BSES Limited

FINAL REPORT – SRDC PROJECT BSS197

PRODUCTS AND MECHANISMS FOR THE AMELIORATION OF SODIC SOILS

by

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SD05006

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SUMMARY

This project set out to examine a number of issues associated with sodic soils. These included: 1) the impact of soil sodicity on crop production; 2) the reduction of adverse impacts of soil sodicity through irrigation management and/or the use of soil ameliorants; 3) the properties and potential efficacy of a range of products being marketed as 'soil ameliorants' throughout the northern part of Queensland; 4) the means by which a selection of these ameliorants effected beneficial changes to sodic soils; and 5) to establish a close linkage between these investigations and a method for the field identification and measurement of sodicity being developed in a closely associated Sugar CRC project.

The impact of soil sodicity on crop production was measured across 17 irrigated sites in the Burdekin district. Crop yield was measured in 20-30 m sections of rows in fields with variable yield and related to corresponding soil sodicity and salinity. This enabled the strong relationship between crop yield and soil sodicity to be established. Crop yield decreased by 2.1 t/ha for each 1% increase in the exchangeable sodium percentage (ESP) of the 250-500 mm depth interval in the soil. This work provided the basis for the development of a 'tool kit' for the identification of sodic soils.

In a trial to assess the best irrigation management for a sodic soil, without chemical amelioration, it was shown clearly that the 'normal' schedule used for non-sodic clay soils was totally inappropriate to optimise production. Significant yield improvement was obtained from more frequent irrigation. In practical terms, shortening the irrigation cycle to 6-7 days was a manageable target for furrow irrigation of these soils to gain significant yield improvement from changed farm practice.

Samples of 19 products being marketed from Mackay north as 'soil ameliorants' were collected. These were subjected to chemical analysis of their elemental composition, including minor elements, by X-ray fluorescence. Their physical properties, including moisture content at supply, particle size distribution and rate of solubilisation of whole product and size fractions, were determined. This has allowed identification of products likely to have the most rapid impact on reducing soils sodicity in any soil environment. It has also defined the quality of products which, in an acid sodic soil, have the potential to be effective, providing the soil acidity and their placement are adequate. Claims of enhanced performance of mixed ameliorative products were examined. The magnitude of the "enhancement" was very small, if any, and in accord with the relative solubility of the separate products.

A simple method to test gypsum products for relative persistence in the soil was developed. This showed that the purity of product, particle size and persistence of product in the soil were all interlinked in determining the efficacy of a particular product.

Field trials were established on acid and alkaline sodic soils to test the effectiveness of a range of products in reducing soil sodicity. From analysis of soils from these trials, the mechanism for improvement in soil properties was identified as an effective reduction in soil ESP, accompanied by an increase in soil aggregate size, stability and wet strength. Of the materials tested in these trials, gypsum proved to be the most effective with encouraging results from earth lime in acid soil environments. Molasses and

lime/molasses mixture results suggest a time lag before any positive results are likely. Surface/subsoil interfacial application of elemental sulfur or sulfuric acid did not impact significantly on soil structure compared with micro-fine gypsum. Additionally, mill ash did not reduce ESP or improve soil structure and had a reducing effect in ratoon crops.

These findings form part of the *Gypsy* (www.clw.csiro.au/products/gypsy/). This allows the estimation of the influence of a gypsum addition on cane yield and cash flow on neutral-alkaline soils, using the relationships between yield and sodicity, and the effect of gypsum on sodicity. The inputs are cation exchange capacity and exchangeable sodium percentage for the 0-25 cm and 25-50 cm depth layers, cost and quality of the gypsum, price of cane, and a discount rate. The output is a cash-flow analysis, with a graph showing net benefit against gypsum rate.

1.0 BACKGROUND

Soil sodicity has become a significant factor to long-term economic sugar production on expansion lands throughout Queensland. Sodic soils represent a significant proportion of existing and potential canelands - Southern Region 10%, Mackay 24%, Proserpine 15%, Burdekin 15% and Mareeba 10% - and could conservatively reduce the industry's production by 500,000 tonnes of cane annually.

Studies on soil amelioration by BSES were reviewed in March 1996 as part of an SRDC-funded project, BSS146 *Farming sodic soils – a situation statement and future direction*. The review panel took account of an open forum comprising the expert group and a broad representation of industry (including research/extension staff, agribusiness and growers), the deliberations of the following workshop, and the client needs and recommendations for future research derived from a focus group.

Aspects identified for the purpose of this study were:
1. to examine the quality, composition and properties of available ameliorants;
2. the relationship of yield loss to the extent and location of sodicity in the soil profile;
3. the use of irrigation management in raising productivity without ameliorants; and
4. the efficacy of products- individually and in combination- and their placement on amelioration.

This project was very closely linked to the CRC-funded project *A Diagnostic Tool Kit for Sodic Soils*. This study builds substantially on the previous work reported to and reviewed at the SRDC-funded workshop.

2.0 OBJECTIVES

The project sought to reduce the impact of soil sodicity through five objectives:

1. Identify the ameliorative products commercially available [Mackay north], their chemical and physical properties and relative efficacy in acid and alkaline environments.
2. Determine the effect of sodicity by depth on yield in a fully irrigated environment.
3. Test commercially available products and other ameliorants by placement methods for relative effectiveness.
4. Determine the mechanisms/extent of action of the ameliorants and reasons for their longevity of operation.
5. Relate these results to the application of a 'tool kit' for identification of sodic soil*s* in field practice.

