crop (Table 4), even though soil and leaf Ca data suggest yield responses would be expected. Despite the low Ca status (and associated low pH and high Al) of the surface soil at Site 4 (Table 1), there was not a significant yield response to lime (Table 4). A high Ca concentration (1.97 cmol(+)/kg) in the subsurface soil (30-50 cm) possibly explains the lack of a significant response at this site. This is consistent with BSES experiments in which little or no response to lime has been recorded where subsurface Ca concentrations are >1.5 cmol(+)/kg.

Application of gypsum increased plant cane yields at Sites 1 and 3 (Table 4). These responses, together with the soil characteristics at each site, indicate that the yield increases obtained with lime and gypsum were responses to calcium. Exchangeable Al (Table 1), soil and soil solution pH values (Table 1 and Appendix 1) would suggest the presence of phytotoxic Al in the unamended soil at each site. A bioassay of soil solution, using the short term root growth of soybean seedlings, indicated the presence of phytotoxic Al at all sites. However, sugarcane responses to lime were not obtained at all sites. Moreover, sites responsive to lime were also responsive to gypsum which does little to ameliorate Al toxicity (see section 6.4.1). This highlights the known tolerance of sugarcane to high soil Al concentrations (Hetherington *et al.* 1986, 1988). A comparison of sugarcane response to lime with that of another crop was possible using the results of a separate lime rate experiment with maize undertaken on the same soil type adjacent to Site 2. The results of this comparison (presented at the recent National Conference on Acid Sulfate Soils), which illustrates the relative tolerance of sugarcane to Al, are presented in Appendix 3.

Treatments comprising a combination of lime and gypsum (Sites 1 and 2) were designed to supply an amount of Ca equivalent to that of the 4 t lime/ha treatment. At Site 1, the lime plus gypsum treatment produced the highest yield (plant cane crop) and this was significantly ($P<0.05$) higher than the yield of the 4 t lime/ha treatment. Rapid availability of Ca from the more soluble gypsum component and greater movement of Ca into the subsurface soil (see section 6.5) may partially explain the higher yield. However, the performance of this treatment, relative to the control, declined in subsequent ratoon crops (Tables 4, 6 and 7) despite the maintenance of a relatively high soil Ca and pH status (see section 6.4). The possibility of the response being due to improved soil physical conditions is unlikely since the yield obtained from treatment with gypsum alone was lower that that of the combined lime and gypsum treatment. There was on average a 13% increase in stalk population in first ratoon compared to plant cane; control plot population increased by 19% but that of Lime + Gypsum plots by only 6%. Weight of individual stalks also declined more rapidly in the combination treatment than in the controls. Thus the poorer ratoon performance of the Lime + Gypsum plots may be related to greater damage in high yielding plots during harvest of the heavily lodged plant standover crop in 1994. A combination of gypsum and MgO also resulted in good yields at Site 3 where soil physical conditions were not considered limiting to growth (Table 4). The efficacy of combinations of lime and gypsum is being examined in recently established field trials in southeast Queensland as part of a project investigating subsurface acidity.

The addition of MgO alone, at a rate of 230 kg/ha, at Site 3 resulted in depressed yields relative to the control (Table 4). The unamended soil at this site was low in Ca and tissue analysis data in Appendix 4c show that the application of a high rate of Mg exacerbated the Ca deficiency. That the soil at Site 3 was also deficient in Mg is evident from the yield increase arising from the application of MgO at a rate of 72 kg /ha (Table 4). In contrast, applications of Ca in the form of $CaCO_3$ (1.13 and 4.52 t lime/ha) markedly increased yields relative to the control. The lime used contained 0.3% Mg and an application rate of 4 t/ha is equivalent to 12 kg /ha which may have met the requirement of the plant cane crop. In addition, improved growth as a result of the supply of Ca may have enabled the crop to better exploit the soil Mg present.

The large plant cane yields at Site 2 are for a 24 month plant stand-over crop. Poor yield and lack of response to lime in the Site 3 first ratoon crop, in 1994, was the result of December harvest of plant cane in 1993 and severe waterlogging during ratooning and the main growing season; better growing conditions resulted in good yield in the second ratoon crop.

There was a significant cane and sugar yield response to 150 kg N/ha in the first ratoon crop at Site 4 (Table 5); there was no additional response to nitrogen above this level. Rate of nitrogen did not affect ccs nor was there a significant interaction between rate of lime and rate of applied nitrogen. Leaf analysis data acquired at intervals of five weeks from February to July 1995 show little difference in tissue nitrogen levels between treatments. It is possible that 129 mm of rain in December 1994 and 530 mm in February 1995 contributed to nitrate leaching and loss of potential for greater differences between nitrogen treatments; all treatments supported tissue N% dry matter between 2 and 2.3% in February, thus cane was not nitrogen deficient.

Table 4. Average cane yield (t/ha) of plant cane and subsequent ratoon crops at each site.

Treatment	Replicates	Plant cane	1st ratoon	2nd ratoon
Site 1 Bisinella				
Control	8	70.0	66.3	
Lime 1 t/ha	8	74.1	66.3	
Lime 2 t/ha	8	76.1	69.2	
Lime 4 t/ha	8	79.8	74.6	
Lime 8 t/ha	4	82.8	71.3	
Gypsum 3.75 t/ha	4	75.3	73.3	
Lime 2 t/ha + Gypsum 3.75 t/ha	4	90.7	68.7	
LSD ($P<0.05$)	4 vs 4	10.8	NS	
LSD ($P<0.05$)	8 vs 8	7.6	NS	
LSD ($P<0.05$)	4 vs 8	9.3	NS	
Site 2 Trevor				
Control	8	233.7	114.0	
Lime 1 t/ha	8	225.4	103.8	
Lime 2 t/ha	8	232.7	96.4	
Lime 4 t/ha	8	215.5	95.9	
Lime 8 t/ha	4	228.4	97.9	
Gypsum 3.75 t/ha	4	226.6	99.5	
Lime 2 t/ha + Gypsum 3.75 t/ha	4	228.2	108.0	
LSD ($P<0.05$)	4 vs 4	NS	12.6	
LSD ($P<0.05$)	8 vs 8	NS	8.9	
LSD ($P<0.05$)	4 vs 8	NS	10.9	
Site 3 Savimaki				
Control	4	76.6	8.8	55.8
MgO 0.072 t/ha	4	94.3	13.3	76.7
Ca/Mg blend 0.5 t/ha	4	84.2	12.0	78.9
Ca/Mg blend 1 t/ha	8	111.3	13.8	85.6
Ca/Mg blend 2 t/ha	8	109.4	14.5	89.2
Ca/Mg blend 4 t/ha	4	122.7	14.5	92.4
Lime 1.13 t/ha	4	107.8	11.6	84.9
Lime 4.5 t/ha	4	120.0	13.5	88.3
MgO 0.23 t/ha + Gypsum 0.68 t/ha	4	119.1	15.5	86.6
MgO 0.23 t/ha	4	54.1	9.2	49.4
Filter mud/ash	4	119.4	20.0	79.9
LSD ($P<0.05$)	4 vs 4	22.6	NS	14.1
LSD ($P<0.05$)	8 vs 8	15.9	NS	10.0
LSD ($P<0.05$)	4 vs 8	19.5	NS	12.2
Site 4 Colley				
Control	4	N/A	81.5	
Lime 1 t/ha	4	N/A	82.5	
Lime 2 t/ha	4	N/A	81.7	
Lime 4 t/ha	4	N/A	92.3	
Lime 8 t/ha	4	N/A	87.3	
LSD ($P<0.05$)	-	-	NS	

Table 5. Average cane and sugar yield and ccs for nitrogen treatments in first ratoon Q110 at Site 4.

Treatment	Tonnes cane/ha	CCS	Tonnes sugar/ha
75 kg N/ha	79 92	13.67	10.93
150 kg N/ha	88.57	13.59	12.03
225 kg N/ha	89.02	13.58	12.09
LSD ($P<0.05$)	6.1	0.43	0.91

6.2 CCS and sugar yield

Sugar yield at all sites (Table 6) generally responded to treatments in a similar manner to cane yield. However ccs was depressed by liming treatments at Sites 1 and 3 (Table 7). At Site 1 application of lime at 8 t/ha gave lowest ccs, the depression below other treatments was significant ($P<0.05$) in the first ratoon crop. Lime at 4.52 t/ha at Site 3 caused significant depression of plant cane ccs below that achieved in Gypsum + MgO, 0.5 and 1.0 t/ha of Ca/Mg blend and the Filter mud/ash treatments; smaller depression in ccs was associated with Ca/Mg blend at 2 and 4 t/ha and lime at 1.13 t/ha. There were no treatment effects in the low yielding first ratoon crop at Site 3, but second ratoon crop effects were similar to those in plant cane.

The phenomenon of depression in ccs associated with response to lime was noted by Ridge *et al* (1980) and further explored by Kingston *et al* (1996) as a consequence of the effects noted at Site 3. Kingston *et al* (1996) concluded that the strongest predictor of ccs depression was a cane yield response of more than 30% to liming products. There were strong associations between depression of ccs and elevated calcium levels in leaf tissue, as reflected by ratio of calcium to other nutrients. The ratio of calcium to magnesium in leaf dry matter was the strongest nutrient index of ccs depression. The authors cited literature reports which suggest elevated calcium levels in sugarcane tissue may be associated with depressed activity of the invertase enzymes. This hypothesis is under investigation in the continuing project BS155.

Prior to commencement of this project it was hypothesised by BSES agronomists that the negative effect of lime on ccs may be related to improved mineralisation of soil nitrogen and higher plant levels of nitrogen after liming. This mechanism was reported by Wood (1993). High plant nitrogen status is associated with higher water content, (Muchow and Robertson 1994). This mechanism could not be substantiated by second ratoon data at Site 3. Data in Table 8 show there were significant differences for treatments between moisture content of stalks; high yielding treatments generally had lower dry matter levels; there was a low but significant association between cane yield and stalk moisture content ($R^2 = 0.18$). Differences in water content among the lower dry matter Ca/Mg blend 4 t/ha, Lime 4 t/ha and Filter mud/ash treatments were not significant, but the latter treatment had significantly higher ccs; over-all there was no significant association between water content and ccs ($R^2 = 0.09$). Table 8 data also show that there were no significant treatment differences in nitrogen content of stalk dry matter, confirming information from plant, and second ratoon leaf analysis. Stalks from three replicates of control, Ca/Mg blend 4 t/ha, Lime 4.5 t/ha and Filter mud/ash treatments were also analysed by CSIRO Division of Tropical Crops and Pastures for ninhydrin reactive amino nitrogen. This analysis, based on different samples to Table 8 data, showed stalks in the Filter mud/ash treatment had higher, but not significantly higher, total nitrogen content than other treatments and that amino nitrogen levels were significantly higher than in other treatments. Higher levels of amino nitrogen usually are an index of luxury uptake of nitrogen and lower ccs (Chapman *et al* 1996). The latter condition did not apply in our data.

Table 6. Average sugar yield (t/ha) of plant cane and subsequent ratoon crops at each site.

Treatment	Replicates	Plant cane	1st ratoon	2nd ratoon
		Site 1 Bisinella		
Control	8	9.51	8.94	
Lime 1 t/ha	8	10.25	9.00	
Lime 2 t/ha	8	10.77	9.50	
Lime 4 t/ha	8	10.96	10.21	
Lime 8 t/ha	4	11.80	9.15	
Gypsum 3.75 t/ha	4	10.46	9.84	
Lime 2 t/ha + Gypsum 3.75 t/ha	4	12.65	8.96	
LSD (P<0.05)	4 vs 4	1.93	NS	
LSD (P<0.05)	8 vs 8	1.36	NS	
LSD (P<0.05)	4 vs 8	1.67	NS	
		Site 2 Trevor		
Control	8	29.32	13.62	
Lime 1 t/ha	8	27.49	12.87	
Lime 2 t/ha	8	28.77	12.30	
Lime 4 t/ha	8	26.62	12.21	
Lime 8 t/ha	4	29.50	12.69	
Gypsum 3.75 t/ha	4	28.80	12.27	
Lime 2 t/ha + Gypsum 3.75 t/ha	4	28.22	12.87	
LSD (P<0.05)		NS	NS	
		Site 3 Savimaki		
Control	4	10.47	1.15	6.87
MgO 0.072 t/ha	4	13.24	1.80	12.05
Ca/Mg blend 0.5 t/ha	4	11.16	1.62	10.38
Ca/Mg blend 1 t/ha	8	14.79	1.93	11.07
Ca/Mg blend 2 t/ha	8	14.08	2.04	11.31
Ca/Mg blend 4 t/ha	4	15.86	1.97	11.68
Lime 1.13 t/ha	4	14.12	1.57	10.55
Lime 4.5 t/ha	4	14.92	1.81	10.89
MgO 0.23 t/ha + Gypsum 0.68 t/ha	4	15.85	2.16	11.06
MgO 0.23 t/ha	4	7.43	1.28	6.82
Filter mud/ash	4	15.64	2.36	10.53
LSD (P<0.05)	4 vs 4	3.37	NS	1.67
LSD (P<0.05)	8 vs 8	2.38	NS	1.18
LSD (P<0.05)	4 vs 8	2.92	NS	1.45
		Site 4 Colley		
Control	4	N/A	11.35	
Lime 1 t/ha	4	N/A	11.29	
Lime 2 t/ha	4	N/A	10.83	
Lime 4 t/ha	4	N/A	12.53	
Lime 8 t/ha	4	N/A	11.88	
LSD (P<0.05)		-	2.18	

Table 7. Average ccs of plant cane and subsequent ratoon crops at each site.

Treatment	Replicates	Plant cane	1st ratoon	2nd ratoon
Site 1 Bisinella				
Control	8	13.57	13.56	
Lime 1 t/ha	8	13.80	13.60	
Lime 2 t/ha	8	14.14	13.76	
Lime 4 t/ha	8	13.71	13.69	
Lime 8 t/ha	4	14.22	12.86	
Gypsum 3.75 t/ha	4	13.85	13.42	
Lime 2 t/ha + Gypsum 3.75 t/ha	4	13.94	13.07	
LSD (P<0.05)	4 vs 4	NS	NS	
LSD (P<0.05)	8 vs 8	NS	NS	
LSD (P<0.05)	4 vs 8	NS	NS	
Site 2 Trevor				
Control	8	12.54	11.95	
Lime 1 t/ha	8	12.13	12.40	
Lime 2 t/ha	8	12.39	12.76	
Lime 4 t/ha	8	12.33	12.75	
Lime 8 t/ha	4	12.84	12.96	
Gypsum 3.75 t/ha	4	12.70	12.29	
Lime 2 t/ha + Gypsum 3.75 t/ha	4	12.41	11.91	
LSD (P<0.05)	4 vs 4	NS	0.63	
LSD (P<0.05)	8 vs 8	NS	0.45	
LSD (P<0.05)	4 vs 8	NS	0.55	
Site 3 Savimaki				
Control	4	13.68	12.98	12.49
MgO 0.072 t/ha	4	14.02	13.47	13.21
Ca/Mg blend 0.5 t/ha	4	13.26	13.44	13.15
Ca/Mg blend 1 t/ha	8	13.28	13.92	12.94
Ca/Mg blend 2 t/ha	8	12.86	13.98	12.70
Ca/Mg blend 4 t/ha	4	12.92	13.48	12.64
Lime 1.13 t/ha	4	13.00	13.65	12.44
Lime 4.5 t/ha	4	12.43	13.48	12.30
MgO 0.23 t/ha + Gypsum 0.68 t/ha	4	13.31	13.87	12.79
MgO 0.23 t/ha	4	13.76	13.81	13.85
Filter mud/ash	4	13.06	13.2	13.20
LSD (P<0.05)	4 vs 4	0.66	NS	0.63
LSD (P<0.05)	8 vs 8	0.47	NS	0.44
LSD (P<0.05)	4 vs 8	0.57	NS	0.54
Site 4 Colley				
Control	4	N/A	13.93	
Lime 1 t/ha	4	N/A	13.71	
Lime 2 t/ha	4	N/A	13.26	
Lime 4 t/ha	4	N/A	13.61	
Lime 8 t/ha	4	N/A	13.57	
LSD (P<0.05)		-	0.50	

Table 8. Results of analysis of second ratoon H56-752 stalks for moisture content, total nitrogen and ccs

Treatment	Stalk moisture (%)	CCS	Total stalk nitrogen (% in dry matter)
Control	75.6	12.49	0.30
MgO 0.072 t/ha	74.8	13.21	0.30
Ca/Mg blend 0.5 t/ha	75.0	13.15	0.29
Ca/Mg blend 1 t/ha	76.3	12.90	0.27
Ca/Mg blend 2 t/ha	75.0	12.73	0.26
Ca/Mg blend 4 t/ha	76.6	12.64	0.30
Lime 1.13 t/ha	75.0	12.44	0.28
Lime 4.5 t/ha	76.1	12.30	0.26
MgO 0.23 t/ha + Gypsum 0.68 t/ha	75.3	12.79	0.28
MgO 0.23 t/ha	74.7	13.85	0.27
Filter mud/ash	76.8	13.20	0.29
LSD (P<0.05)	1.41	0.66	0.05

6.3 Effect of treatments on crop nutrition

6.3.1 Leaf nutrient levels

Nutrient content of the third leaf was used to assess crop nutrient status in relation to treatments; data are reported in Appendices 4a, b, c and d.

The leaf assay data showed liming and magnesium treatments generally had non-significant to minor impact on nutrients other than calcium, magnesium, zinc and manganese. These results will be discussed below. Gypsum caused a small rise in leaf sulfur levels, but control levels at all sites were above the critical value for deficiency. The Filter mud/ash treatment elevated phosphorus and potassium levels in plant and ratoon crops at Site 3.

Levels of calcium in leaf dry matter of control plots indicated cane at all sites was deficient in calcium in relation to the current industry standard of 0.20%; cane at Sites 2, 3 and 4 was also deficient in relation to the 0.15% critical value used in the South African industry. Leaf calcium levels generally increased in response to use of liming products or gypsum at all sites. There was no significant increase in leaf calcium in CP51-21 plant cane at Site 1 for rates of lime above 2 t/ha, but increases due to application of lime at 4 and 8 t/ha were each significant in the first ratoon crop. Leaf calcium in Q110 at Sites 2 and 4 showed smaller responses to treatment than did varieties at other sites; all values except those for lime at 8 t/ha in the first ratoon at Site 4 were less than 0.20%, yet Site 2 is a fertile and high yielding humic gley soil. Deficiency of both calcium and magnesium in leaf dry matter of un-amended H56-752 at Site 3 confirms conclusions from soil analysis. Application of lime at 4.52 t/ha at Site 3 resulted in leaf calcium values of 0.25% for plant and ratoon crops, this was significantly higher than those achieved by all other treatments. Calcium deficiency in leaf tissue at Site 3 was exacerbated, particularly in plant cane, by application of 230 kg/ha of magnesium oxide.

A Mitscherlich fit to the relationship between relative cane yield (see Appendix 5 for method of calculation) and Ca% in leaf dry matter in Figure 1 indicated that the critical calcium concentration in the index leaf was 0.175% (90% relative yield), for plant cane data from responsive Sites 1 and 3.