With the exception of determining the absolute longevity of operation of ameliorants, which was limited by the duration of the trials in which it could be measured, all of the objectives in this project have been achieved and in some cases exceeded. The development of a rapid method for assessing the relative performance of ameliorative products was not envisaged at the commencement of the project. The strong linkage with the development of the 'tool kit' accomplished more than "relating these investigations to its application in field practice".

Objective 1 – Identify the ameliorative products commercially available [Mackay north], their chemical and physical properties and relative efficacy in acid and alkaline environments.

Samples of 19 products being marketed from Mackay north as 'soil ameliorants' were collected. These were subjected to chemical analysis of their elemental composition, including minor elements, by X-ray fluorescence. Their physical properties, including moisture content at supply, particle size distribution and rate of solubilisation of whole product and size fractions, were determined. This has allowed identification of products likely to have the most rapid impact on reducing soils sodicity in any soil environment. It has also defined the quality of products which, in an acid sodic soil, have the potential to be effective, providing the soil acidity and their placement are adequate. Claims of enhanced performance of mixed ameliorative products were examined. The magnitude of the 'enhancement' was very small, if any, and in accord with the relative solubility of the separate products.

A simple method to test gypsum products for relative persistence in the soil was developed. This showed that the purity of product, particle size and persistence of product in the soil were all interlinked in determining the efficacy of a particular product.

Objective 2 – Determine the effect of sodicity by depth on yield in a fully irrigated environment.

Objective 5 – Relate these results to the application of a 'tool kit' for identification of sodic soils in field practice.

The impact of soil sodicity on crop production was measured across 17 irrigated sites in the Burdekin district. Crop yield was measured in 20-30 m sections of rows in fields with variable yield and related to corresponding soil sodicity and salinity. This enabled the strong relationship between crop yield and soil sodicity to be established. Crop yield decreased by 2.1 t/ha for each 1% increase in the exchangeable sodium percentage (ESP) of the 250-500 mm depth interval in the soil. This work provided the basis for the development of a 'tool kit' for the identification of sodic soils (Nelson 2000, 2001).

In a trial to assess the best irrigation management for a sodic soil, without chemical amelioration, it was shown clearly that the 'normal' schedule used for non-sodic clay soils was totally inappropriate to optimise production. Significant yield improvement was obtained from more frequent irrigation. In practical terms, shortening the irrigation cycle to 6-7 days was a manageable target for furrow irrigation of these soils to gain significant yield improvement from changed farm practice.

Objective 3 – Test commercially available products and other ameliorants by placement methods for relative effectiveness.

Objective 4 – Determine the mechanisms/extent of action of the ameliorants and reasons for their longevity of operation.

Field trials were established on acid and alkaline sodic soils to test the effectiveness of a range of products in reducing soil sodicity. From analysis of soils from these trials, the mechanism for improvement in soil properties was identified as an effective reduction in soil ESP, accompanied by an increase in soil aggregate size, stability and wet strength. Of the materials tested in these trials, gypsum proved to be the most effective with encouraging results from earth lime in acid soil environments. Molasses and lime/molasses mixture results suggest a time lag before any positive results are likely. Surface/subsoil interfacial application of elemental sulfur or sulfuric acid did not impact significantly on soil structure compared with micro-fine gypsum. Additionally, mill ash did not reduce ESP or improve soil structure and had a reducing effect in ratoon crops.

3.0 OBJECTIVE 1 - Identify the ameliorative products commercially available [Mackay north], their chemical and physical properties and relative efficacy in acid and alkaline environments

At the commencement of this project, 18 products were being marketed for ‘amelioration’ of sodic soils in the Queensland sugar industry. These products were collected and analysed in various ways to assess their chemical and physical properties, particularly those that relate to their suitability for use in sodic soil amelioration.

3.1 Product sampling

Samples were collected from commercial stocks of products held by distribution agents at centres from Mackay to Cairns. A small quantity of product, exposed directly to the atmosphere, was removed from the surface of the stack immediately prior to sampling at each site around the stack. Numerous randomly positioned samples were taken with a 40 mm by 2 m tube sampler pushed into the stockpile repeatedly until 15-20 kg of product were collected. Samples were stored in 20 L sealable plastic containers. This stock was later mixed thoroughly on new plastic sheeting and subsampled for use in product analysis.

3.2 Analysis methods

Samples were subjected to the following analyses:

1. moisture content;
2. particle-size distribution;
3. chemical analysis of major and minor elements;
4. rate of solubilisation of whole product and component fractions;
5. selected analysis of saturated solutions of single products and mixtures of products;
6. repeated product dissolution of gypsum samples.

3.2.1 Moisture content

Duplicate 25-30 g samples of each product were weighed accurately and dried in a forced-draught oven at 60°C for 72 hours (to constant weight), the lower drying temperature being used to prevent loss of water of hydration. Per cent moisture content was calculated from loss of weight.

3.2.2 Particle size distribution

Duplicate weighed samples (~100g) of product were sieved on a RotoTap®- type shaker for 60 seconds with fractions being collected by a nest of sieves, into fractions:

- >2.00 mm
- >1.00-<2.00 mm
- >0.50-<1.00 mm
- >0.212-<0.50 mm
- >0.125-<0.212 mm
- <0.125 mm.

Because of the high delivered moisture content of By-Product Gypsum, the sample was air-dried to 2.88% moisture (w/w) from its original value of 12.57%; all subsequent testing was carried out on this air-dried product. The delivered moisture content of this product will necessarily have to be taken into account when comparing cost of products from different sources.

3.2.3 Chemical analysis of major and minor elements

X-ray fluorescence was used to analyse for major and minor elements. Subsamples of products were sent to the CSIRO, Adelaide where 2 g finely-ground, dry material were fused with 8 g 12-22 lithium borate flux (Graham Riley, CSIRO, Adelaide, pers. comm.) and subjected to energy dispersive X-ray fluorescence for elemental analysis.

3.2.4 Rate of solubilisation of whole product and component fractions

In order to gain some appreciation of the relative rate of solubilisation of products in the field, duplicate 5 g samples of whole product and each size fraction (<1.0 mm) were placed in 60 mL capacity vials to each of which was added 50 mL distilled water. Vials were capped, gently inverted twice initially and then again every 10 minutes during the first 1.5 hours, at approximately 20-minute intervals for the next 5.5 hours, and thereafter every daylight hour to 144 hours. Vial inversion was spread to allow mixing immediately prior to each conductivity measurement, which was used as the index of solubilization.

3.2.5 Selected analysis of saturated solutions of single products and mixtures of products

To address some perceptions and claims of significantly enhanced performance of mixed ameliorative products, the relative composition of equilibrium solutions of two lime products, three gypsum products and their respective 1:1 (w/w) mixtures were examined. David Mitchell Lime (DML) pulverised lime and Burdekin Lime Co. (BLC) earth lime were mixed in equal weights with By-Product Gypsum (ex Incitec), Winton gypsum (BLC & Inkerman Lime Company (ILC)) and BLC Hughenden gypsum and gently agitated for 144 hours to allow equilibrium concentrations to be reached. Aliquots of the supernatant solutions were then analysed by ICP in the BSES laboratory at Indooroopilly.

3.2.6 Repeated product dissolution of gypsum samples

In order to gain an appreciation of the relative persistence of gypsum products with repeated irrigation applications or rainfall events, six gypsum samples were subjected to a repetitive dissolution test of 14 'irrigations'. Duplicate samples of each product were mixed in the ratio 1.5 g product to 40 mL distilled water in a capped centrifuge tube and shaken on an end over end shaker for 30 minutes. Tubes were then centrifuged at 3000 rpm for 7 minutes and the supernatant liquid removed. A further 40 mL distilled water was added and the centrifuged solid rapidly resuspended using a vortex mixer and again shaken for 30 minutes.

This process was repeated until the 14 'irrigations' were complete. Supernatant solutions were retained separately, the conductivity of the solutions measured and subsamples forwarded to the BSES laboratory, Indooroopilly for analysis for calcium, magnesium, sodium, potassium and sulfur contents.

3.3 Results and discussion

3.3.1 Moisture content, particle size distribution and solubility

The moisture and particle size distribution of the products are shown in Table 1. Products have been grouped into gypsum and non-gypsum for ease of comparison.

The significant issue here is that this moisture, together with product purity, has to be accounted for in comparing the value of the products relative to their individual cost/unit. The solubility of these types of products is a function of both their particle-size distribution and purity of product; this is particularly so for the rate of solubilization.

Table 1a Gypsum products: particle size distribution

Product	**%w/w moisture**	**>2.0 mm**	**1.0 to <2.0 mm**	**0.5 to <1.0 mm**	**0.212 to <0.5 mm**	**0.125 to <0.212 mm**	**<0.125 mm**
Ayr L&G Gypsum	2.0	12.4	12.6	12.9	14.6	10.0	37.5
Zinabac Gypsum	3.8	8.0	12.1	15.0	17.1	12.3	35.5
ILC/BLC Winton Gypsum	2.3	18.9	10.7	12.5	15.0	10.5	32.4
BLC Hughenden Gypsum	1.5	4.2	15.0	18.2	22.7	15.2	24.8
By-Product Gypsum	2.9	4.1	2.4	0.3	4.8	24.3	64.1
CGSS* Gypsum	5.9	10.6	9.6	12.5	16.4	13.5	37.5
CGSS* Crystal Gypsum	0.8	1.2	0.5	1.6	23.3	59.5	13.9

*CGSS = Cane Growers Spreading Services

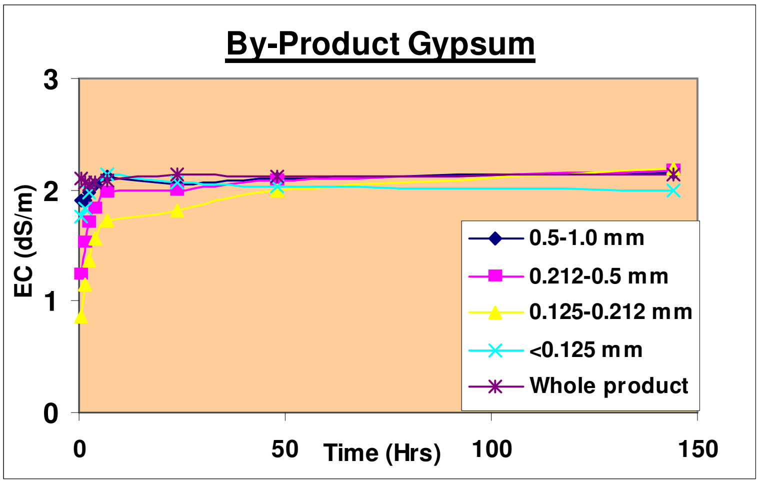
Table 1b Other products: particle size distribution