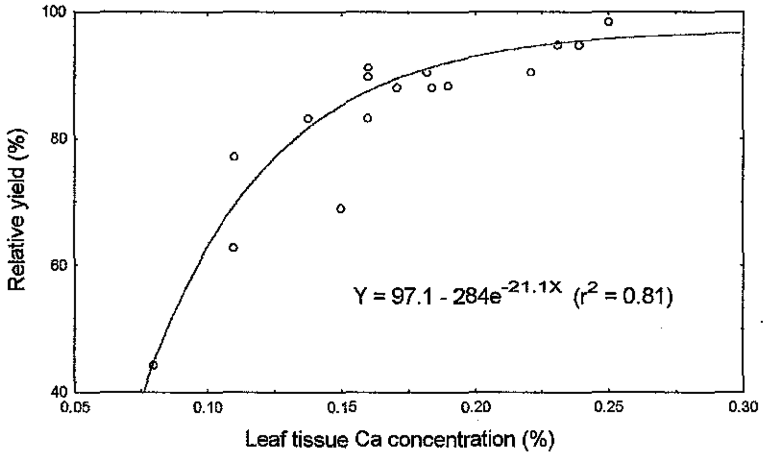

Figure 1. The relationship between relative cane yield (plant cane) and leaf tissue Ca concentration for Sites 1 and 3.

A critical leaf Ca concentration of 0.13% was derived from Figure 2 for the second ratoon crop at Site 3. This compares with a critical Ca concentration of 0.17% obtained for the plant cane crop at this site (data not shown). Decreases in critical leaf tissue concentrations with plant chronological age have been reported for numerous crop and pasture species.

The Australian Sugar Industry currently relies on a single value of 0.20% as the critical value for leaf calcium. Anderson and Bowen (1990) report values ranging from 0.13 to 0.20%. Further data will be available from BS155 and the *Amelioration of sub-soil acidity* project of the authors to further refine the critical values for leaf calcium. Collaboration with other BSES researchers will also allow analysis of the data of Ridge *et al* (1980) by the Mitscherlich functions. Given the low levels of leaf calcium attained in Q110 there may also be justification for determining a range of critical values for different varieties.

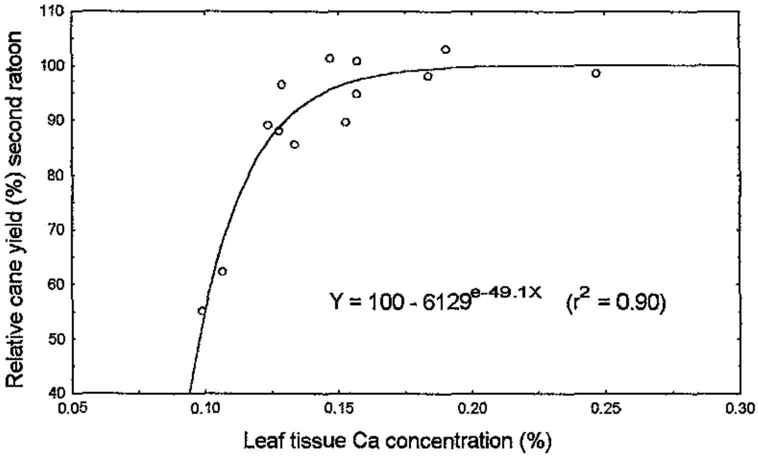

Figure 2. The relationship between relative cane yield (second ratoon) and leaf tissue Ca concentration at Site 3.

Use of calcitic lime alone generally had no significant effect on levels of magnesium in leaf dry matter, even though the lime contained 0.3% Mg and 4.52 tonnes of lime would supply 13.5 kg of magnesium. However, the deficient and slightly lower level of leaf magnesium in the latter treatment than in control plots at Site 3 was significant in plant and second ratoon crops, yet cane and sugar yields were not significantly lower than treatments where both calcium and magnesium were in adequate supply from 4 t/ha of the Ca/Mg blend.

Application of magnesium, as magnesium oxide, either alone, in the Ca/Mg blend or with gypsum raised leaf magnesium above deficiency and significantly above control values in the plant and first ratoon crops at Site 3. Leaf magnesium values in magnesium treated plots generally declined from plant to second ratoon, to the extent where values for 0.5 and 1 t/ha of the Ca/Mg blend were the same as those in control plots. The Filter mud /ash treatment applied 110 kg/ha of magnesium (equivalent to 1.4 t/ha of the Ca/Mg blend), and by second ratoon resulted in leaf magnesium values which were the same as those for the 0.5 and 1 t/ha Ca/Mg blend.

Levels of zinc in leaf dry matter were above the critical value of 0.10% in all treatments across sites. Uptake of zinc at Site 1 in cane which received lime at 8 t/ha was significantly less than the control, but not different from other liming regimes. Rate of lime had no consistent effect on zinc uptake in Q110 at Sites 2 and 4. Liming products had greatest effect on zinc uptake from the poorly buffered humus podzol soil at Site 3, where the Ca/Mg blend at 4 t/ha and both rates of lime usually resulted in lower levels of leaf zinc than in other treatments. The effect may be due to a confounding of lower availability of soil zinc with higher, but still acidic pH, and suppression of zinc assimilation by higher levels of leaf calcium, as shown in Figure 3.

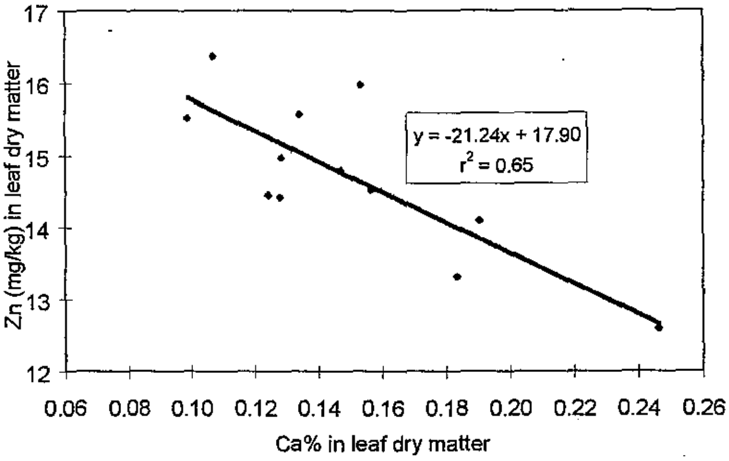

Figure 3. Relationship between levels of calcium and zinc in leaf dry matter for second ratoon H56-752 at Site 3.

There was a trend at all sites to lower levels of manganese in leaf dry matter with increasing rate of liming product. Effects were most pronounced and significant at Sites 1, 3 and 4 (Appendices 4a, b, c and d). While manganese toxicity is recognised as an impact of soil acidity in many crop species, Anderson and Bowen (1990) report the optimal range for leaf manganese in sugarcane varies between 249 mg/kg for leaf blades to 400 mg/kg for composite analysis of leaves one to four. Leaf manganese values in BS98 canes ranged to 350 mg/kg with many values around 200 mg/kg. There was a significant negative association between cane yield and leaf manganese for plant cane at Sites 1 and 3 and for first ratoon at Site 4, with R^2 values of 0.89, 0.51 and 0.80 respectively. Application of higher rates of lime also had a strong and significant negative effect on level of extractable manganese in soil as shown in Figures 4 and 5 for Sites 1 and 4 and soil manganese levels had a significant positive effect on leaf manganese levels (Figures 6 and 7). Comparison of the latter figures shows CP51-21 at Site 1 achieved higher plant manganese levels at lower values of soil manganese than did varieties at Sites 2, 3 and 4.

Manganese was considered to be non-toxic in this data set, because effects on soil and leaf manganese are related to pH effects of lime or the Ca/Mg blend at Sites 1, 3 and 4 and the pH effect of MgO at Site 3, but, for plant cane at Site 1, gypsum alone did not significantly depress soil or leaf manganese levels (soil data Table 13; leaf data Appendix 4a) and produced yields which were not significantly different from those achieved by 4 or 8 t/ha of lime. If it was argued that response to lime was the result of amelioration of manganese toxicity, poor yields in unamended soil would be expected to be associated with high soil and leaf Mn. Data in Table 9 show this is not so. Relative yield of control plots for each site was compared to extractable soil manganese and leaf manganese values. Lowest relative yield was obtained at the lowest soil manganese and moderate tissue levels of manganese and a high relative yield pertained at Site 4 for high soil and leaf manganese. Further data to examine the role of leaf manganese levels in the 400 to 800 mg/kg range will available from the *Amelioration of sub-soil acidity* project of the authors (data not shown).

Table 9. Relative yield of control plots at Sites 1 to 4 in relation to extractable soil manganese and manganese in leaf dry matter.

Site	Relative yield of control plots (%)	Extractable soil Mn (mg/kg)	Mn in leaf dry matter (mg/kg)
1	83	35.1	234
2	104	11.7	108
3	63	1.2	105
4	102	145	247

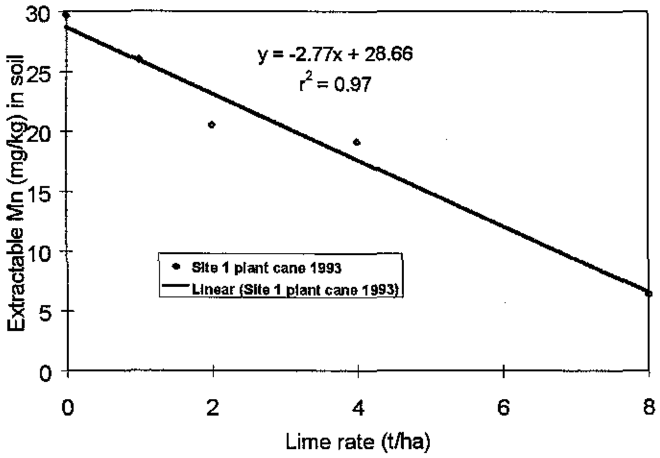

Figure 4. Effect of applying lime in 1992 on extractable manganese (0-10 cm depth) in a yellow podzolic soil at Site 1 in 1993.

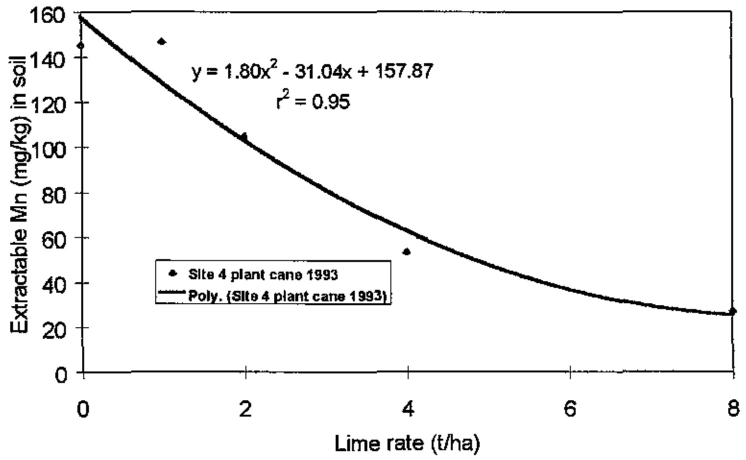

Figure 5. Effect of applying lime in 1992 on extractable manganese (0-10 cm depth) in a gleyed podzolic soil at Site 4 in 1993.

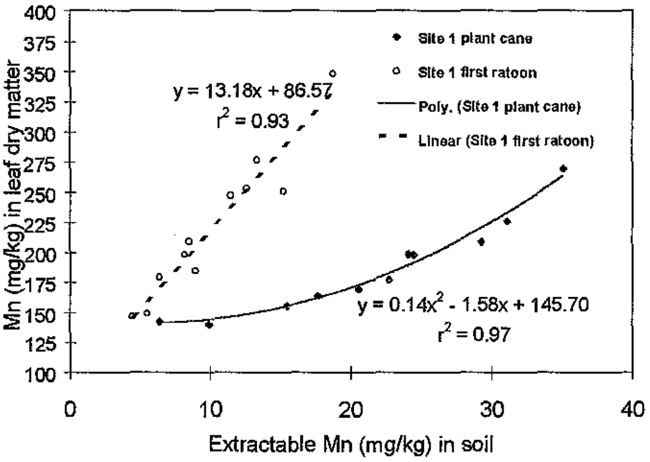

Figure 6. Effect of extractable manganese in soil on manganese in leaf dry matter for CP51-21 at Site 1.

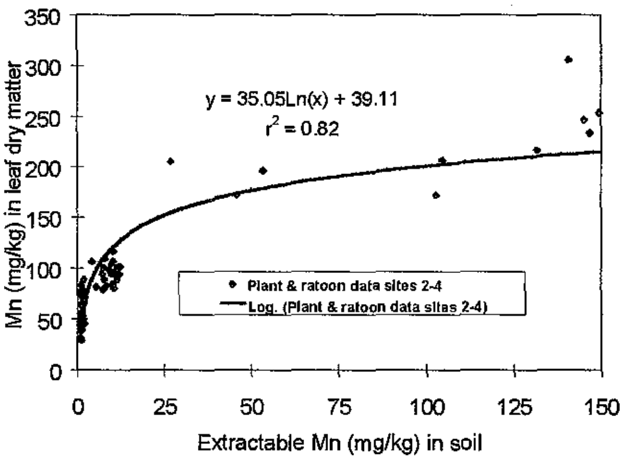

Figure 7. Effect of extractable manganese in soil on manganese in leaf dry matter of sugarcane at Sites 2, 3 and 4.

Lime and the Ca/Mg blend reduced aluminium levels in leaf dry matter only at Site 3, where values in control plots were on average 1.7 times higher than at Sites 1, 2 and 4. This response is consistent with data in Table 1 where exchangeable acidity at Site 3 is a higher proportion of effective cation exchange capacity (ECEC). Aluminium levels in leaf tissue at Site 3 are unlikely to be toxic because values in the high yielding Gypsum + MgO treatment were not significantly different from controls.

6.3.2 Nutrients in sugarcane biomass

Biomass sampling was undertaken in this project to provide information on crop uptake and field export of nutrients, particularly calcium and magnesium; export of the latter bases is of significance to post-liming re-acidification of soil and for development of strategies to maintain base status of soil. Data in Moody and Aitken (1997) suggest that, of the causes of acidification in sugarcane production systems, about 30% is attributable to the removal of alkalinity in harvested product.

All biomass components were sampled in selected treatments in plant and first ratoon Q110 at Site 4 and stalk biomass only for second ratoon H56-752 at Site 3 in this reporting period. All biomass components were sampled in selected treatments at all sites in July 1996 (data not reported).

Average total nutrient uptake data, across treatments, for plant and first ratoon Q110 were scaled to 85 tonnes cane/ha for comparison with average data from BSES soil fertility monitoring sites in the Maryborough, Moreton and Rocky Point areas. These data in Table 10 show a high level of consistency in the nutrient uptake of sugarcane in the region. Uptake of calcium in Q110 plant cane was lower than in first ratoon and the regional average; this may be associated with lower availability of calcium from lime in the year of application.

Table 10. Comparison of biomass nutrient uptake of Q110 at Site 4 in relation to the regional average for sugarcane yielding 85 tonnes cane/ha.

Data source	Nutrients in sugarcane biomass (kg/ha)									
	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn
Q110 plant	137	22	257	26	32	24	0.064	0.54	8	7
Q110 ratoon	145	24	215	37	37	33	0.072	39	3.3	6.2
Region	134	20	234	31	36	34	-	-	-	-

Analysis of stalks of H56-752 from Site 3 showed that treatments had a significant effect on uptake of calcium and magnesium as well as the mass of nutrient per tonne of cane produced (nutrient uptake efficiency) (Table 11). For example lime at 4.5 t/ha resulted in significantly higher uptake of calcium and calcium per tonne of cane, for similar cane yields (Table 4) than did 4 t/ha of the Ca/Mg blend. There was however no significant difference in the range of 0.075 to 0.115 kg Ca/t achieved from commercial rates of the Ca/Mg blend, lime at 1.1 t/ha or the Gypsum + MgO treatment. There was similar consistency for the rate of magnesium uptake across commercial rates of the Ca/Mg blend and the Gypsum + MgO treatment.

Cane yield is a readily available parameter and can therefore be used to estimate total uptake of nutrients or nutrient export in stalk if the relevant ratios are available and the proportion of biomass nutrient in stalk are available. Relevant data from Sites 3 and 4 are shown in Table 12; these data will be supplemented by information from the 1996 sampling, to provide a comprehensive calculator of removal of calcium and magnesium from cane fields. These data will be important because Table 12 data show that Q110 at Site 4 assimilated more magnesium per tonne of cane than did H56-752 in any treatment at Site 3. The lower proportion of total calcium uptake contained in stalk than for magnesium is a reflection of the immobility of calcium in plants as it is mostly bound in cell walls.

Table 11. Uptake of calcium and magnesium by stalks of second ratoon H56-752 at Site 3 and nutrient uptake efficiency of stalks.

Treatment	Nutrient in stalk (kg/ha)		Uptake efficiency (kg/tonne cane)	
	Ca	Mg	Ca	Mg
Control	2.9	5.5	0.055	0.096
MgO 0.072 t/ha	4.7	8.1	0.063	0.109
Ca/Mg blend 0.5 t/ha	6.4	9.4	0.083	0.120
Ca/Mg blend 1.0 t/ha	7.2	10.1	0.081	0.113
Ca/Mg blend 2.0 t/ha	9.0	12.2	0.102	0.139
Ca/Mg blend 4.0 t/ha	9.4	14.0	0.103	0.152
Lime 1.13 t/ha	9.6	8.3	0.115	0.097
Lime 4.5 t/ha	15.4	9.2	0.180	0.105
Gypsum 0.68 t/ha + MgO 0.23 t/ha	6.5	10.4	0.075	0.121
MgO 0.23 t/ha	2.8	7.0	0.058	0.144
Filter mud/ash	4.8	8.0	0.062	0.102
LSD (P<0.05)	3.6	3.2	0.045	0.035

Table 12. Uptake efficiency of calcium and magnesium in sugarcane stalk and the proportion of biomass nutrients contained in stalk.

Site / Variety	Treatment	Nutrient uptake efficiency (kg/tonne cane)		Proportion of biomass nutrients in stalk (%)	
		Ca	Mg	Ca	Mg
3 / H56-752	Control	0.055	0.096	-	-
	Ca/Mg blend 2 .0 t/ha	0.102	0.139	-	-
	Ca/Mg blend 4 .0 t/ha	0.103	0.152	-	-
	Lime 1.13 t/ha	0.115	0.097	-	-
	Lime 4 .5 t/ha	0.18	0.105	-	-
4 / Q110 plant	Control	0.059	0.201	28.3	55.9
	Lime 2.0 t/ha	0.098	0.222	30.1	58.8
	Lime 8.0 t/ha	0.123	0.244	32.1	62.8
4 / Q110 ratoon	Control	0.071	0.197	22.7	50.9
	Lime 2/t/ha	0.091	0.202	24.4	51.4
	Lime 4.0 t/ha	0.118	0.248	25.6	52.0
	Lime 8.0 t/ha	0.125	0.167	29.4	44.5
Grand mean		0.103	0.173	27.5	53.8
Commercial rates mean		0.115	0.167	26.7	54.1

6.4 Effects of treatments on soil chemistry

6.4.1 Effects of amendments on surface soil properties

Where appropriate, soil data (eg exchangeable Ca and Mg concentrations) obtained for the 0-10, 10-20 and 20-30 cm depth intervals were used to compute the concentration in the 0-25 cm depth since this is the sampling depth commonly used by cane producers for soil testing. Concentrations of exchangeable cations in the 0-10 cm depth were very well correlated with those in the 0-25 cm depth (Appendix 6).