Product	%w/w moisture	>2.0 mm	1.0 to <2.0 mm	0.5 to <1.0 mm	0.212 to <0.5 mm	0.125 to <0.212 mm	<0.125 mm
DML NIBS	4.2	8.1	16.8	20.2	12.3	6.7	36.0
ILC Earth Lime	2.7	8.2	12.0	14.7	16.7	10.0	38.3
BLC Earth Lime	1.3	12.3	19.7	26.9	15.3	8.6	26.9
Chillagoe Lime	0.1	0.0	0.0	1.2	30.4	16.4	52.0
Zinabac Rock Lime	0.1	0.0	0.0	15.1	26.4	14.4	44.1
DML Pulverised Lime	0.1	3.7	28.3	18.8	15.7	11.0	22.6
Ayr L&G Earth Lime	3.8	14.6	15.1	16.6	16.3	8.1	29.3
Mt Molloy Lime	0.1	0.0	0.0	27.4	23.0	23.6	26.0
DML Ag Lime (Calcium)	0.1	0.0	0.2	29.5	26.2	14.7	29.4
MIN+	0.9	0.0	1.4	2.4	4.4	59.3	32.5

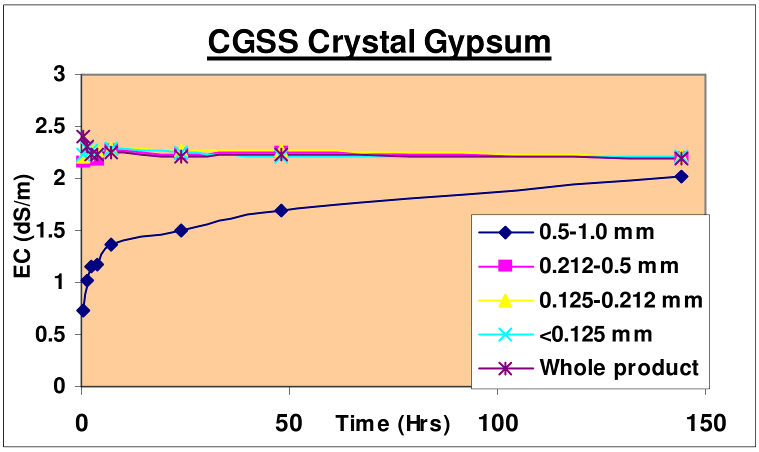
Clearly, the concentration of fine material in By-Product and CGSS Crystal Gypsum has enhanced the rate at which each of these products has reached saturation compared with the other products; this is apparent in the graphs of their respective solubility rates (Figure 1). The dominant influence of the high proportion of fine (< 0.5 mm) material is reflected in the rate of attainment of saturation for CGSS Crystal and By-Product Gypsum when compared with BLC Hughenden and BLC Winton Gypsum for example.

A similar situation existed for the other products where, with the exception of DML Nibs, the conductivity of the products rose slowly and fairly uniformly to saturation, with a final conductivity of 0.1-0.2 dS/m. The exception in this group was BLC Earth Lime, which reached 0.348 dS/m. DML Nibs is a by-product of 'burnt lime'/'quicklime' manufacture (i.e. calcium oxide) and contains varying quantities of calcium oxide, calcium hydroxide and calcium carbonate as a result of the kiln-firing system used in its manufacture and subsequent method of storage. Hence, the much higher conductivity of the saturated solution was the result of a combination of chemical reaction of calcium oxide with the water, the solubilization of calcium hydroxide present and formed, and the reasonably high proportion of fine material present. The very high pH of the saturated solution (>11), potential for at least short-term salinisation, and the irregular quantities available make it an unattractive proposition for sodic soil amelioration. Figure 2 shows the solubility curves for a selection of lime products. The balance of solubility curves for both product groups appear in Appendix 1.

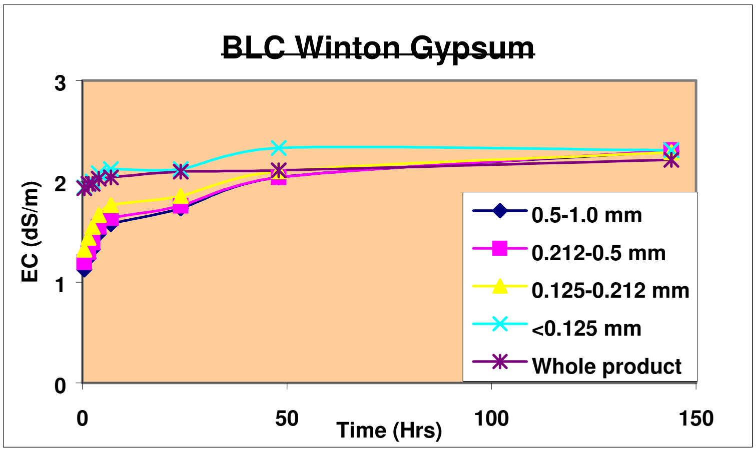
Lime products will require a mild to strongly acid soil environment to increase the solubilization of calcium to a level where cation exchange can take place with a beneficial impact on reduction of sodicity. The pH prevailing in the alkaline sodic soils prevents any significant dissolution of calcium and consequent beneficial effects.



By-Product Gypsum



CGSS Crystal Gypsum



BLC Winton Gypsum

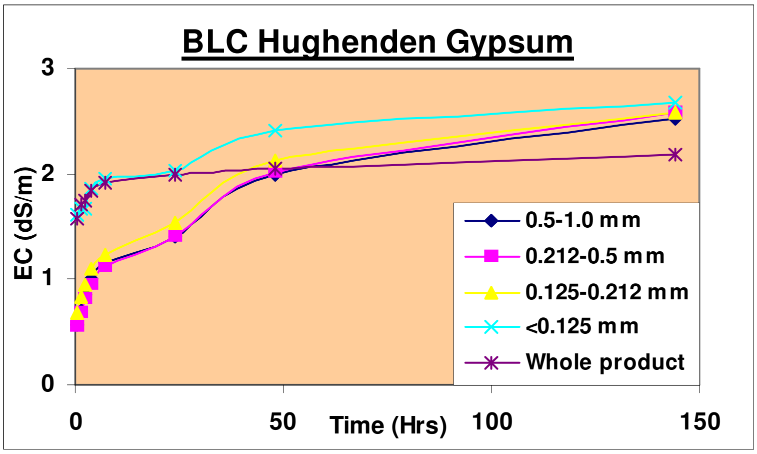
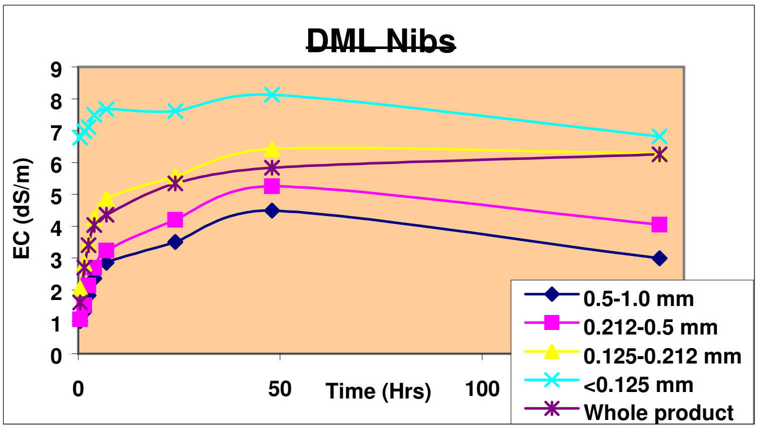
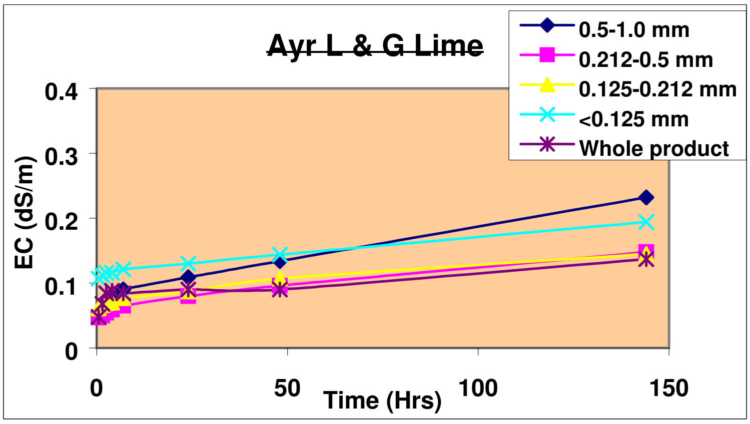


Figure 1 Rate of solubilization of four gypsum products (whole and fine fractions)





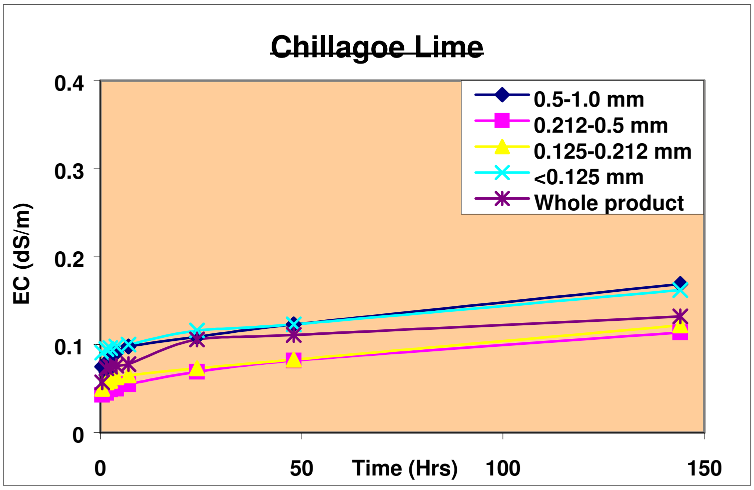


Figure 2 Rate of solubilization of three lime products

Figure 3 shows the solubility curve for a crushed and ground basaltic rock product for which ameliorative properties have been claimed. The solubility of the product does not support the claimed reactivity of the product in a sodic soil environment.

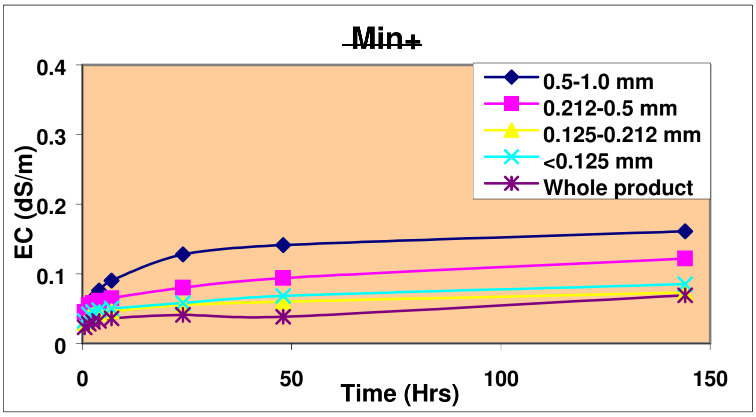


Figure 3 Solubility curve for Min+ (whole product and fine fractions)

3.3.2 Chemical analysis of products

XRF analysis of products shows a wide range of purity for both within the gypsum group and other products group (Table 2). For pure gypsum, sulfur content should be 18.61% and calcium 23.27%. Only By-Product and CGSS Crystal approach these levels, with Hughenden well below the legislated value for a registered gypsum product.