Treatments had the expected effect on soil properties (0-10 cm depth, Table 13) in that lime application increased soil pH, exchangeable calcium and the effective cation exchange capacity (ECEC). Lime application decreased soil aluminium (both exchangeable and Al_{Ca}) and manganese concentrations (Table 13).
The application of gypsum alone (Sites 1 and 2, Table 13) increased soil calcium but had little or no effect on soil pH. Gypsum application also resulted in some decreases in exchangeable Mg (Sites 1 and 2, Table 13) presumably due to displacement of Mg from the exchange capacity by Ca. In situations where soil Mg is low the application of high rates of gypsum should be accompanied by addition of Mg.

At Site 3, application of Filter mud/ash (120 t/ha) had only small effects on the measured soil properties apart from an increase in pH_w (Table 13). Since exchangeable Ca was increased to only 0.19 cmol(+)/kg, it is suggested that the high yield of plant cane in the Filter mud/ash treatment (Table 4) was due to nutritional/physical effects in addition to the amelioration of calcium deficiency or acidity. Increased leaf concentrations of P and K associated with the Filter mud/ash treatments were discussed in Section 6.3.1. The residual value of the Filter mud/ash relative to the control was maintained for the plant cane and second ratoon crops (Table 4).

The difference in soil pH buffer capacities across the sites is shown in Figure 8. The slopes of the regression lines (Figure 8) represent the pH increase per unit of applied lime and are a measure of pH buffer capacity. The pH buffer capacities are tabulated in Table 14 and reflect the different soil properties. For example, at Site 2 the organic matter, clay and acidity levels are high giving a well buffered soil and hence the small pH increase per unit of added lime.

Table 13. Soil properties (0-10 cm depth) at each site after harvest of the plant cane crop. Values are the average of either four replicate plots or eight (for reapplication treatments) replicate plots.

Treatment	Soil pH_w	Soil pH_{Ca}	ECEC	Exchangeable Ca	Mg	Al	Al_{Ca}	Mn_{Ca}
			(cmol(+)/kg)				(mg/kg)	
			Site 1 Bisinella					
Control	4.70	3.94	3.96	0.56	0.30	2.86	37.4	29.8
Lime 1 t/ha	4.93	4.09	4.09	1.14	0.37	2.28	20.9	26
Lime 2 t/ha	5.05	4.23	4.35	1.84	0.37	1.84	13.3	20.5
Lime 4 t/ha	5.47	4.62	5.03	3.60	0.43	0.74	2.9	19.2
Lime 8 t/ha	6.19	5.49	7.67	7.03	0.38	ND[A]	<0.25	6.4
Gypsum 3.75 t/ha	4.72	4.01	3.90	0.96	0.24	2.32	28.8	24.1
Lime 2 t/ha + Gypsum 3.75 t/ha	4.81	4.24	5.47	3.04	0.35	1.77	10.6	15.5
			Site 2 Trevor					
Control	4.75	4.00	11.54	1.80	1.78	6.90	46.5	12.0
Lime 1 t/ha	4.84	4.10	11.45	2.57	1.85	5.92	30.2	10.2
Lime 2 t/ha	4.97	4.21	11.66	3.64	2.02	4.92	18.6	10.3
Lime 4 t/ha	5.14	4.36	12.04	5.35	1.75	3.91	10.5	7.5
Lime 8 t/ha	5.48	4.70	13.18	8.8	1.69	1.69	2.47	4.2
Gypsum 3.75 t/ha	4.71	4.04	11.88	2.64	1.37	6.96	42.8	9.8
Lime 2 t/ha + Gypsum 3.75 t/ha	4.95	4.24	11.61	4.22	1.51	4.89	17.1	7.5
			Site 3 Savimaki					
Control	4.71	4.17	1.55	0.08	0.04	1.49	27.6	1.2
MgO 0.072 t/ha	4.83	4.22	1.65	0.11	0.09	1.46	24.6	1.6
Ca/Mg blend 0.5 t/ha	5.05	4.29	1.52	0.28	0.08	1.15	16.9	1.8
Ca/Mg blend 1 t/ha	5.33	4.47	1.75	0.64	0.20	0.87	9.8	1.8
Ca/Mg blend 2 t/ha	5.78	4.88	2.10	1.29	0.36	0.37	3.4	1.2
Ca/Mg blend 4 t/ha	6.39	5.55	3.49	2.61	0.76	ND[A]	1.2	0.8
Lime 1.13 t/ha	5.21	4.37	1.67	0.58	0.05	1.01	13.6	2.0
Lime 4.5 t/ha	6.33	5.43	2.96	2.74	0.06	ND[A]	1.6	1.0
MgO 0.23 t/ha + Gypsum 0.68 t/ha	5.15	4.33	1.84	0.35	0.24	1.23	16.8	2.0
MgO 0.23 t/ha	5.24	4.31	1.35	0.10	0.21	0.99	15.2	1.8
Filter mud/ash	5.10	4.22	1.57	0.19	0.09	1.21	20.4	1.6
			Site 4 Colley					
Control	4.78	4.08	3.06	0.48	0.32	1.67	21.5	145
Lime 1 t/ha	4.88	4.20	3.05	0.93	0.36	1.14	10.3	146
Lime 2 t/ha	4.92	4.32	3.45	1.51	0.32	0.82	6.4	105
Lime 4 t/ha	5.49	4.81	4.29	3.12	0.41	0.24	0.9	53.4
Lime 8 t/ha	6.05	5.45	5.90	5.01	0.33	0.04	0.3	26.8

[A] Not detectable

When averaged across all soils, the pH increase per tonne of lime was about 0.2 pH units. Until the commencement of this project extensive lime rate trials had not been undertaken on caneland in southern Queensland. Information on the magnitude of the pH increases to be expected from liming soils in the region has been forwarded to extension officers. Although sugarcane is tolerant of low pH, the pH increases expected from amendment application are of immediate relevance to cane producers who practice multiple cropping. In these situations producers wish to apply amendment with the aim of achieving a target pH suitable for crops other than sugarcane. The pH increases per unit of added lime are also of interest to producers given a recently emerged problem regarding the reduced effectiveness of chlorpyrifos at elevated pH values. Values in Table 14 may be used as a guide to ensure that lime application does not increase the pH above that considered too high (>pH 6 to 6.5) for chlorpyrifos effectiveness. It should be noted that the pH increases would need to be modified if amendments of different neutralising value were to be used.

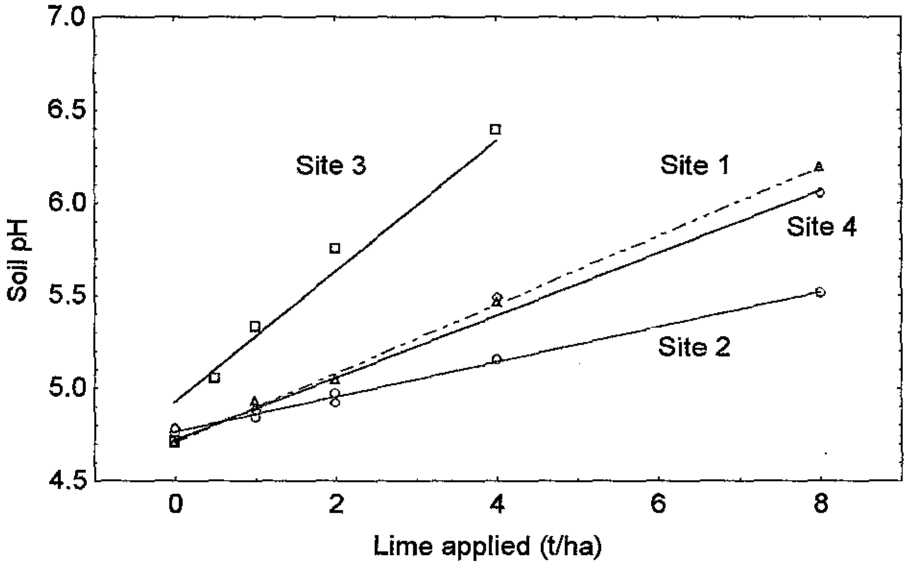

Figure 8. The relationship between soil pH (0-10 cm depth) and rate of applied lime at each of four field trial sites.

Table 14. Soil pH buffer capacity (0-10 cm depth) at each site

Site	Soil type	pH buffer capacity (pH change/t lime)
1	Yellow podzolic	0.19
2	Humic gley	0.09
3	Humus podzol	0.36
4	Gleyed podzolic	0.17

Treatments combining lime (2 t/ha) and gypsum (3.75 t/ha) at Sites 1 and 2 when compared to the application of 2 t lime/ha resulted in similar soil pH values, a higher soil Ca status (as expected) and only minor differences in Al and Mn status (Table 13). Although the soil Ca concentrations (0-10 cm depth) in the lime plus gypsum treatments were slightly lower than those in the 4 t lime/ha treatments (equivalent Ca applications, Sites 1 and 2, Table 13), all Ca levels were more than adequate for sugarcane. However, at Site 1 which was responsive to the addition of Ca, a combination of lime and gypsum gave the best plant cane yields (Table 4).

Increases in effective cation exchange capacity (ECEC) resulted from the application of amendments which increased soil pH (Table 13). The increase in nutrient holding capacity was satiated almost entirely by calcium. Other studies have also demonstrated marked increases in ECEC following lime application (eg Edmeades 1982). However, Haysom *et al.* (1986) in examining the effects of lime on sugarcane soils in north

Queensland reported that, although pH increased, there was little or no change in ECEC at any of the sites. The present study has shown a curvilinear increase in ECEC with increasing lime rate (soil pH) in all soils (Table 4). Increases in soil pH as a result of lime application are well known to producers but the ability of lime to increase the soil's nutrient holding capacity is a benefit that is not widely recognised. The increased ECEC has the potential to hold nutrients in the root zone and reduce the likelihood of loss through leaching. However, results to date provide no evidence that the increased ECEC is utilised by nutrients other than Ca. Appendix 7 shows exchangeable Ca, Mg and K and ECEC data for three consecutive years after the application of lime at Site 1. Despite the maintenance of an increased ECEC there was no increase in exchangeable Mg or K. In other cropping situations, where fertilisers containing K are applied annually and tillage more frequent than for sugarcane production, increases in exchangeable K occupying the increased ECEC have been recorded three to four years after lime application (Aitken, unpublished data).

The concentration of extractable manganese in the unamended soil was considered high at Site 1 and extremely high at Site 4 (Table 13). As expected, liming reduced these concentrations but the pH values required to reduce manganese to negligible levels were higher than those required to reduce aluminium. There is little information on the relationship between soil manganese levels and crop response for sugarcane particularly where soil manganese concentrations may be toxic. The relationships between soil and leaf manganese concentrations arising from the present project are discussed in Section 6.3.1. It should be noted that the test used to measure soil Mn in this study is regarded as a suitable index of Mn toxicity for a range of crops (Hoyt and Nyborg 1971, Bromfield *et al.* 1983), but is not appropriate for identifying Mn deficiency. Current soil tests for manganese are not considered reliable for the identification of manganese deficiency in sugarcane (Calcino 1994). Extractable (0.01 M $CaCl_2$) Mn values >15-20 mg/kg have been found to be toxic to row crops such as wheat, soybean, barley and maize (Hoyt and Nyborg 1971, Dickson *et al.* 1995, Moody *et al.* 1995). Although cane yields were not responsive to lime application at Site 4, the extractable Mn value in unamended soil at this site (145 mg/kg, Table 13) is extremely high compared to values recorded for a range of Queensland soils (Moody *et al.* 1995).

6.4.2 Relationships between yield response and soil properties - predicting the need for amendment

The relationships between various soil tests and cane yield response across all sites was investigated to ascertain which soil parameter was governing the response to amendment. It was recognised that local environmental and soil physical conditions could have measurable effects on productivity and therefore relative cane yield was used as the measure of responsiveness to treatment with amendment. Calculation of these relative yields is described in Appendix 5.

Relative yields (plant cane) across all sites were then plotted against the respective soil test values for a range of soil parameters (Figure 9). Plotted points represent the average of individual treatments for each site (Appendix 8 shows plots of individual replicate relative yields against various soil tests). The relationships and coefficients of determination for Mitscherlich functions fitted to each, indicate that soil calcium concentrations were best related to yield response. That the lime responses are responses to calcium is supported by the finding that responses to gypsum were also recorded at sites responsive to lime (Table 4).

The finding that soil calcium levels best predict the response of sugarcane to lime supports earlier work by BSES in north Queensland (Hurney 1971, Haysom *et al.* 1986, Ridge *et al.* 1980). As expected, the good relationship between soil Ca and yield response obtained for the 0-10 cm depth (Figure 9a) also held for the 0-25 cm depth (Figure 10). For the suite of trial sites in the present project, 95% of maximum yield was associated with a soil calcium value (0-25 cm depth) of 0.68 cmol(+)/kg (Figure 10) and the results indicate that there would be little or no response to Ca amendment if the soil Ca status was above 1 to 1.5 cmol(+)/kg. If 90% relative yield is taken as the criterion for defining the soil Ca concentration then the relationships (Figures 9a and 10) indicate critical concentrations of 0.73 cmol(+)/kg (0-10 cm sampling depth) and 0.44 cmol(+)/kg (0-25 cm sampling depth). Hurney (1987) obtained a critical value of 0.65 cmol(+)/kg for Ca (0-25 cm depth) in highly leached north Queensland canegrowing soils. This critical level was based on the BSES 0.02 M HCl extraction technique. Sample exchange and inter-laboratory calibration shows that 0.65 cmol(+)/kg in the BSES extractant is equivalent to 0.55 cmol(+)/kg 1 M NH_4OAc and 1 M NH_4Cl extractants used by Incitec Ltd, DPI, and DNR. Thus there is good agreement between the critical value of 0.44 cmol(+)/kg derived from this project and advice to industry. We can now be confident that the Ca soil test criterion is applicable to both tropical and sub-tropical soils.

The results also indicate that modeling the changes in soil calcium would be an appropriate way in which to predict the residual value of lime applications and the need for lime reapplication.

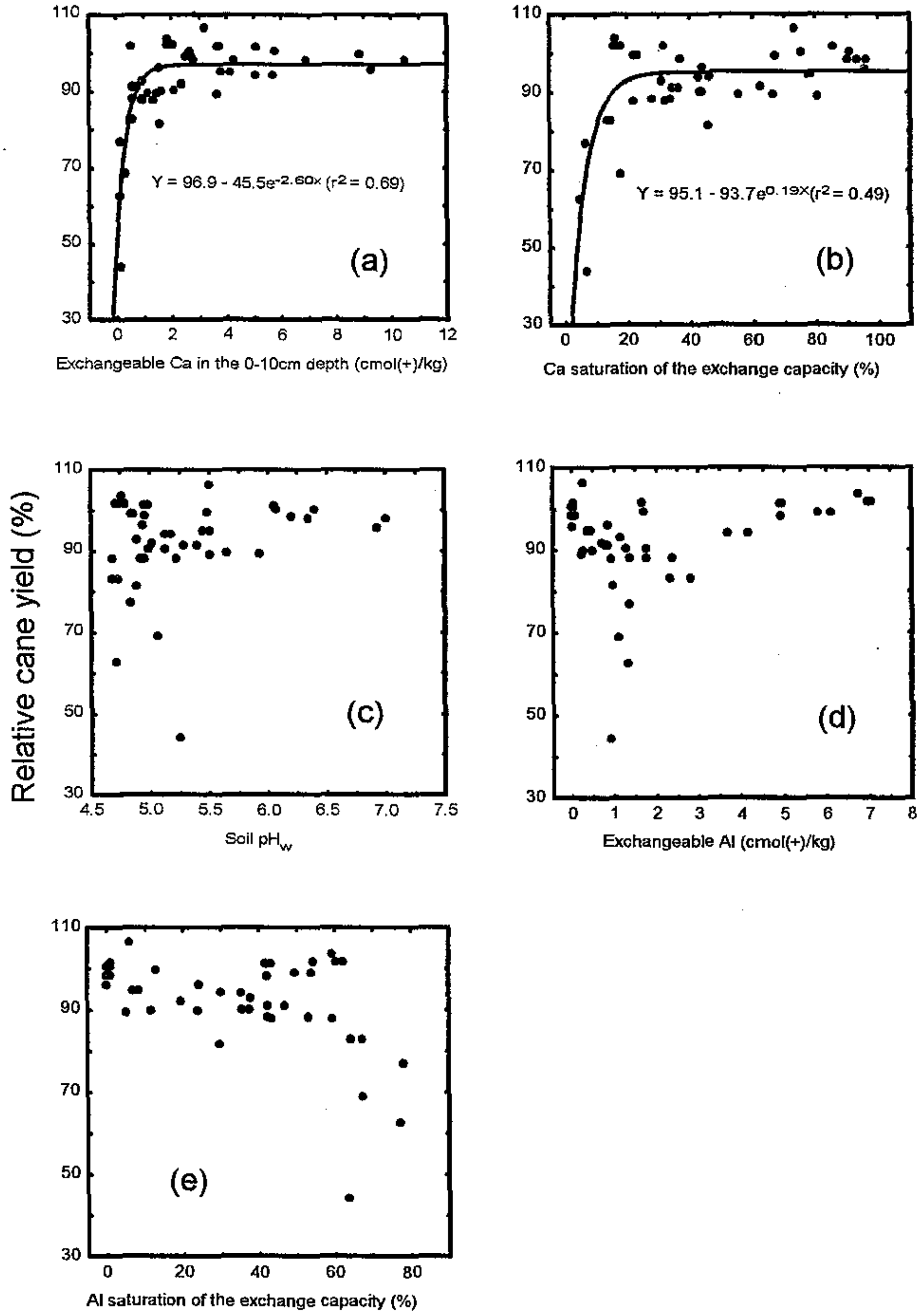

Figure 9. Relationships between relative cane yield and soil chemical tests (0-10 cm depth) across all sites and treatments.

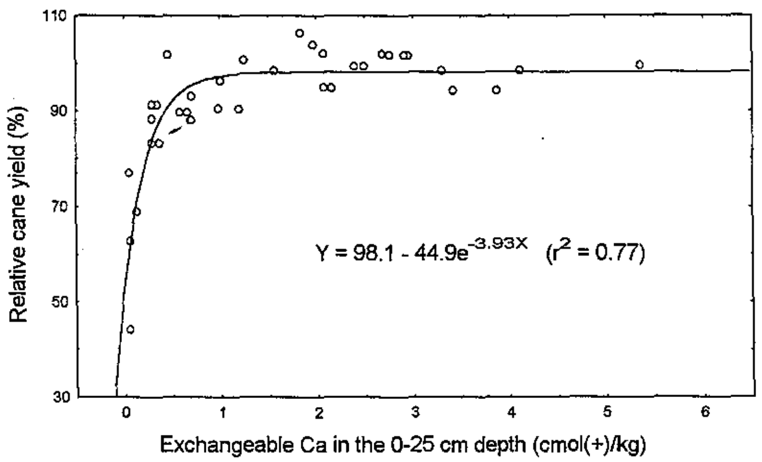

Figure 10. The relationship between relative cane yield (plant cane) and exchangeable Ca in the 0-25 cm depth.