Table 2 Gypsum and other products chemical analysis

Gypsum source	Si %	Al %	Fe %	Mg %	Ca %	Na %	K %	P %	Mn %	S %
Ayr L&G	3.99	0.76	0.30	0.39	19.87	-0.01	0.02	0.00	0.01	15.46
Zinabac	4.56	1.02	0.41	0.44	19.44	0.02	0.11	0.00	0.01	14.87
ILC/BLC Winton	6.64	1.36	0.52	0.48	22.65	0.04	0.15	0.01	0.02	16.88
BLC Hughenden	11.89	1.90	1.12	0.54	15.29	0.13	0.40	0.05	0.03	9.12
BLC	5.42	1.20	0.63	0.46	17.37	0.06	0.12	0.00	0.01	13.47
By-Product	0.02	0.03	0.01	0.27	23.94	0.01	0.00	0.07	0.00	18.26
CGSS	6.94	1.51	0.61	0.47	15.94	0.03	0.13	0.00	0.02	12.46
CGSS Crystal	1.71	0.39	0.15	0.37	22.44	0.03	0.04	0.00	0.01	17.88
Other products										
ILC Earth Lime	13.53	2.60	1.82	2.64	18.45	0.55	0.14	0.03	0.07	0.01
Proserpine Lime	0.37	0.09	0.05	0.35	37.73	0.00	0.01	0.00	0.01	0.38
BLC Earth Lime	7.73	0.95	0.54	4.51	24.09	0.09	0.10	0.00	0.02	0.10
Chillagoe Lime	0.65	0.11	0.07	0.61	37.66	0.01	0.02	0.00	0.01	0.42
Zinabac Rock Lime	1.05	0.16	0.09	0.54	36.95	0.03	0.05	0.00	0.01	0.02
DML Pulv. Lime	1.93	0.31	0.18	0.74	36.66	0.07	0.07	0.00	0.02	0.02
Ayr L&G Earth Lime	5.64	0.67	0.33	2.94	25.16	0.11	0.09	0.00	0.02	0.02
Mt Molloy Lime	1.65	0.05	0.06	0.69	33.52	0.04	0.00	0.02	0.05	0.02
DML Ag. Lime	3.47	0.49	0.36	0.92	30.87	0.14	0.10	0.01	0.03	0.04
DML NIBS	3.54	0.76	0.35	0.78	39.67	0.11	0.09	0.00	0.02	0.04
MIN+	14.87	2.62	4.03	5.39	5.57	0.87	0.65	0.14	0.12	0.01

This wide quality range is also a contributor to the rate of attainment of a saturated solution of the product and should be a major consideration in comparative costing when selecting for farm application. It will also have a significant effect on the persistence of the product in its ameliorative function.

Similarly, pure lime ($CaCO_3$) products should contain approximately 40% calcium. Only five products approach this high purity level, all of which are ground rock limestone or a direct derivative of it. However, earth lime deposits are commonly regarded as good quality if they exceed approximately 24% calcium, and two of these products analysed fall in this category. Three earth lime products contain some magnesium, although below the level which would classify them as dolomite. The Min+ product has very low calcium levels, but also contains extremely low levels of sulfur. This reinforces the inability of the product to reach reactivity levels necessary to be an effective ameliorant as shown by the extremely low product solubility. Recent research by Priyono and Gilkes (2004) confirms that silicate rocks, finely milled and mixed with soil (at 10 t/ha) had only minor effects on increasing E.C. and pH of 1:5 soil:water mixtures. Elements released during dissolution are considered readily available plant nutrients, although further research is required to identify the soils/plants for which application would be most beneficial.

Of the products, Hughenden gypsum, across the minor elements listed (Table 3), consistently had the highest concentrations followed by Min+. However, for the minor element probably regarded as most important, cadmium, by-product gypsum had the highest level, which exceeds the current legislative standard, followed by Hughenden gypsum which falls just inside the current standard.

Table 3 Minor elements in ‘ameliorant’ products (mg/kg)

Gypsum source	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Mo**	**Cd**	**Hg**	**Pb**
Ayr L&G	38.5	<0.8	4.8	16.1	<0.4	1.7	<0.5	0.0	1.9	10.2
Zinabac	52.7	5.5	11.2	16.9	2.5	<0.4	<0.5	0.9	<1.4	9.3
ILC/BLC Winton	21.2	0.0	2.4	16.9	0.0	n.a.	n.a.	n.a.	n.a.	0.0
BLC Hughenden	89.7	102.9	88.7	399.3	30.5	10.0	54.9	12.9	1.9	14.9
BLC	77.1	3.1	9.6	20.9	0.8	<0.4	0.9	<0.3	<1.4	10.2
By-Product	<1.6	<0.8	6.4	20.1	<0.4	1.7	1.7	21.4	<1.4	7.4
CGSS	42.5	11.0	16.0	30.5	0.8	1.7	0.9	0.0	1.9	26.0
CGSS Crystal	<1.6	<0.8	8.0	12.1	<0.4	<0.4	<0.5	0.9	<1.4	2.8
Other products										
ILC Earth Lime	16.5	63.7	46.3	60.3	0.0	n.a.	n.a.	n.a.	n.a.	12.1
Proserpine Lime	17.3	17.3	12.8	20.1	0.0	n.a.	n.a.	n.a.	n.a.	0.0
BLC Earth Lime	42.5	3.1	4.8	14.5	<0.4	<0.4	<0.5	0.9	<1.4	6.5
Chillagoe Lime	2.4	3.1	4.8	12.1	<0.4	0.8	<0.5	0.9	2.8	9.3
Zinabac Rock Lime	1.6	<0.8	5.6	12.9	1.6	<0.4	<0.5	2.6	<1.4	9.3
DML Pulv. Lime	24.4	3.1	11.2	60.3	3.3	<0.4	<0.5	0.9	2.8	11.1
Ayr L&G Earth Lime	14.2	<0.8	6.4	16.1	<0.4	<0.4	<0.5	0.0	<1.4	4.6
Mt Molloy Lime	50.3	<0.8	9.6	24.9	2.5	<0.4	<0.5	1.7	<1.4	4.6
DML Ag. Lime	39.3	2.4	8.8	30.5	2.5	<0.4	<0.5	0.9	<1.4	13.9
DML NIBS	18.1	0.8	8.0	37.0	<0.4	0.8	0.9	1.7	<1.4	10.2
MIN+	328.8	249.1	72.7	144.6	1.6	1.7	6.9	0.0	2.8	7.4