6.4.3 Residual value of amendment - predicting the residual value of lime

The residual value of lime and gypsum treatments was assessed by using both yield and soil data. Since cane yields tend to decrease with each ratoon crop, the relative yield (treatment yield/control yield) was calculated for each successive crop and plotted against time. As it was also apparent that soil Ca concentrations were a good guide to the need for amendment application (Section 6.4.2), it was considered that the change in soil Ca with time after application should also be modelled.

Only data from Site 3 (significant treatment effects and yield data for each of three years) was used to undertake a preliminary examination of the residual value of selected amendments in relation to yield. All treatments maintained relative yields over the three years. For example, yields from the $CaCO_3$/MgO blend (4 t/ha) were 1.6 times that of the control in each of the three years (Table 4). Similarly, Filter mud/ash maintained its relative performance over three years. However, results from the 1996 harvest at Site 3 (part of project BS155), not reported here, show a marked decline in the relative yield of the Filter mud/ash treatment whereas the yield from $CaCO_3$/MgO blend remained at 1.6 times that of the control yield. This indicates the need for long term monitoring.

The increase in soil calcium in the 0-10 cm depth after 1 year (exchangeable calcium 1 year after amendment application minus initial soil calcium, cmol(+)/kg) could be predicted from the rate of calcium addition (Figure 11). The regression line (solid line, Figure 11) is very close to the theoretical line obtained by assuming that all of the added Ca is retained on the exchange complex in the depth of incorporation. This highlights the lack of substantial movement of Ca from the 0-10cm depth in the first year after application.

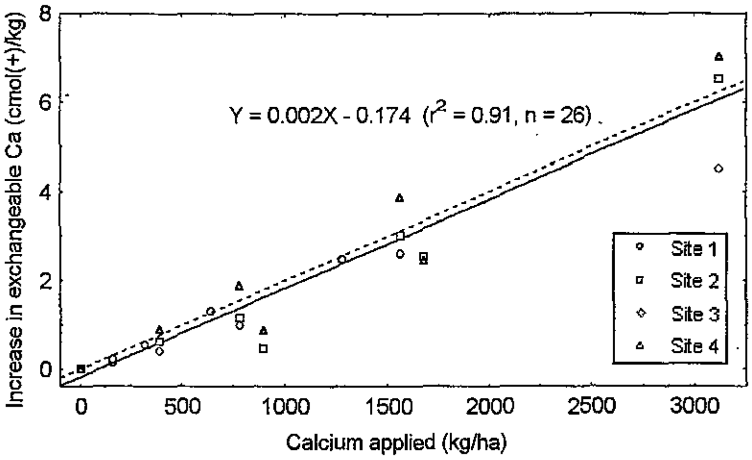

Figure 11. The relationship between rate of calcium addition and the increase in exchangeable Ca one year after amendment application for all sites and treatments. The broken line represents the theoretical line assuming that all added Ca is retained on the exchange complex.

The relationship obtained in Figure 11 indicates that the result of a soil test prior to amendment addition together with the rate of Ca added could be used to predict the soil's Ca status at harvest of the plant cane crop. This prediction, together with a model of the 'run down' in Ca over time will allow determination of the longevity of amendment effects and the appropriate time for reapplication. Further development of this approach and the inclusion of crop uptake and export of Ca in cane stalks will be examined in BS155 activities.

Conversely, this relationship (Figure 11) also allows prediction of the amount of amendment required to achieve a target exchangeable Ca value. For example, if a producer wishes to achieve a target exchangeable Ca concentration of 2 cmol(+)/kg and a soil test indicates that the Ca status is 0.9 cmol(+)/kg then the relationship (Figure 11) indicates that the Ca required is 640 kg/ha.

The effect of time after lime application (4t /ha) on soil pH_w and Ca (0-10cm depth) for selected rates of lime at each site is shown Figure 12. The effects of time after amendment application on soil properties for each treatment are presented in Appendices 9 to 18.

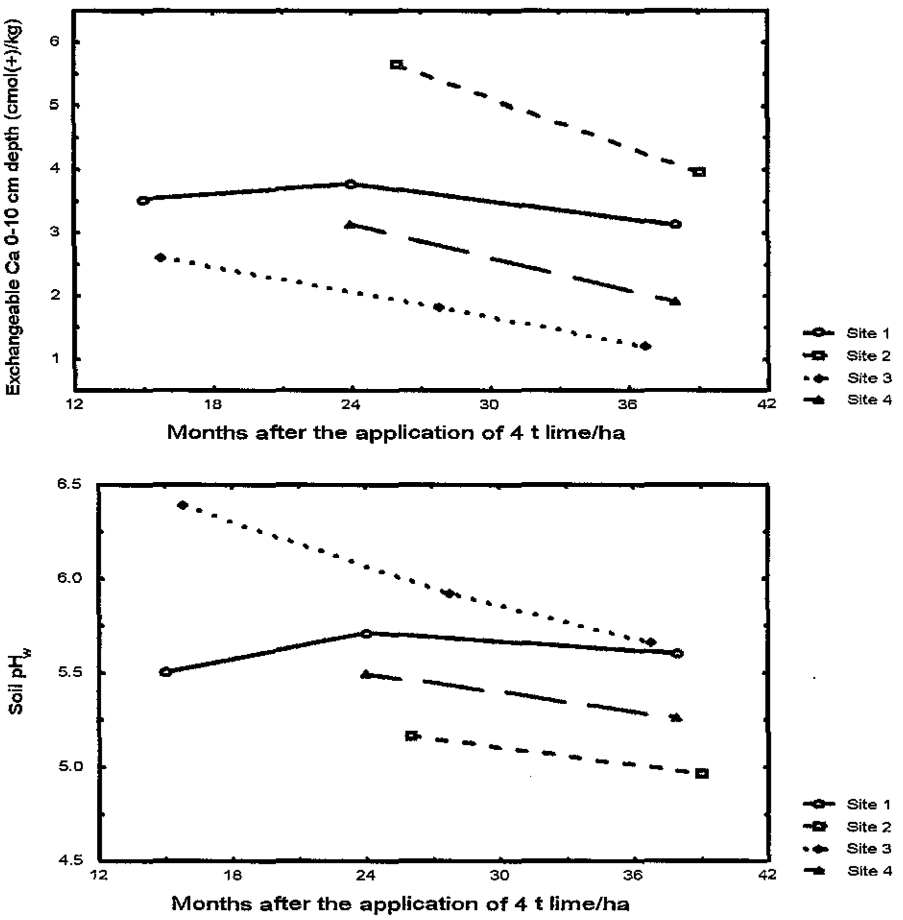

Figure 12. The effect of time after lime application (4 t/ha) on soil pH and exchangeable calcium (0-10 cm depth) at each site.

Data for only a limited period (two or three years) is currently available but Figure 12 shows that it is likely the attenuation of calcium can be modelled to allow prediction of the residual value of the amendment. When data for subsequent years are available (BS155) the rate of decrease in soil Ca will be related to soil properties to develop predictive relationships.

In general there was little change in soil Mg over time except where high rates of Mg were applied at Site 3 (Appendices 13 and 14). In this coarse textured soil exchangeable Mg decreased linearly but the rate of decline was less than that for Ca (Figure 13).

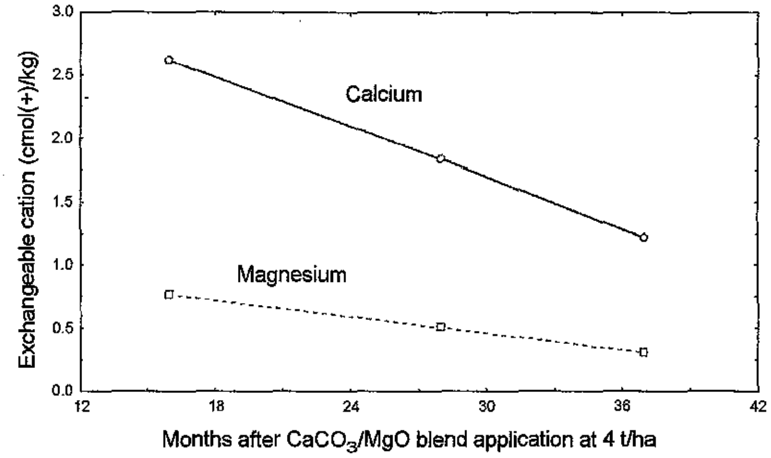

Figure 13. The change in exchangeable Ca and Mg concentrations with time after the application of 4 t CaCO3/MgO blend/ha at Site 3.

6.5 Effect of amendment on subsurface soil properties

The effect of lime (8 t/ha) and a combination of lime (2 t/ha) plus gypsum (3.75 t/ha) on soil profile properties 38 months after treatment application at Site 1 is shown in Figure 14. Lime (8 t/ha) resulted in minimal increases in pH_w (about 0.1 pH unit) in the 20-30 and 30-50 depth intervals after 38 months (Figure 14a). The ineffectiveness of lower rates of lime application on subsurface pH is highlighted by the absence of any increase in subsurface pH in the 2 t lime/ha treatment (Figures 14a and c). The lower pH_w values for the Lime plus Gypsum treatment are attributed to a salt effect on pH_w as a result of the leaching of the dissolution products from the gypsum. This is supported by the absence of any difference in pH_{Ca} values in the subsoil (Figure 14c). Despite an increase in exchangeable Ca there was no decrease in exchange acidity at depth (Figures 14b and e).

The observation that subsurface Ca concentrations in the Lime plus Gypsum treatment (equivalent Ca to that added in the 4 t lime/ha treatment) were similar to those in the 8 t lime/ha treatment (Figure 14b) is attributed to the greater solubility of gypsum. The lower Ca levels in the 0-10 cm depth in the Lime plus Gypsum treatments compared to the 4 t lime/ha treatments (Sites 1 and 2, Table 13) is further evidence that there was greater movement of Ca from the surface to the subsurface in the Lime plus Gypsum treatments. That the increases in subsurface Ca in the Lime plus Gypsum treatment are primarily due to the gypsum component is supported by the absence of any subsurface effect arising from the application of lime alone at 2 t/ha (Figure 15). Calcium concentrations in unamended soil were low throughout the profile at Site 1 (Figure 14b) and the movement of Ca into the subsurface may partially explain the fact that plant cane yields were highest for the Lime plus Gypsum treatment (Table 4). There is little doubt that low application rates of lime (eg 2 t/ha) had a minimal impact on subsurface chemical properties at this site.

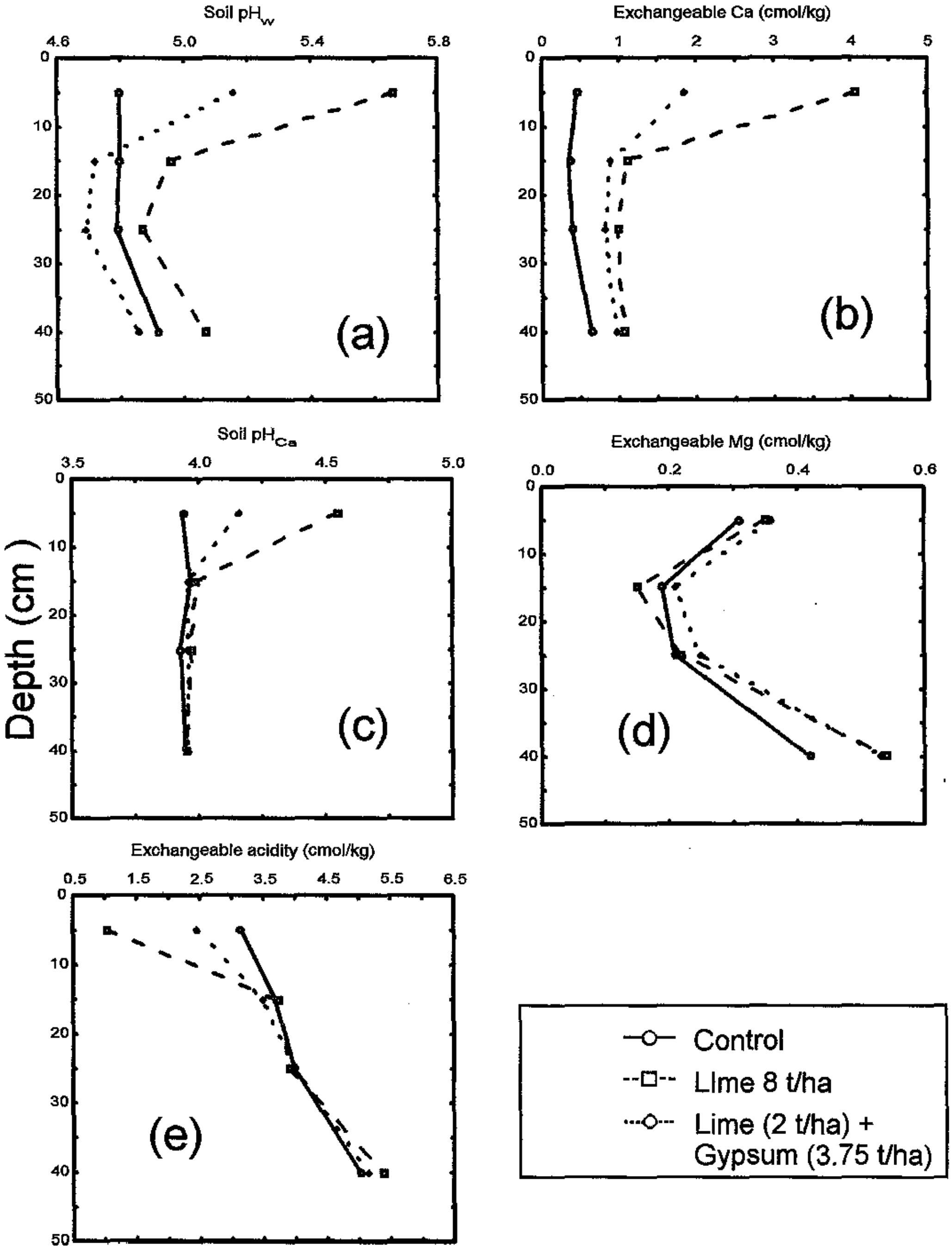

Figure 14. The effect of lime and lime plus gypsum treatments on soil profile chemical properties 38 months after application at Site 1.

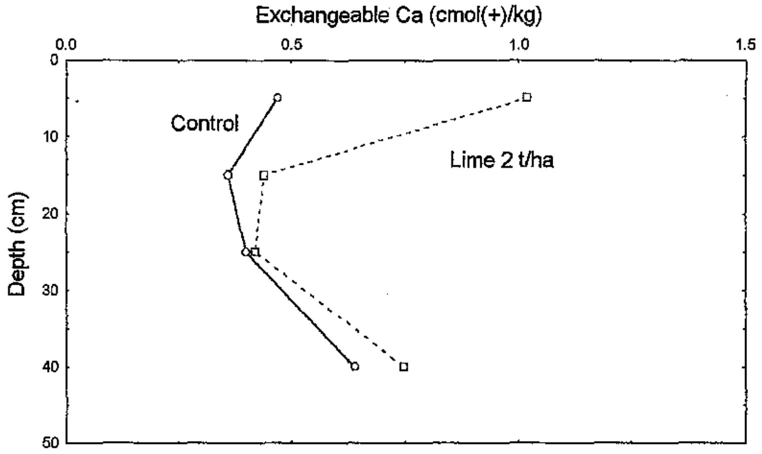

Figure 15. The effect of lime (2 t/ha) on soil profile Ca concentrations 38 months after application at Site 1.

At Site 4 there was little or no effect of lime below the 10-20 cm depth after 38 months for application rates of either 4 or 8 t/ha (Figure 16). Similarly, at Site 2 which had a high clay and organic matter levels (Table 1, Appendix 1), there was little effect of lime on pH and acidity below the 10-20 cm depth (data not shown).

The soil at Site 3 was very sandy (about 90% sand) with an annual rainfall of 1570 mm and, of all the sites studied, it would be conducive to leaching of the reaction products of lime into the subsurface soil. Application of the $CaCO_3/MgO$ blend at 4 t/ha and lime at 4.52 t/ha (equivalent in neutralising value to 4 t $CaCO_3/MgO$ blend/ha) at Site 3 resulted in pH_w increases of around 0.1 to 0.3 pH units in the 30-50 and 50-70 cm depths after 2 to 3 years (Figures 17a and 18a). However, increases in exchangeable Ca at these depths were minimal (Figures 17b and 18b) possibly due to the very low cation exchange capacity of the subsurface soil at this site (Appendix 1). After 37 months, lime (4.52 t/ha) had caused a more than 10 fold increase in exchangeable Ca in the 0-10 cm depth but exchangeable Ca at 30-50 cm was only 0.1 cmol/kg. Although exchangeable acidity in the surface was reduced by amendment there were only small reductions in acidity at 30-50 cm and no change at 50-70 cm (Figures 17e and 18e).

It has been suggested by some sections of the industry that lime can be rapidly leached from sandy soils in the Moreton region. The elevated soil pH and Ca levels in the surface soil at Site 3 after three years (Figures 17 and 18) is contrary to this belief.

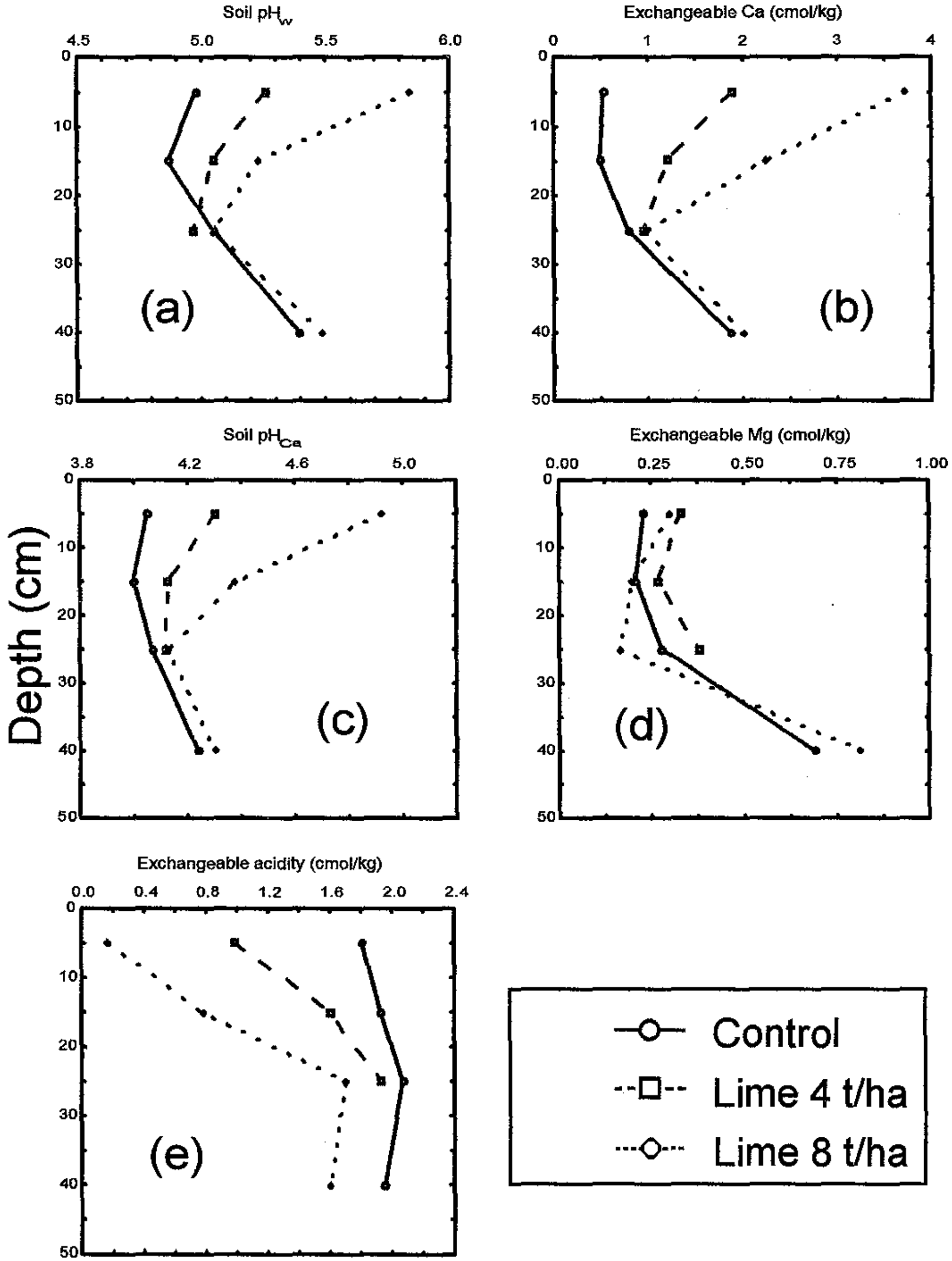

Figure 16. The effect of selected lime treatments on soil profile chemical properties 38 months after application at Site 4.

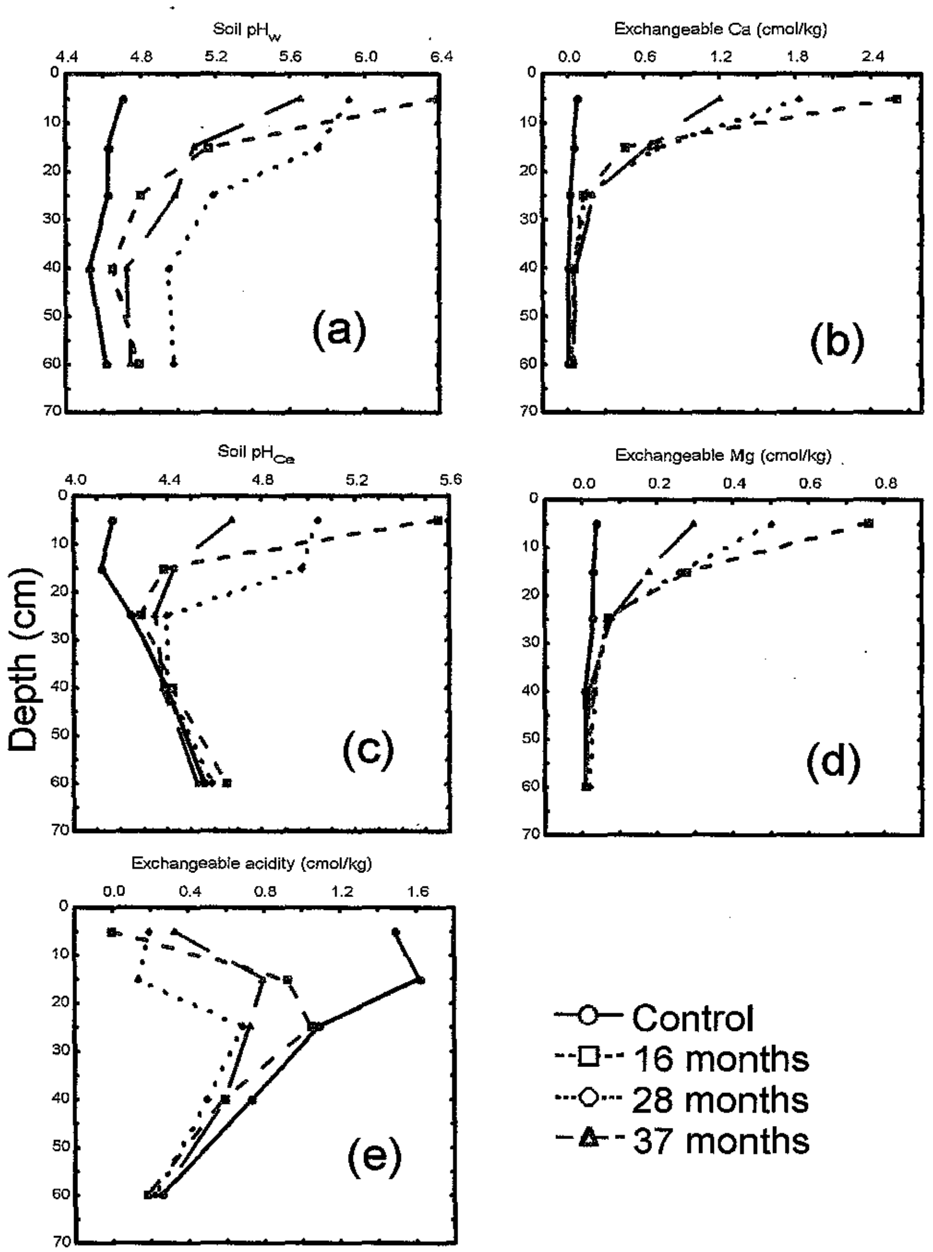

Figure 17. The effect of a $CaCO_3/MgO$ blend (4 t/ha) on soil profile properties at 16, 28 and 37 months after treatment application at Site 3.

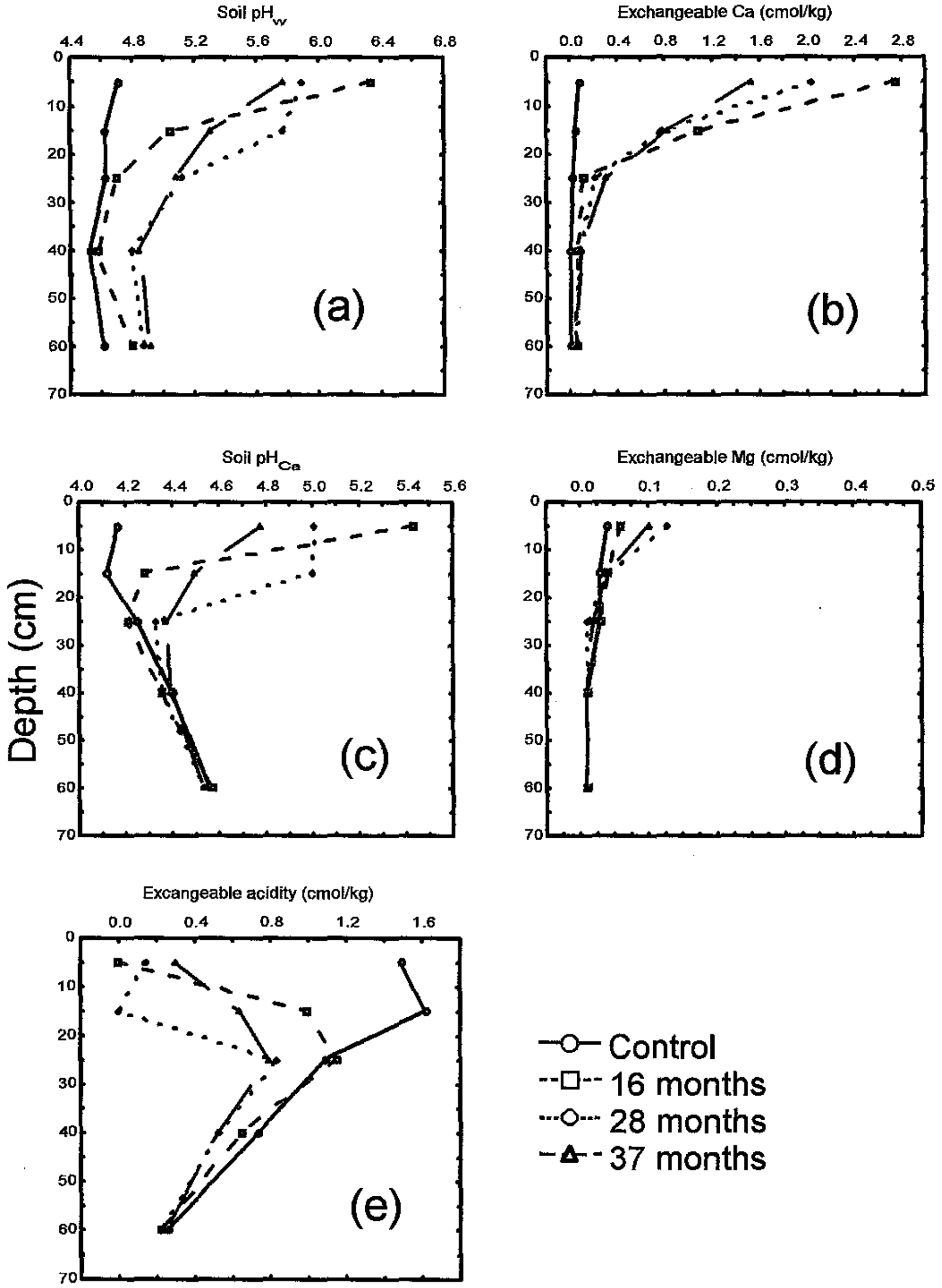

Figure 18. The effect of lime (4.52 t/ha) on soil profile properties at 16, 28 and 37 months after treatment application at Site 3.

The role of MgO in the blend as a supply of available Mg is evident from Figure 17d. The small increase in exchangeable Mg in the 0-10 cm depth from the application of 4.52 t lime/ha (Figure 18d) is attributed to the fact that this lime contains 0.3% Mg.

When the $CaCO_3$/MgO blend and lime were applied at equivalent neutralising values (4 and 4.52 t/ha, respectively) there was little difference in the soil pH_w increases observed (Table 15). A comparison of the effects of these two amendments on soil profile properties is given in Figure 19. Although no detailed study was undertaken, the results suggest that, for equivalent neutralising rates, a blend of MgO and lime gave no observable advantage in ameliorating acidity at depth compared to lime. However, differing degrees of fineness of the two amendments complicate the comparison and may explain the small differences observed (Table 15, Figure 19a). The lime was 98% <0.25mm whereas the $CaCO_3$/MgO blend was 45% <0.25mm The capacity of the blend to supply Mg has been previously discussed.

Table 15. The increase in soil pH (treatment pH - control pH) after 37 months at various depths for a $CaCO_3$/MgO blend and lime applied at equivalent neutralising rates at Site 3.

Depth	pH_w increase		pH_{Ca} increase	
(cm)	$CaCO_3$/MgO blend	Lime	$CaCO_3$/MgO blend	Lime
0-10	0.80	0.91	0.45	0.55
10-20	0.20	0.41	0.20	0.27
20-30	0.20	0.30	0.02	0.05
30-50	0.11	0.22	0.05	0.06
50-70	0.09	0.26	0.02	0.03

At Site 3 a combination of MgO and gypsum (equivalent in NV and Ca to that of the 0.5 t $CaCO_3$/MgO blend/ha) resulted in plant cane yields markedly higher than those from the treatment with 0.5 t $CaCO_3$/MgO blend/ha (Table 4). This increased yield was attributed to the greater solubility of the gypsum as sulphur levels in leaf tissue were not deficient and similar in both treatments across years (Appendix 4c). The effect of the MgO/gypsum treatment on soil profile properties is shown in Figure 20.

The soils at Sites 1 and 4 are typical of the majority of soils supporting sugarcane in southeast Queensland. The results clearly demonstrate that typical rates of lime application will do little to correct subsurface acidity in the soils of the region.

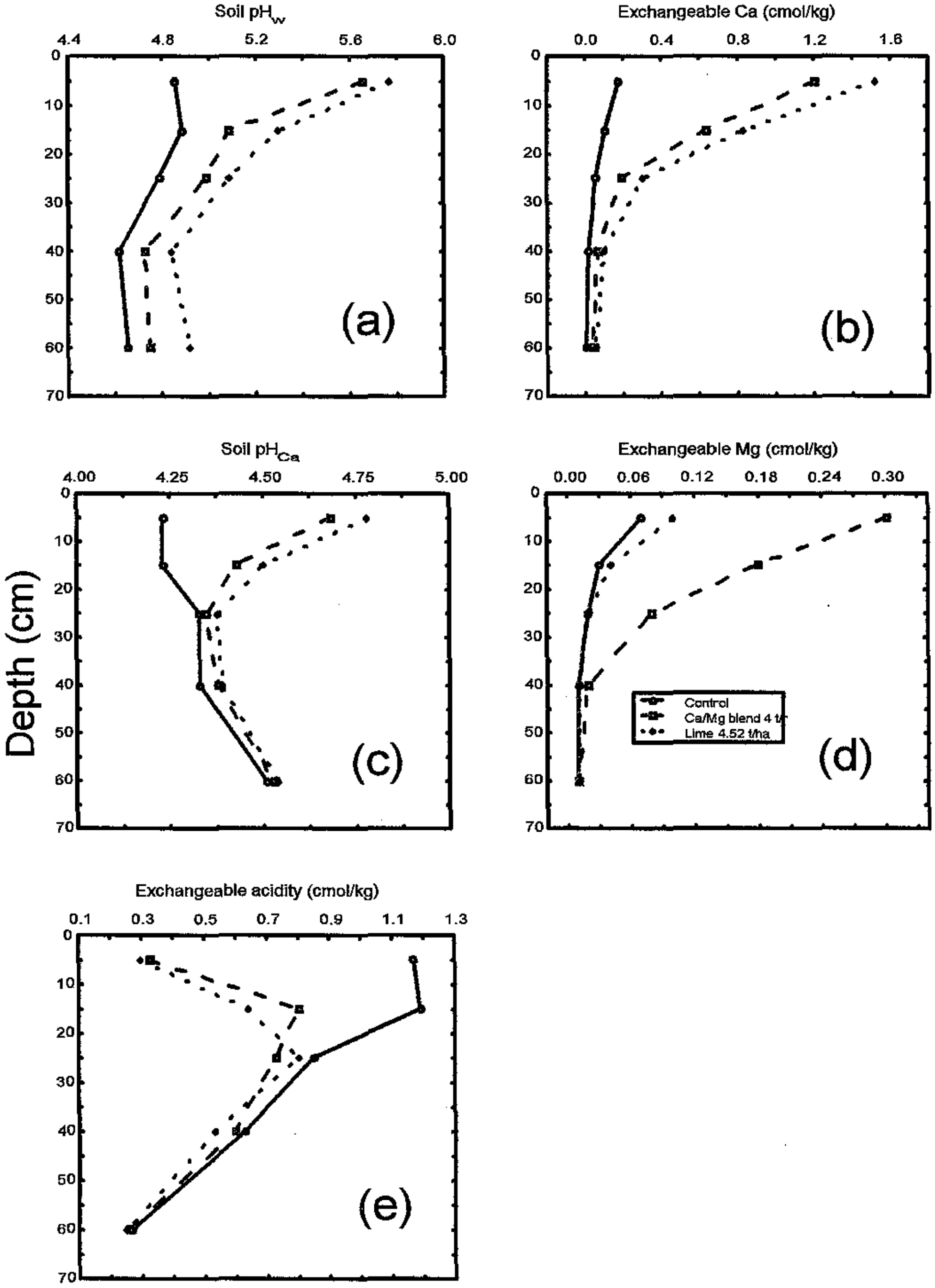

Figure 19. The effects of a $CaCO_3$/MgO blend (4 t/ha) and lime at an equivalent neutralising value (4.52 t/ha) on soil profile properties 37 months after application at Site 3.

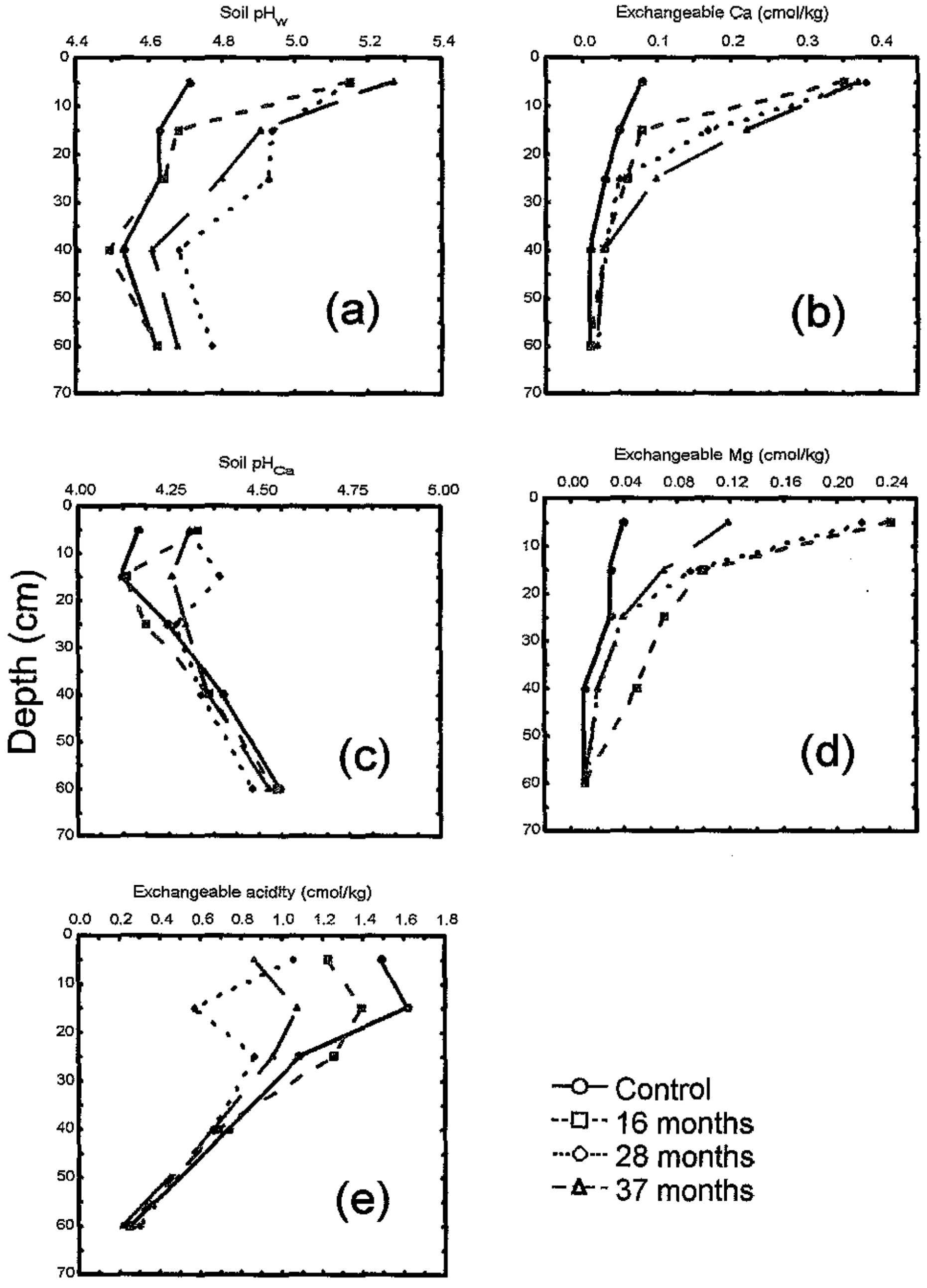

Figure 20. The effect of magnesium oxide plus gypsum on soil profile properties at 16, 28 and 37 months after treatment application at Site 3.