n.a. = not available

It is understood that later supplies of By-Product Gypsum than that sampled in this project fall within the acceptable limit. Cadmium content is not a problem for sugarcane, as it does not accumulate the element during its growth; however, subsequent land use for other crops may result in undesirable accumulation in the edible portions of those crops, eg peanuts (K. Norman, pers. comm.).

3.3.3 Product mixtures and enhanced solubility

Results of the investigation into the ‘enhanced’ solubility of mixtures of selected ameliorants are shown in Table 4. These were the results obtained from the saturated solutions of the products after 144 hours of gentle agitation. An important finding was that the quality of pulverised rock limestone for use in an alkaline sodic-soil environment was poor, contrary to some popular claims, although it may be eminently suitable for nutrition in a highly leached or in a strongly acid environment.

There were slight differences in the composition of the saturated solutions from the gypsum products. It was interesting that, when mixed with pulverised limestone, the solubilization of calcium was slightly enhanced, whilst that of magnesium and sodium was suppressed. In contrast, this enhancement of calcium solubility was slightly less when earth lime was used in the mix, but the magnesium solubility was slightly enhanced while the sodium remained suppressed.

The enhancement of calcium solubility by the by-product gypsum was probably due to the presence of small amounts of residual phosphoric acid, as reflected in the pH of the saturated solution of by-product gypsum. This residual acid would also account for the slightly lower sulfur content resulting from mixes with the by-product gypsum.

Table 4 pH and elemental concentrations of saturated solutions after 144 hours

Product or 1:1w/w mix	Calcium me/L	Magnesium me/L	Sodium me/L	Sulfur me/L	pH
Pulverised lime (P)	1.2	0.1	0.1	0.1	8.7
Earth lime (E)	2.1	0.8	0.1	2	8.7
By-product gypsum (B)	30.8	0.2	0.4	32.2	4.8
Hughenden gypsum (H)	31.6	0.2	0.4	32.2	7.7
Winton gypsum (W)	32.4	0.5	0.6	33.8	7.8
PB	34.0	0.0	0.0	31.8	7.8
PH	34.7	0.0	0.0	33.6	7.8
PW	35.3	0.2	0.0	34.5	7.8
EB	33.4	1.6	0.0	33.4	7.8
EH	33.8	1.3	0.0	34.2	7.9
EW	35.4	1.5	0.0	35.7	7.8

3.3.4 Repeated product dissolution of gypsum samples

While initial solubility of the gypsum in the products results in the attainment of saturation in a relatively short time, this test clearly demonstrates the marked differences in the ability to repeatedly generate saturated or high concentration solutions of gypsum over time (Figure 4). These would be required to rapidly ameliorate the soil to a level where productivity would be sufficiently improved to ensure a reasonable rate of cost recovery/return on the investment in the ameliorant.

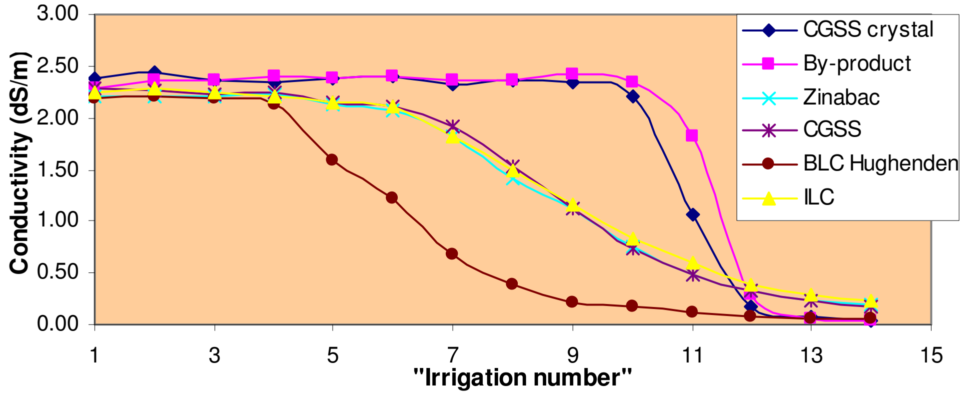


Figure 4 Repeat gypsum solubilities

The changes in calcium and sulfur concentrations (Figure 5) follow very closely a similar pattern, as expected. This will influence the persistence of the calcium in solution to exchange with the soil sodium in the amelioration process.