7. IMPLICATIONS AND RECOMMENDATIONS

7.1 Future research

The residual value of lime should be assessed on a time scale of more than one crop cycle, as this is the time base relevant to commercial use of lime. SRDC recognised this and agreed to fund this research for another four years as BS155. The new project will generate data to allow development of a soil based model to quantify the residual value of lime and to focus on a physiological mechanism for the often observed adverse effect of lime response on ccs.

The current project and the developing issue of degradation of chlorpyrifos at soil pH in the 6.0 to 6.5 range suggests need for increased focus on optimising blends of lime and gypsum to manage soil acidity and calcium nutrition in canelands. This is of particular importance where growers have multiple crop enterprises with different soil pH and calcium requirements. The current research team is well qualified to address this issue.

7.2 Difficulties

Difficulties were encountered in the 1993 harvest season as three of the four experiments were not harvested commercially because of the rain interrupted harvest season. Plant cane data were obtained by the sampling method from one of the three stand-over sites at the end of the 1993 season. In 1994 no yield data were obtained from Site 4 of the plant-standover experiments because a *run-away* cane fire caused un-scheduled harvest and there was not enough time to relocate the weigh truck. At Site 1 an old and underpowered harvester was unable to separate heavily lodged cane and cane was carried between plots in the harvester; these data were considered unreliable.

After second ratoon harvest at Site 4 a severe infestation of soldier fly was discovered in a large section of the Site 4 experiment. Second ratoon yield data will therefore be of no value, and first ratoon data must be viewed with caution. Soil data will still be of value.

8. INTELLECTUAL PROPERTY

No intellectual property of commercial significance arose from this project.

9. TECHNOLOGY TRANSFER

A significant level of technology transfer has occurred throughout this project.

- The Site 3 experiment was the focus for a field visit by international scientists attending the *Symposium on Plant - Soil Interactions at low pH* at Coolum in 1993;
- Drs Aitken and Kingston discussed results of the projects at BSES and Agri-Business field days, respectively, in the Moreton area in 1995 and Dr Aitken outlined southern districts' soil acidity research to a meeting of the Mourilyan Cane Protection and Productivity Board (November 1995). Presentations were supported by posters.
- Project work featured in a poster display on opening day of the CRC for Sustainable Sugar Production at James Cook University in Townsville;
- The following paper was presented to the 1996 ASSCT Conference at Mackay; *Kingston, G., Hurney, A.P. and Aitken, R.L. (1996). Depression of ccs in sugarcane after use of liming products: Economic significance and associations with soil chemistry and leaf nutrient composition. Proc. Aust. Soc. Sugarcane Technol. 18: 164-173.;*
- A poster paper *Differential response of sugarcane and maize to surface soil amelioration by Aitken, R.L., Kingston, G. and Dickson, T.* was presented to the Second National Conference on Acid Sulfate Soils at Coffs Harbour in September 1996;
- Results of soil pH change in response to lime application were distributed to BSES Extension staff.

10. FINANCIAL DETAILS

The project was funded from 1st July 1993 to 30th June 1996, with the following annual project allocations:

Year	Funding
1993/94	$53 610
1994/95	$52 230
1995/96	$52 230

11. ACKNOWLEDGEMENTS

We gratefully acknowledge the Sugar Research and Development Corporation for providing funding for this work. We thank Lime Products for providing the Ca/Mg blend used at Site 3 and David Mitchell Ltd for generously supplying the lime for these trials. The expert technical assistance of Monica Anink (BSES) and both Pat Victor and Bruce Compton (DNR) is appreciatively recognised. Our appreciation is also expressed to the cane growers on whose properties the trials were conducted.

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13. APPENDICES

Appendix 1. Soil and soil solution data for various depths at each site. Data are for composite samples of the respective depths taken from control (no lime) plots at the time of amendment application (August 1992).

	GPS			Soil solution^{A}		Soil:water (1:5)		Soil: 0.01M calcium chloride (1:5)			Organic carbon	Clay	Silt	Sand	ECEC	Exchangeable	
Site	Lat. S	Long E	Depth (cm)	pH	EC (mS/cm)	pH	EC (mS/cm)	pH	Extractable Al^{B} (mg/kg)	Extractable Mn^{B} (mg/kg)	(%)	(%)	(%)	(%)	(cmol/kg)	Ca (cmol/kg)	Al
1 Bisinella	26°35'02.1"	152°59'23.9"	0-10	4.01	0.52	4.78	0.04	3.92	54	21	-	27	39	34	3.96	0.46	2.86
			10-20	3.94	0.47	4.75	0.03	3.90	59	17	-	22	30	48	4.32	0.29	3.39
			20-30	3.90	0.48	4.69	0.03	3.89	63	17	-	22	30	48	4.10	0.24	3.30
2 Trevor	26°34'40.3"	153°02'27.6"	0-10	4.05	1.72	4.84	0.16	4.08	40	11	4.8	36	32	32	11.54	1.80	6.90
			10-20	4.08	1.26	4.81	0.15	4.08	41	11	3.3	36	31	33	11.83	1.88	6.93
			20-30	4.12	1.43	4.78	0.19	4.12	33	12	2.7	37	29	34	12.92	2.47	5.96
3 Savimaki	26° 35' 38.1"	153o 04' 26.0"	0-10	4.36	0.27	5.15	0.02	4.17	25	<0.2	1.1	8	3	89	1.55	0.08	1.49
			10-20	4.45	0.20	5.09	0.01	4.16	27	<0.2	1.4	8	4	88	1.62	0.05	1.62
			20-30	4.39	0.20	4.97	0.02	4.20	27	<0.2	1.3	8	4	88	1.22	0.03	1.09
4 Colley	26°31'50.6"	152°56'13.2"	0-10	4.26	0.34	4.74	0.03	4.05	32	120	1.4	28	29	43	3.06	0.48	1.67
			10-20	4.26	0.32	4.80	0.03	4.06	31	113	1.3	26	29	45	3.19	0.42	1.95
			20-30	4.27	0.28	4.78	0.03	4.04	33	110	1.3	26	32	42	3.56	0.59	2.35

[A] Soil solution extracted from soil at field capacity (10 kPa matric suction) by centrifugation

[B] Extracted with 0.01M calcium chloride (1:5 soil:solution)

Appendix 2a. Effect of amendment on primary shoot population of H56-752 at Site 3 (humus podzol site) 56 days after planting.

Treatment		Shoots / 10 m of row	Homogenous groups * LSD (P<0.05)
No.	Description		
10	Lime 4.52 t/ha	35.5	a
13	Mud / ash 120 t/ha	29.0	a
8	Ca/Mg blend 4 t/ha	28.8	a b
5	Ca/Mg blend 4 t/ha	28.3	a b
11	MgO 0.23 t/ha + Gypsum 0.68 t/ha	25.3	b c
6	Ca/Mg blend 2 t/ha	25.3	b c d
7	Ca/Mg blend 2 t/ha	25.0	b c d
9	Lime 1.13 t/ha	22.8	b c d e
2	MgO 0.072 t/ha	22.5	b c d e
4	Ca/Mg blend 1 t/ha	19.3	c d e f
1	Control	18.0	d e f
3	Ca/Mg blend 0.5 t/ha	15.3	e f
12	MgO 0.23 t/ha	12.3	f

*Treatments followed by the same letter are not significantly different.

Appendix 2b. Effect of amendment on mature stalk populations in H56-752 plant cane at Site 3.

Treatment		Shoots / 10 m of row	Homogenous groups * LSD (P<0.05)
No	Description		
10	Lime 4.52 t/ha	108.5	a
8	Ca/Mg blend 4 t/ha	99.5	a b
11	MgO 0.23 t/ha + Gypsum 0.68 t/ha	94.3	a b
7	Ca/Mg blend 2t/ha	92.8	a b
6	Ca/Mg blend 2t/ha	92.5	b
5	Ca/Mg blend 1t/ha	91.8	b
13	Mud / ash 120 t/ha	88.3	b
4	Ca/Mg blend 1t/ha	87.5	b c
9	Lime 1.13 t/ha	87.3	b c
2	MgO 0.072 t/ha	87.3	b c
3	Ca/Mg blend 0.5 t/ha	71.8	c d
1	Control	69.8	d e
12	MgO 0.23 t/ha	54.0	e

*Treatments followed by the same letter are not significantly different.

Appendix 3. Differential response of sugarcane and maize to surface soil amelioration on an acid sulphate soil.

(A paper presented at the National Acid Sulfate Soils Conference, September 1996)

Although considerable attention has been given to off-site environmental impacts arising from the use of acid sulfate soils (ASS) for agriculture in Australia, there has been relatively less documentation of the effects of ASS on crop growth. Reghenzani and Haysom (1986) reported extremely poor growth of sugarcane due to ASS conditions in tropical north Queensland. However, many ASS are very productive for acid-tolerant crops such as sugarcane particularly where the surface 30 to 40 cm is relatively free from acidity or potential acidity. Recent studies have provided guidelines for the management of the watertable under sugarcane aimed at maximising productivity and minimising off-site environmental impacts. Maintenance of sulfidic subsurface material in a waterlogged state would allow sugarcane production without off-site environmental effects provided the surface soil is nonlimiting to growth. Management of these soils for agricultural production depends *inter alia* on identification of situations where amelioration of acidity in the surface soil would be beneficial to the crop. Results reported in this paper contrast the response of sugarcane and maize to the amelioration of the surface soil on an ASS in the Maroochy floodplain.

Sugarcane and maize were grown in separate field trials on a Hydrosol (Isbell 1996) in the Maroochy River floodplain in southeast Queensland. At both sites, grey-blue sulfidic clay with yellow mottles occurs at 25-35 cm depth and adjacent drains contain red-orange flocs. Selected properties of the unamended surface soils are given in Table 1. At each site the surface soil (0-10 cm depth) was amended with five rates of lime (0, 1, 2, 4 and 8 t ha^{-1}) or single rates of gypsum (3.75 and 2 t ha^{-1} at the sugarcane and maize sites, respectively). Amendments were broadcast onto plots (10 m by 9 m for sugarcane, 20 m by 6 m for maize) and mixed into the soil using rotary harrows at least six weeks prior to planting. A randomised block design with four replications of each treatment was used at each site. The lime used had a neutralising value of 98, a fineness rating (% < 0.25 mm) of 96.8% and a calcium content of 39%. The gypsum used comprised 96% $CaSO_4.2H_2O$ and 4% $CaCO_3$ and was 80% < 0.15 mm. Following the establishment of crops at each site, yield data were obtained by weighing machine (sugarcane) and using a 2-row header (maize). Grain yield of maize was determined on a 14% moisture basis. Relative yield was calculated as treatment yield x 100 / maximum yield.

Table 1. Soil properties.

Crop	Depth (cm)	Soil solution pH	Exchangeable cations (cmol(+) kg^{-1})		Organic carbon (%)
			Calcium	Aluminium	
Sugarcane	0-10	4.05	1.80	6.74	4.8
Maize	0-10	3.89	2.48	6.29	7.0

The yield of maize was extremely poor on the unamended soil and lime application resulted in a 83% increase in maize grain yield (Figure 1). Concentrations of 1M KCl extractable Al in unamended soil (0-10 cm depth) were similar at both sites (Table 1) but aluminium saturation was higher at the sugarcane site (Figure 1). Despite these Al levels, sugarcane yields were not significantly ($P<0.05$)

affected by lime treatment. Sugarcane and maize yields were not significantly ($P<0.05$) affected by gypsum application.

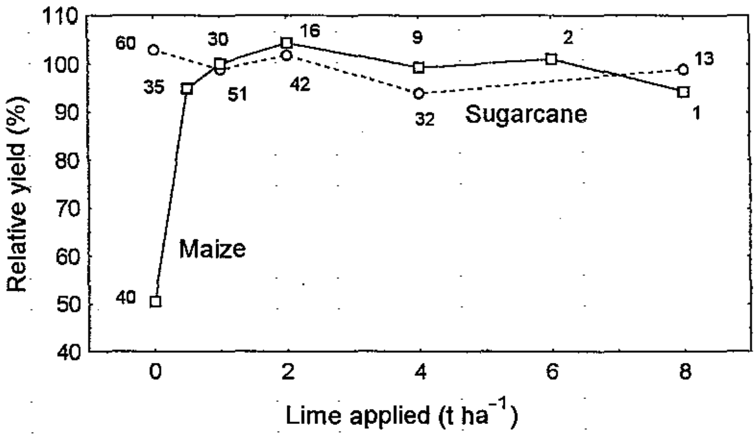

Figure 1. Effect of rate of applied lime on the relative yield of sugarcane (- - -) and maize (—) grown in an ASS on the Maroochy River floodplain. Aluminium saturation values are shown as data labels.

The increased maize yield as a result of lime application was due to the amelioration of aluminium toxicity in the surface soil and was achieved at economic application rates of lime. The absence of a sugarcane response to lime, despite the presence of phytotoxic aluminium, is attributed to the tolerance of sugarcane to aluminium (Hetherington *et al.* 1986) and to the adequate concentrations of calcium in the surface soil (Table 1). In non-sulfidic agricultural soils, sugarcane responses to lime are generally attributed to an increased supply of calcium rather than the amelioration of aluminium toxicity (Hurney 1987, Kingston and Aitken unpublished data). Calcium concentrations at both sites (Table 1) were above the value considered critical for sugarcane. It is suggested that where the surface soil is not excessively acidic ($pH_w > 4.0$), then the soil's calcium status would provide an index of the likelihood of a sugarcane yield response to lime application. Although the results presented highlight the tolerance of sugarcane to aluminium, they also demonstrate that amelioration would be required if less tolerant crops were to be grown on these soils.

More importantly, the management of the watertable will be critical to the long term effects of surface soil amelioration. In many situations the effects of surface liming these soils can be negated by oxidation of subsurface pyrite and a subsequent flooding event which brings large quantities of acid into contact with the limed soil. At the maize site, the pH_w of the 8 t lime ha^{-1} treatment was 5.8 (0-10 cm depth) five months after lime application. After a further 12 months, which included a flood following a dry period, the pH_w had decreased to 4.7. In contrast, over a 3 year period at the sugarcane site (not flooded) the pH_w for the 8t lime ha^{-1} treatment has remained at 5.2 to 5.5

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Appendix 4a. Nutrient content of leaf dry matter for plant and first ratoon crops of CP51-21 at Site 1 (Yellow podzolic) in relation to applied ameliorant.

Site 1 CP51-21 Plant cane 1993

Treatment - Reps	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Control - 4	2.29	0.32	1.11	0.15	0.25	0.17	5.8	18.6	85	234	27
Lime 1 t/ha -8	2.30	0.32	1.11	0.18	0.24	0.17	5.7	19.3	88	193	25
Lime 2 t/ha - 8	2.32	0.32	1.09	0.23	0.26	0.16	5.6	20.1	84	183	25
Lime 4 t/ha - 8	2.27	0.31	1.10	0.23	0.26	0.17	5.5	18.9	82	167	25
Lime 8 t/ha - 4	2.21	0.30	1.08	0.25	0.25	0.17	5.3	17.7	73	142	30
Gypsum 3.75 t/ha - 4	2.29	0.30	1.16	0.18	0.22	0.20	5.8	18.6	77	199	33
Lime 2 t/ha + Gypsum 3.75 t/ha - 4	2.22	0.30	1.19	0.25	0.23	0.21	5.6	18.9	72	156	21
LSD ($P<0.05$) 4 vs 4	NS	NS	0.09	0.04	NS	0.02	NS	NS	17	100	12
LSD ($P<0.05$) 8 vs 8	NS	NS	0.07	0.03	NS	0.01	NS	NS	12	71	8
LSD ($P<0.05$) 4 vs 8	NS	NS	0.08	0.03	NS	0.02	NS	NS	15	86	10

Site 1 CP51-21 First ratoon 1995

Treatment - Reps	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Control - 4	1.86	0.30	1.32	0.15	0.24	0.16	5.2	20	58	299	17
Lime 1 t/ha - 8	1.78	0.31	1.27	0.18	0.25	0.16	5.5	19	63	243	22
Lime 2 t/ha - 8	1.76	0.30	1.31	0.18	0.22	0.15	5.3	18	55	200	17
Lime 4 t/ha - 8	1.81	0.30	1.27	0.25	0.25	0.15	5.3	18	60	192	20
Lime 8 t/ha - 4	1.74	0.31	1.23	0.29	0.25	0.15	5.1	17	56	147	17
Gypsum 3.75 t/ha - 4	1.91	0.30	1.33	0.18	0.20	0.16	5.2	18	56	253	18
Lime 2 t/ha + Gypsum 3.75 t/ha - 4	1.97	0.30	1.22	0.25	0.21	0.17	5.6	18	56	180	18
LSD ($P<0.05$) 4 vs 4	NS	NS	0.10	0.04	0.04	0.01	NS	1.8	8	144	NS
LSD ($P<0.05$) 4 vs 8	NS	NS	0.07	0.03	0.03	0.01	NS	1.3	6	102	NS
LSD ($P<0.05$) 8 vs 8	NS	NS	0.09	0.03	0.04	0.01	NS	1.6	7	125	NS

Appendix 4b. Nutrient content of leaf dry matter for plant and first ratoon crops of Q110 at Site 2 (Humic gley) in relation to applied ameliorant.

Site 2 Q110 Plant cane 1993

Treatment - Reps	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Control - 4	1.90	0.23	1.16	0.12	0.20	0.15	6.0	18	85	108	29
Lime 1 t/ha - 8	1.93	0.24	1.14	0.13	0.19	0.16	6.2	18	91	104	30
Lime 2 t/ha - 8	1.89	0.23	1.20	0.13	0.19	0.15	6.2	19	93	104	26
Lime 4 t/ha - 8	1.85	0.23	1.17	0.14	0.18	0.15	6.3	19	93	99	30
Lime 8 t/ha - 4	1.83	0.24	1.20	0.14	0.18	0.15	6.0	19	78	94	27
Gypsum 3.75 t/ha - 4	1.85	0.24	1.21	0.12	0.18	0.16	6.2	19	173	103	29
Lime 2 t/ha + Gypsum 3.75 t/ha - 4	1.96	0.24	1.16	0.15	0.20	0.16	6.1	18	82	109	35
LSD (P<0.05) 4 vs 4	NS	0.01	NS	0.03	NS	0.01	NS	1.1	78	NS	NS
LSD (P<0.05) 4 vs 8	NS	0.01	NS	0.02	NS	0.01	NS	0.8	55	NS	NS
LSD (P<0.05) 8 vs 8	NS	0.01	NS	0.02	NS	0.01	NS	1.0	67	NS	NS

Site 2 Q110 First ratoon 1995

Treatment - Reps	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Control - 4	1.88	0.25	1.27	0.11	0.15	0.15	6.5	20	67	92	31
Lime 1 t/ha - 8	1.99	0.25	1.29	0.13	0.14	0.15	6.3	21	69	82	37
Lime 2 t/ha - 8	1.96	0.25	1.28	0.13	0.16	0.16	6.3	23	71	88	37
Lime 4 t/ha - 8	2.09	0.24	1.22	0.15	0.15	0.15	6.1	21	69	84	35
Lime 8 t/ha - 4	1.94	0.25	1.27	0.16	0.14	0.15	6.2	22	65	82	28
Gypsum 3.75 t/ha - 4	1.96	0.25	1.33	0.14	0.15	0.16	6.3	22	64	94	28
Lime 2 t/ha + Gypsum 3.75 t/ha - 4	1.82	0.26	1.34	0.14	0.14	0.16	6.3	21	66	83	32
LSD (P<0.05) 4 vs 4	0.15	0.02	0.10	0.02	0.02	0.01	NS	2.0	NS	NS	NS
LSD (P<0.05) 4 vs 8	0.11	0.01	0.07	0.01	0.01	0.01	NS	1.4	NS	NS	NS
LSD (P<0.05) 8 vs 8	0.13	0.02	0.09	0.02	0.02	0.01	NS	1.8	NS	NS	NS

Appendix 4c. Nutrient content of leaf dry matter for plant, first and second ratoon crops of H56-752 at Site 3 (Humus podzol) in relation to applied ameliorant.

Treatment - Reps	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Site 3 H56-752 Plant cane 1993											
Control - 4	1.79	0.21	1.09	0.11	0.09	0.14	6.6	20.7	195	105	47
MgO 0.072 t/ha - 4	1.86	0.22	1.06	0.11	0.14	0.14	6.6	19.6	136	87	44
Ca/Mg blend 0.5 t/ha - 4	1.80	0.20	1.04	0.15	0.12	0.13	6.4	19.8	121	79	40
Ca/Mg blend 1.0 t/ha - 8	1.76	0.21	1.07	0.16	0.13	0.13	6.4	17.5	189	55	38
Ca/Mg blend 2.0 t/ha - 8	1.76	0.21	1.04	0.17	0.15	0.13	6.2	16.5	135	47	40
Ca/Mg blend 4.0 t/ha - 4	1.75	0.22	1.11	0.16	0.16	0.13	6.2	15.0	160	33	35
Lime 1.13 t/ha - 4	1.79	0.20	1.09	0.19	0.08	0.13	6.4	18.5	129	67	38
Lime 4.52 t/ha - 4	1.76	0.21	1.12	0.25	0.07	0.13	6.0	14.8	154	36	37
Gypsum 0.68 t/ha + MgO 0.23 t/ha - 4	1.77	0.20	1.14	0.13	0.15	0.14	6.3	18.0	124	67	43
MgO 0.23 t/ha - 4	1.73	0.21	0.98	0.08	0.20	0.13	6.1	17.5	157	80	39
Filter mud/ash 120 t/ha - 4	1.76	0.21	1.35	0.14	0.11	0.13	5.6	15.2	79	68	41
LSD (P<0.05) - 4 vs 4	0.09	NS	0.09	0.02	0.02	0.01	0.5	1.6	90	13	8
LSD (P<0.05) - 8 vs 8	0.07	NS	0.06	0.02	0.01	0.01	0.3	1.1	63	9	6
LSD (P<0.05) - 4 vs 8	0.08	NS	0.07	0.02	0.01	0.01	0.4	1.4	78	11	7
Site 3 H56-752 First ratoon 1994											
Control - 4	1.40	0.20	1.09	0.11	0.08	0.11	5.5	16.4	137	56	27
MgO 0.072 t/ha - 4	1.47	0.20	1.13	0.12	0.10	0.11	5.1	16.0	127	57	27
Ca/Mg blend 0.5 t/ha - 4	1.42	0.21	1.09	0.17	0.10	0.11	5.5	17.4	127	54	28
Ca/Mg blend 1.0 t/ha - 8	1.49	0.22	1.04	0.17	0.12	0.11	5.7	18.2	113	58	25
Ca/Mg blend 2.0 t/ha - 8	1.45	0.22	1.03	0.19	0.13	0.11	5.4	16.3	91	49	23
Ca/Mg blend 4.0 t/ha - 4	1.43	0.23	1.01	0.20	0.15	0.11	5.1	14.9	81	40	20
Lime 1.13 t/ha - 4	1.46	0.21	1.12	0.17	0.08	0.11	5.1	15.2	126	55	27
Lime 4.52 t/ha - 4	1.46	0.21	1.01	0.25	0.07	0.11	5.3	19.6	80	44	21
Gypsum 0.68 t/ha + MgO 0.23 t/ha - 4	1.47	0.21	1.11	0.13	0.12	0.12	5.3	17.2	110	57	24
MgO 0.23 t/ha - 4	1.47	0.22	1.04	0.11	0.14	0.10	5.2	17.3	130	57	26
Filter mud/ash 120 t/ha - 4	1.61	0.24	1.14	0.16	0.11	0.12	5.6	14.3	142	75	28
LSD (P<0.05) - 4 vs 4	0.18	0.02	0.09	0.04	0.02	0.01	NS	4.6	33	12	3
LSD (P<0.05) - 8 vs 8	0.13	0.02	0.06	0.03	0.02	0.01	NS	3.3	23	9	2
LSD (P<0.05) - 4 vs 8	0.16	0.02	0.07	0.03	0.02	0.01	NS	4.0	29	10	2
Site 3 H56-752 Second ratoon 1995											
Control - 4	1.82	0.28	1.21	0.11	0.08	0.13	6.3	16.4	57	64	43
MgO 0.072 t/ha - 4	1.92	0.30	1.21	0.13	0.10	0.14	6.5	15.6	57	77	41
Ca/Mg blend 0.5 t/ha - 4	1.75	0.28	1.20	0.13	0.08	0.12	5.8	14.4	53	51	34
Ca/Mg blend 1.0 t/ha - 8	1.74	0.28	1.18	0.15	0.08	0.13	5.9	15.4	55	44	36
Ca/Mg blend 2.0 t/ha - 8	1.77	0.29	1.17	0.17	0.09	0.13	5.7	13.9	52	39	30
Ca/Mg blend 4.0 t/ha - 4	1.72	0.28	1.16	0.19	0.10	0.12	5.5	14.1	51	29	28
Lime 1.13 t/ha - 4	1.74	0.28	1.20	0.16	0.07	0.13	6.0	14.6	58	54	29
Lime 4.52 t/ha - 4	1.91	0.28	1.14	0.25	0.06	0.13	5.7	12.6	56	31	30
Gypsum 0.68 t/ha + MgO 0.23 t/ha - 4	1.75	0.28	1.23	0.13	0.10	0.13	6.1	15.0	55	49	33
MgO 0.23 t/ha - 4	1.82	0.28	1.11	0.10	0.11	0.13	6.0	15.5	52	57	31
Filter mud/ash 120 t/ha - 4	1.95	0.32	1.28	0.12	0.08	0.13	5.9	14.5	88	73	32
LSD (P<0.05) - 4 vs 4	0.17	0.02	0.10	0.03	0.01	0.01	0.4	2.0	16	13	12
LSD (P<0.05) - 8 vs 8	0.12	0.01	0.07	0.02	0.01	0.01	0.3	1.4	11	10	8
LSD (P<0.05) - 4 vs 8	0.15	0.01	0.08	0.03	0.01	0.01	0.4	1.7	14	12	10

Appendix 4d. Nutrient content of leaf dry matter for plant and first ratoon crops of Q110 at Site 4 (Gleyed podzolic) in relation to applied ameliorant.

Site 4 Q110 Plant cane 1993

Treatment	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Control	2.05	0.23	1.27	0.13	0.12	0.13	4.7	17	79	247	25
Lime 1 t/ha	2.05	0.23	1.38	0.15	0.12	0.14	4.2	16	72	233	29
Lime 2 t/ha	2.02	0.23	1.35	0.15	0.12	0.14	4.2	16	70	207	23
Lime 4 t/ha	2.01	0.22	1.28	0.18	0.13	0.14	4.3	15	80	196	30
Lime 8 t/ha	2.00	0.23	1.30	0.18	0.11	0.14	4.5	16	80	205	28
LSD (P<0.05)	NS	0.01	0.09	0.04	0.02	0.01	NS	1.6	NS	36	NS

Site 4 Q110 First ratoon 1995

Treatment	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn	Al
	%						mg/kg				
Control	1.74	0.22	1.31	0.11	0.11	0.14	5.2	18	53	306	26
Lime 1 t/ha	1.72	0.22	1.36	0.14	0.11	0.14	5.0	20	60	254	29
Lime 2 t/ha	1.78	0.22	1.33	0.17	0.13	0.14	5.0	18	65	217	28
Lime 4 t/ha	1.67	0.21	1.26	0.18	0.12	0.13	4.7	22	63	172	28
Lime 8 t/ha	1.72	0.23	1.33	0.21	0.12	0.14	4.7	21	64	172	26
LSD (P<0.05)	NS	0.02	0.09	0.02	0.02	0.01	NS	3.4	6	74	NS

Appendix 5. Calculation of relative cane yield.

At each responsive site, cane yield was plotted against the rate of lime applied (see Figure A5 below). A Mitscherlich equation was statistically fitted to the relationship and the maximum yield taken as that defined by the Mitscherlich function (see below). The yield of each treatment was then expressed as a percentage of the maximum yield to give relative yield.

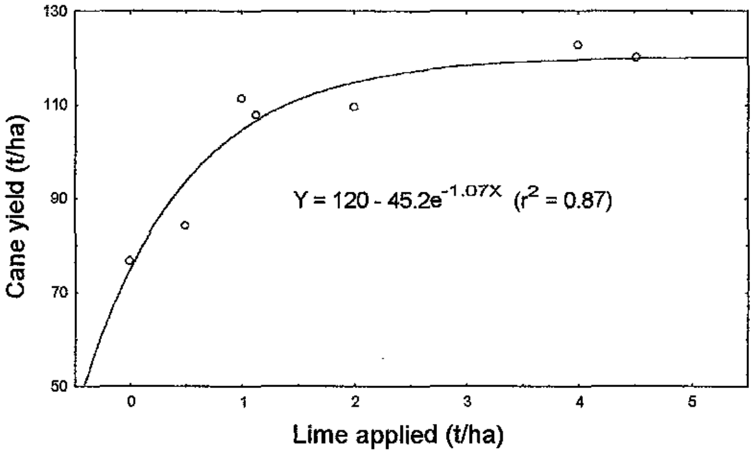


Figure A5. The relationship between cane yield and the rate of applied lime at Site 3.

The Mitscherlich function takes the form $Y = A - Be^{-CX}$; A represents the maximum yield (120 t/ha in the above example), B is the yield response (maximum yield - yield without amendment, 45.2 t/ha in the above example) and C is the curvature coefficient (the rate at which maximum yield is approached).

The Mitscherlich model cannot cope with yields which decrease beyond the maximum such as might be obtained by a lime-induced micronutrient deficiency or a nutrient toxicity. However, this model is popular because model constants have biological meaning and can be used directly in the calibration of soil and plant tests.

Appendix 6. Relationships between exchangeable Ca in 0-10 cm and 0-25 cm depths.

There was a very strong linear relationship between exchangeable Ca concentration in the 0-10 cm depth and that in the 0-25 cm depth at each of Sites 1, 3 and 4 (Figures A6.1a, c and d). At these sites, Ca concentrations in the 0-25 cm depth were approximately half that in the 0-10 cm depth reflecting the decrease in exchangeable Ca with depth. The relationship was not as good at Site 2 (Figure A6.1b) which had a high clay status (humic gley) and relatively high calcium concentration throughout the surface 30 cm. There was also a strong linear relationship across sites (Figure A6.2) although Site 2 data, because of a high Ca status in the subsurface soil, tended to lie outside the relationship for Sites 1, 3 and 4.

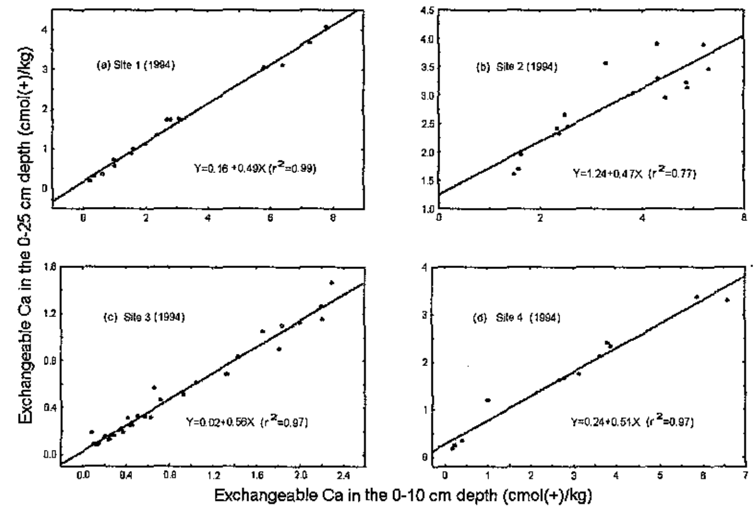


Figure A6.1 The relationship between Ca concentration in the 0-10 cm depth and that in the 0-25 cm depth at (a) Site 1, (b) Site 2, (c) Site 3 and (d) Site 4 for soil data obtained in 1994. All units are cmol (+)/kg soil.

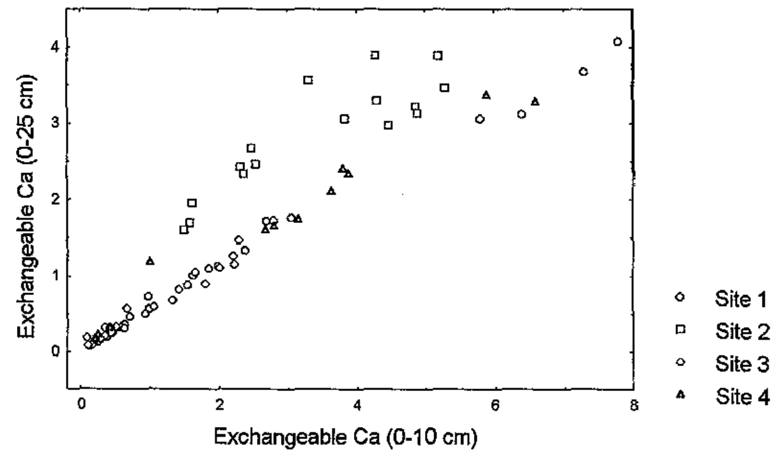


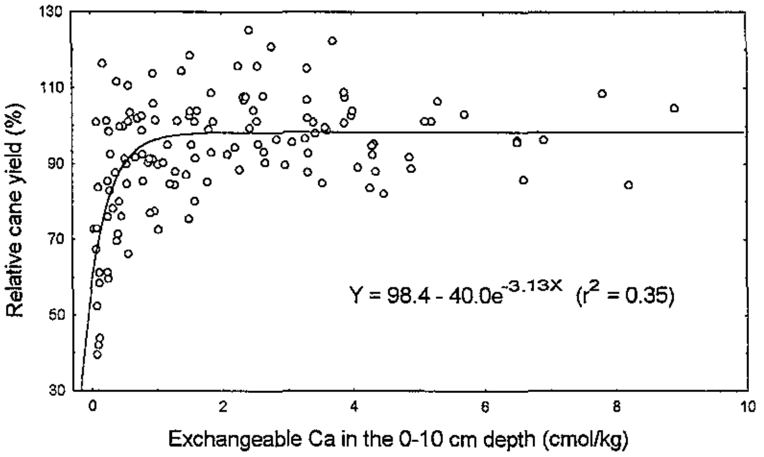
Figure A6.2 The relationship between Ca concentration in the 0-10 cm depth and that in the 0-25 cm depth for all sites (data from the 1994 sampling). All units are cmol(+)/kg soil.

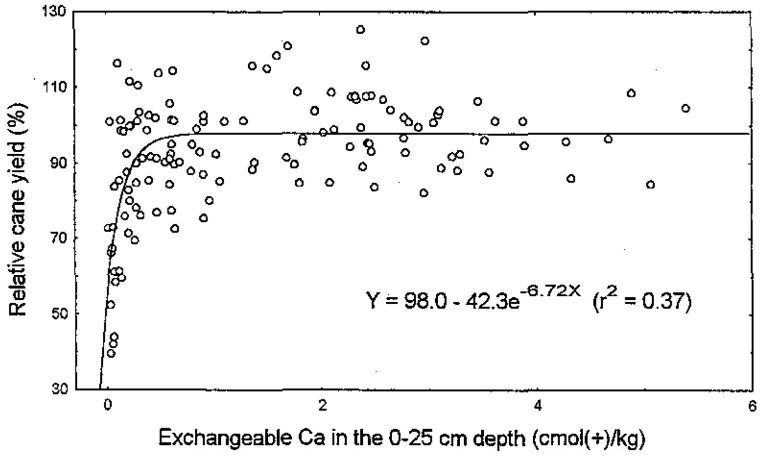
Appendix 7. Exchangeable Ca, Mg, K and ECEC (0-10 cm depth) at various times after the application of lime (8 t/ha) at Site 1.

Parameter		Months after lime application		
		15	24	38
Ca	cmol(+)/kg	7.03	6.82	4.07
	% saturation	92	90	72
Mg	cmol(+)/kg	0.38	0.43	0.35
	% saturation	5	6	6
K	cmol(+)/kg	0.17	0.16	0.14
	% saturation	2	2	3
ECEC	cmol(+)/kg	7.67	7.57	5.68

ECEC = Effective Cation Exchange Capacity

Appendix 8. Relationships between relative cane yield (plant cane) and exchangeable Ca in the 0-10cm and 0-25 cm depths. Plotted points represent individual replicates of treatments across all sites





Appendix 9. Mean soil pH_w values (0-10 cm depth) at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	4.70	4.78	4.83
Lime 1 t/ha	4.93	5.00	5.06
Lime 2 t/ha	5.05	5.10	5.12
Lime 4 t/ha	5.47	5.76	5.55
Lime 8 t/ha	6.19	6.27	5.66
Gypsum 3.75 t/ha	4.72	4.92	4.92
Lime 2 t/ha + Gypsum 3.75 t/ha	4.81	5.18	5.16
		Site 2 Trevor	
Control	ND[A]	4.75	4.76
Lime 1 t/ha	ND[A]	4.84	4.87
Lime 2 t/ha	ND[A]	4.97	4.90
Lime 4 t/ha	ND[A]	5.14	4.95
Lime 8 t/ha	ND[A]	5.48	5.23
Gypsum 3.75 t/ha	ND[A]	4.71	4.77
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	4.95	4.87
		Site 3 Savimaki	
Control	4.71	4.66	4.86
MgO 0.072 t/ha	4.83	4.74	5.14
Ca/Mg blend 0.5 t/ha	5.05	5.03	5.35
Ca/Mg blend 1 t/ha	5.33	5.33	5.24
Ca/Mg blend 2 t/ha	5.78	5.56	5.53
Ca/Mg blend 4 t/ha	6.39	5.92	5.66
Lime 1.13 t/ha	5.21	5.29	5.44
Lime 4.5 t/ha	6.33	5.89	5.77
MgO 0.23 t/ha + Gypsum 0.68 t/ha	5.15	5.15	5.27
MgO 0.23 t/ha	5.24	5.15	5.29
Filter mud/ash	5.10	4.94	5.08
		Site 4 Colley	
Control	ND[A]	4.78	4.98
Lime 1 t/ha	ND[A]	4.88	4.95
Lime 2 t/ha	ND[A]	4.92	5.10
Lime 4 t/ha	ND[A]	5.49	5.26
Lime 8 t/ha	ND[A]	6.05	5.84

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 10. Mean soil pH_{Ca} values (0-10 cm depth) at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	3.94	3.92	3.96
Lime 1 t/ha	4.09	4.02	4.11
Lime 2 t/ha	4.23	4.17	4.16
Lime 4 t/ha	4.62	4.76	4.46
Lime 8 t/ha	5.49	5.35	4.55
Gypsum 3.75 t/ha	4.01	4.04	4.04
Lime 2 t/ha + Gypsum 3.75 t/ha	4.24	4.32	4.16
		Site 2 Trevor	
Control	ND[A]	4.00	4.05
Lime 1 t/ha	ND[A]	4.10	4.12
Lime 2 t/ha	ND[A]	4.21	4.16
Lime 4 t/ha	ND[A]	4.36	4.22
Lime 8 t/ha	ND[A]	4.70	4.50
Gypsum 3.75 t/ha	ND[A]	4.04	4.08
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	4.24	4.14
		Site 3 Savimaki	
Control	4.17	4.10	4.23
MgO 0.072 t/ha	4.22	4.15	4.25
Ca/Mg blend 0.5 t/ha	4.29	4.24	4.33
Ca/Mg blend 1 t/ha	4.47	4.40	4.35
Ca/Mg blend 2 t/ha	4.88	4.65	4.57
Ca/Mg blend 4 t/ha	5.55	5.04	4.68
Lime 1.13 t/ha	4.37	4.42	4.40
Lime 4.5 t/ha	5.43	5.01	4.78
MgO 0.23 t/ha + Gypsum 0.68 t/ha	4.33	4.31	4.31
MgO 0.23 t/ha	4.31	4.29	4.33
Filter mud/ash	4.22	4.25	4.23
		Site 4 Colley	
Control	ND[A]	4.08	4.05
Lime 1 t/ha	ND[A]	4.20	4.07
Lime 2 t/ha	ND[A]	4.32	4.17
Lime 4 t/ha	ND[A]	4.81	4.30
Lime 8 t/ha	ND[A]	5.45	4.92

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 11. Mean exchangeable calcium concentrations (cmol(+)/kg) in the 0-10 cm soil depth at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	0.46	0.54	0.49
Lime 1 t/ha	1.14	1.08	0.99
Lime 2 t/ha	1.84	1.81	1.32
Lime 4 t/ha	3.60	3.91	3.00
Lime 8 t/ha	7.03	6.82	4.07
Gypsum 3.75 t/ha	0.96	0.94	0.80
Lime 2 t/ha + Gypsum 3.75 t/ha	3.04	2.73	1.85
		Site 2 Trevor	
Control	ND[A]	1.80	1.81
Lime 1 t/ha	ND[A]	2.57	2.44
Lime 2 t/ha	ND[A]	3.64	3.01
Lime 4 t/ha	ND[A]	5.35	4.03
Lime 8 t/ha	ND[A]	8.80	6.09
Gypsum 3.75 t/ha	ND[A]	2.64	2.26
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	4.22	3.33
		Site 3 Savimaki	
Control	0.08	0.16	0.18
MgO 0.072 t/ha	0.11	0.19	0.23
Ca/Mg blend 0.5 t/ha	0.28	0.34	0.33
Ca/Mg blend 1 t/ha	0.64	0.61	0.40
Ca/Mg blend 2 t/ha	1.29	1.02	0.77
Ca/Mg blend 4 t/ha	2.61	1.83	1.21
Lime 1.13 t/ha	0.58	0.74	0.51
Lime 4.5 t/ha	2.74	2.04	1.52
MgO 0.23 t/ha + Gypsum 0.68 t/ha	0.35	0.38	0.37
MgO 0.23 t/ha	0.10	0.34	0.23
Filter mud/ash	0.19	0.32	0.20
		Site 4 Colley	
Control	ND[A]	0.48	0.54
Lime 1 t/ha	ND[A]	0.93	0.63
Lime 2 t/ha	ND[A]	1.51	1.16
Lime 4 t/ha	ND[A]	3.12	1.90
Lime 8 t/ha	ND[A]	5.01	3.73

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 12. Mean exchangeable calcium concentrations (cmol(+)/kg) in the 0-25 cm soil depth at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	0.33	0.41	0.43
Lime 1 t/ha	0.71	0.69	0.70
Lime 2 t/ha	1.10	1.04	0.85
Lime 4 t/ha	2.12	2.09	1.77
Lime 8 t/ha	4.11	3.47	2.28
Gypsum 3.75 t/ha	0.60	0.62	0.60
Lime 2 t/ha + Gypsum 3.75 t/ha	1.83	1.62	1.26
		Site 2 Trevor	
Control	ND^A	2.03	2.02
Lime 1 t/ha	ND^A	2.44	2.46
Lime 2 t/ha	ND^A	2.94	2.77
Lime 4 t/ha	ND^A	3.65	3.26
Lime 8 t/ha	ND^A	5.35	4.43
Gypsum 3.75 t/ha	ND^A	2.69	2.99
Lime 2 t/ha + Gypsum 3.75 t/ha	ND^A	3.30	3.13
		Site 3 Savimaki	
Control	0.06	0.09	0.13
MgO 0.072 t/ha	0.05	0.13	0.17
Ca/Mg blend 0.5 t/ha	0.14	0.21	0.23
Ca/Mg blend 1 t/ha	0.33	0.36	0.28
Ca/Mg blend 2 t/ha	0.63	0.59	0.51
Ca/Mg blend 4 t/ha	1.25	1.04	0.78
Lime 1.13 t/ha	0.30	0.43	0.35
Lime 4.5 t/ha	1.56	1.18	1.00
MgO 0.23 t/ha + Gypsum 0.68 t/ha	0.19	0.23	0.26
MgO 0.23 t/ha	0.05	0.21	0.15
Filter mud/ash	0.12	0.19	0.16
		Site 4 Colley	
Control	ND^A	0.47	0.57
Lime 1 t/ha	ND^A	0.71	0.60
Lime 2 t/ha	ND^A	1.01	0.94
Lime 4 t/ha	ND^A	1.84	1.43
Lime 8 t/ha	ND^A	2.77	2.58

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 13. Mean exchangeable magnesium concentrations (cmol(+)/kg) in the 0-10 cm soil depth at various times after treatment application.

Treatment	1993	1994	1995
			Site 1 Bisinella
Control	0.30	0.32	0.32
Lime 1 t/ha	0.37	0.39	0.41
Lime 2 t/ha	0.37	0.43	0.39
Lime 4 t/ha	0.43	0.48	0.50
Lime 8 t/ha	0.38	0.43	0.35
Gypsum 3.75 t/ha	0.24	0.24	0.25
Lime 2 t/ha + Gypsum 3.75 t/ha	0.35	0.37	0.36
			Site 2 Trevor
Control	ND[A]	1.78	1.80
Lime 1 t/ha	ND[A]	1.85	1.97
Lime 2 t/ha	ND[A]	2.02	2.00
Lime 4 t/ha	ND[A]	1.75	1.65
Lime 8 t/ha	ND[A]	1.69	2.03
Gypsum 3.75 t/ha	ND[A]	1.37	1.77
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	1.51	1.39
			Site 3 Savimaki
Control	0.04	0.08	0.07
MgO 0.072 t/ha	0.09	0.08	0.07
Ca/Mg blend 0.5 t/ha	0.08	0.13	0.10
Ca/Mg blend 1 t/ha	0.20	0.21	0.11
Ca/Mg blend 2 t/ha	0.36	0.30	0.19
Ca/Mg blend 4 t/ha	0.76	0.50	0.30
Lime 1.13 t/ha	0.05	0.14	0.09
Lime 4.5 t/ha	0.06	0.13	0.10
MgO 0.23 t/ha + Gypsum 0.68 t/ha	0.24	0.22	0.12
MgO 0.23 t/ha	0.21	0.23	0.16
Filter mud/ash	0.09	0.14	0.07
			Site 4 Colley
Control	ND[A]	0.32	0.23
Lime 1 t/ha	ND[A]	0.36	0.21
Lime 2 t/ha	ND[A]	0.32	0.27
Lime 4 t/ha	ND[A]	0.41	0.33
Lime 8 t/ha	ND[A]	0.33	0.30

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 14. Mean exchangeable magnesium concentrations (cmol(+)/kg) in the 0-25 cm soil depth at various times after treatment application.

Treatment	1993	1994	1995
Site 1 Bisinella			
Control	0.20	0.21	0.24
Lime 1 t/ha	0.25	0.25	0.31
Lime 2 t/ha	0.25	0.27	0.29
Lime 4 t/ha	0.30	0.33	0.39
Lime 8 t/ha	0.26	0.26	0.25
Gypsum 3.75 t/ha	0.15	0.13	0.17
Lime 2 t/ha + Gypsum 3.75 t/ha	0.23	0.25	0.28
Site 2 Trevor			
Control	ND[A]	2.05	2.01
Lime 1 t/ha	ND[A]	2.15	2.23
Lime 2 t/ha	ND[A]	2.34	2.27
Lime 4 t/ha	ND[A]	1.88	1.77
Lime 8 t/ha	ND[A]	1.96	2.30
Gypsum 3.75 t/ha	ND[A]	1.95	2.01
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	1.69	1.81
Site 3 Savimaki			
Control	0.04	0.05	0.04
MgO 0.072 t/ha	0.07	0.05	0.05
Ca/Mg blend 0.5 t/ha	0.06	0.08	0.07
Ca/Mg blend 1 t/ha	0.13	0.13	0.08
Ca/Mg blend 2 t/ha	0.20	0.19	0.13
Ca/Mg blend 4 t/ha	0.43	0.32	0.21
Lime 1.13 t/ha	0.04	0.09	0.06
Lime 4.5 t/ha	0.04	0.07	0.06
MgO 0.23 t/ha + Gypsum 0.68 t/ha	0.15	0.13	0.09
MgO 0.23 t/ha	0.13	0.13	0.11
Filter mud/ash	0.06	0.10	0.05
Site 4 Colley			
Control	ND[A]	0.27	0.24
Lime 1 t/ha	ND[A]	0.27	0.14
Lime 2 t/ha	ND[A]	0.23	0.23
Lime 4 t/ha	ND[A]	0.31	0.31
Lime 8 t/ha	ND[A]	0.21	0.24

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 15. Mean exchangeable acidity (cmol(+)/kg) in the 0-10 cm depth at various times after treatment application.

Treatment	1993	1994	1995
			Site 1 Bisinella
Control	2.98	2.77	2.85
Lime 1 t/ha	2.38	2.27	2.46
Lime 2 t/ha	1.93	1.68	2.35
Lime 4 t/ha	0.75	0.43	1.01
Lime 8 t/ha	<0.1	<0.1	1.05
Gypsum 3.75 t/ha	2.50	2.22	2.32
Lime 2 t/ha + Gypsum 3.75 t/ha	1.86	1.46	2.46
			Site 2 Trevor
Control	ND[A]	6.96	6.02
Lime 1 t/ha	ND[A]	5.94	5.63
Lime 2 t/ha	ND[A]	4.94	5.22
Lime 4 t/ha	ND[A]	3.94	4.56
Lime 8 t/ha	ND[A]	1.69	2.90
Gypsum 3.75 t/ha	ND[A]	6.98	6.02
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	4.92	5.24
			Site 3 Savimaki
Control	1.49	1.47	1.17
MgO 0.072 t/ha	1.46	1.38	1.15
Ca/Mg blend 0.5 t/ha	1.15	1.11	0.88
Ca/Mg blend 1 t/ha	0.86	0.87	0.92
Ca/Mg blend 2 t/ha	0.37	0.57	0.61
Ca/Mg blend 4 t/ha	<0.1	0.38	0.33
Lime 1.13 t/ha	1.01	0.82	0.75
Lime 4.5 t/ha	<0.1	0.29	0.30
MgO 0.23 t/ha + Gypsum 0.68 t/ha	1.23	1.07	0.87
MgO 0.23 t/ha	0.99	0.81	0.78
Filter mud/ash	1.21	0.85	1.03
			Site 4 Colley
Control	ND[A]	1.79	1.81
Lime 1 t/ha	ND[A]	1.24	1.70
Lime 2 t/ha	ND[A]	0.90	1.37
Lime 4 t/ha	ND[A]	0.24	0.99
Lime 8 t/ha	ND[A]	<0.10	0.17

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 16. Mean exchangeable aluminium (cmol(+)/kg) in the 0-10 cm depth at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	2.86	2.56	2.27
Lime 1 t/ha	2.28	2.04	1.96
Lime 2 t/ha	1.84	1.51	2.01
Lime 4 t/ha	0.74	0.38	0.96
Lime 8 t/ha	<0.10	<0.10	1.03
Gypsum 3.75 t/ha	2.32	1.93	2.19
Lime 2 t/ha + Gypsum 3.75 t/ha	1.77	1.42	2.41
		Site 2 Trevor	
Control	ND[A]	6.90	5.43
Lime 1 t/ha	ND[A]	5.92	4.85
Lime 2 t/ha	ND[A]	4.92	4.13
Lime 4 t/ha	ND[A]	3.91	3.48
Lime 8 t/ha	ND[A]	1.69	2.37
Gypsum 3.75 t/ha	ND[A]	6.96	4.67
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	4.89	4.21
		Site 3 Savimaki	
Control	1.49	1.47	1.11
MgO 0.072 t/ha	1.46	1.38	1.08
Ca/Mg blend 0.5 t/ha	1.15	1.11	0.85
Ca/Mg blend 1 t/ha	0.84	0.97	0.87
Ca/Mg blend 2 t/ha	0.37	0.57	0.59
Ca/Mg blend 4 t/ha	<0.10	0.19	0.32
Lime 1.13 t/ha	1.01	0.82	0.71
Lime 4.5 t/ha	<0.10	0.15	0.27
MgO 0.23 t/ha + Gypsum 0.68 t/ha	1.23	1.07	0.84
MgO 0.23 t/ha	0.99	0.81	0.75
Filter mud/ash	1.21	0.85	1.00
		Site 4 Colley	
Control	ND[A]	1.67	1.78
Lime 1 t/ha	ND[A]	1.14	1.68
Lime 2 t/ha	ND[A]	0.82	1.36
Lime 4 t/ha	ND[A]	0.24	0.98
Lime 8 t/ha	ND[A]	<0.10	0.16

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 17. Mean extractable (0.01 M $CaCl_2$) aluminium (mg/kg) in the 0-10 cm depth at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	37.2	31.8	37.0
Lime 1 t/ha	20.9	22.3	25.2
Lime 2 t/ha	13.3	11.5	20.9
Lime 4 t/ha	2.9	1.3	3.9
Lime 8 t/ha	<0.1	<0.1	4.3
Gypsum 3.75 t/ha	28.8	21.7	27.0
Lime 2 t/ha + Gypsum 3.75 t/ha	10.7	6.9	19.4
		Site 2 Trevor	
Control	ND^A	46.5	43.5
Lime 1 t/ha	ND^A	30.2	32.0
Lime 2 t/ha	ND^A	18.6	25.8
Lime 4 t/ha	ND^A	10.5	18.7
Lime 8 t/ha	ND^A	2.5	5.0
Gypsum 3.75 t/ha	ND^A	42.8	35.1
Lime 2 t/ha + Gypsum 3.75 t/ha	ND^A	17.1	23.4
		Site 3 Savimaki	
Control	27.6	26.8	22.0
MgO 0.072 t/ha	24.6	22.5	20.6
Ca/Mg blend 0.5 t/ha	16.9	14.4	13.5
Ca/Mg blend 1 t/ha	9.8	6.8	13.4
Ca/Mg blend 2 t/ha	3.3	2.5	6.3
Ca/Mg blend 4 t/ha	1.2	1.1	5.3
Lime 1.13 t/ha	13.6	5.5	11.2
Lime 4.5 t/ha	1.6	0.8	3.8
MgO 0.23 t/ha + Gypsum 0.68 t/ha	16.8	9.8	15.1
MgO 0.23 t/ha	15.2	5.7	12.5
Filter mud/ash	20.4	9.8	18.1
		Site 4 Colley	
Control	ND^A	21.5	26.8
Lime 1 t/ha	ND^A	10.3	21.5
Lime 2 t/ha	ND^A	6.4	12.3
Lime 4 t/ha	ND^A	0.9	5.9
Lime 8 t/ha	ND^A	0.3	0.9

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.

Appendix 18. Mean extractable (0.01 M $CaCl_2$) manganese (mg/kg) in the 0-10 cm depth at various times after treatment application.

Treatment	1993	1994	1995
		Site 1 Bisinella	
Control	29.3	31.4	15.1
Lime 1 t/ha	26.0	19.0	11.0
Lime 2 t/ha	20.5	15.5	10.3
Lime 4 t/ha	19.1	8.4	8.5
Lime 8 t/ha	6.4	1.5	4.5
Gypsum 3.75 t/ha	24.1	28.1	12.6
Lime 2 t/ha + Gypsum 3.75 t/ha	15.5	15.0	6.4
		Site 2 Trevor	
Control	ND[A]	12.0	11.8
Lime 1 t/ha	ND[A]	10.3	10.4
Lime 2 t/ha	ND[A]	10.2	10.0
Lime 4 t/ha	ND[A]	7.5	7.6
Lime 8 t/ha	ND[A]	4.2	5.5
Gypsum 3.75 t/ha	ND[A]	9.8	10.8
Lime 2 t/ha + Gypsum 3.75 t/ha	ND[A]	7.5	8.3
		Site 3 Savimaki	
Control	1.2	1.9	1.0
MgO 0.072 t/ha	1.6	2.3	1.1
Ca/Mg blend 0.5 t/ha	1.8	2.7	1.3
Ca/Mg blend 1 t/ha	1.8	2.5	1.2
Ca/Mg blend 2 t/ha	1.2	1.6	1.1
Ca/Mg blend 4 t/ha	0.8	1.5	1.1
Lime 1.13 t/ha	2.0	2.4	1.4
Lime 4.5 t/ha	1.0	1.1	0.8
MgO 0.23 t/ha + Gypsum 0.68 t/ha	2.0	1.9	1.2
MgO 0.23 t/ha	1.8	1.9	1.1
Filter mud/ash	1.6	3.2	1.2
		Site 4 Colley	
Control	ND[A]	145.3	140.8
Lime 1 t/ha	ND[A]	146.8	149.6
Lime 2 t/ha	ND[A]	104.7	131.8
Lime 4 t/ha	ND[A]	53.4	102.9
Lime 8 t/ha	ND[A]	26.8	45.9

[A] Soil not sampled in 1993 as the plant cane crop was stood over due to very wet conditions during the harvest season.