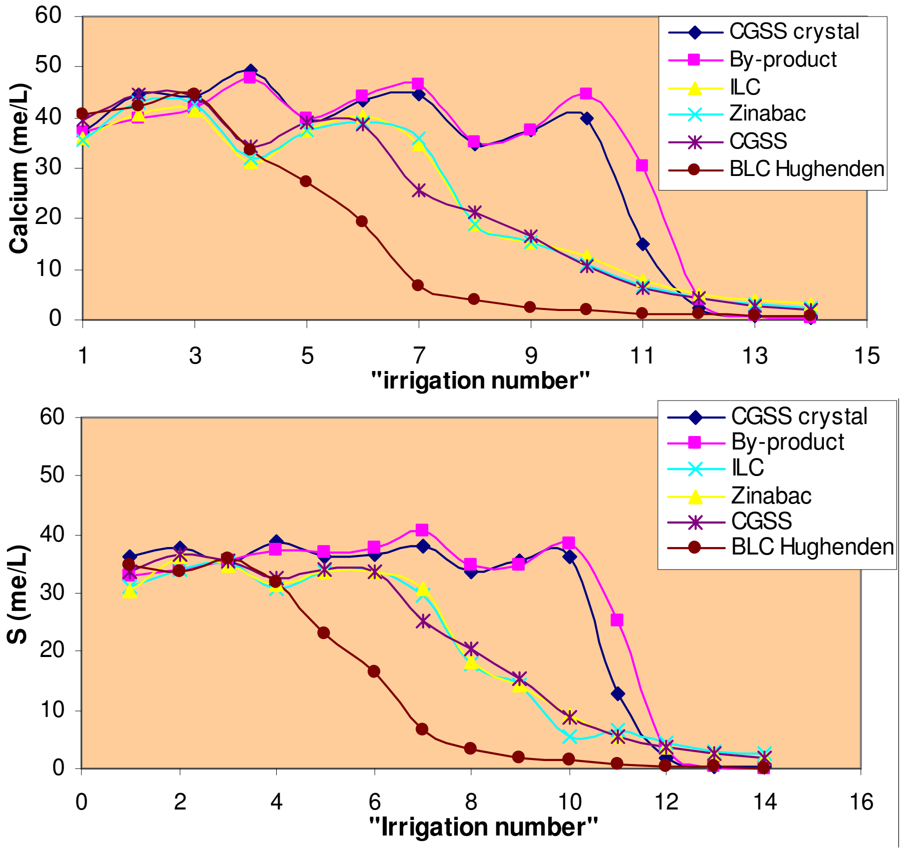


Figure 5 **Changes in calcium (upper) and sulfur concentrations (lower) following gypsum dissolution**

3.4 Conclusions

The implications for gypsum used for amelioration of sodic soils are that purity of product (i.e. chemical composition), particle-size distribution and rate and persistence of product in the soil are all interlinked in determining the probable efficacy of any particular product. There is a clear need for regular determination of some or all of these characters to enable product quality assessment and true cost comparisons to be made.

These relationships are summarised in the model *Gypsy* (www.clw.csiro.au/products/gypsy/). This allows the estimation of the influence of a gypsum addition on cane yield and cash flow on neutral-alkaline soils, using the relationships between yield and sodicity, and the effect of gypsum on sodicity. The inputs are cation exchange capacity and exchangeable sodium percentage for the 0-25 cm and 25-50 cm depth layers, cost and quality of the gypsum, price of cane, and a discount rate. The output is a cash-flow analysis, with a graph showing net benefit against gypsum rate.

4.0 OBJECTIVES 2 and 5 - Effect of sodicity by depth on yield in a fully irrigated environment and the relationship of these results to the application of a ‘tool kit’ for identification of sodic soils in field practice

4.1 Methods and materials

Seventeen sites with variable sodicity were selected from throughout the Burdekin district for the initial study of these aspects. Yields were measured at each site in 10-14 plots, three rows wide and each 20-30 m long, according to the uniformity of the crop in each of the sections. Accurate crop yields were determined using the BSES truck-mounted weighing unit and the contractor’s harvester to cut the pre-marked plots. All plots were in the same three rows, so variety, crop class and management factors were constant within each site. Varieties included in the study were Q96, Q117, Q127, Q133 and Q124. Crop classes were plant cane through to fourth ratoon.

Electromagnetic induction (EM38) readings were taken to measure soil salinity and soil samples were taken (0.125 m depth increments to 0.75 m) were taken from five to eight plots suitably representing the range of yields at each site. Soil from the cores was combined for each depth increment in each plot, air-dried and ground to pass through a 2 mm sieve. All samples were analysed for electrical conductivity and pH (both 1:5 soil:water), exchangeable cations (1M NH_4Cl extraction), nutrients, organic carbon (after Rayment and Higginson 1992) and particle size distribution (Gee and Bauder 1986).

All soil data collected from these sites were used in the development of a ‘tool kit’ for the identification of sodic soils (Nelson 2000, 2001).

4.2 Results and discussion

Soils examined in this study were clay-loams to clays, with neutral to alkaline pH. The data clearly showed that, for irrigated conditions in the Burdekin, the decrease in crop production was considerably greater at 2.1 t ha^{-1} per 1% increase in exchangeable sodium percentage (ESP) of the 0.25-0.50 m depth interval (Figure 6) than what we reported for rain-fed conditions at Mackay. Soil electrical conductivity ($EC_{1:5}$) and ESP, weighted for depth, together accounted for 79.5% of the variation in yield over all sites. Sodicity- and salinity-related parameters ($EC_{1:5}$, electro-magnetic induction meter readings, exchangeable Na content and ESP) were highly correlated.

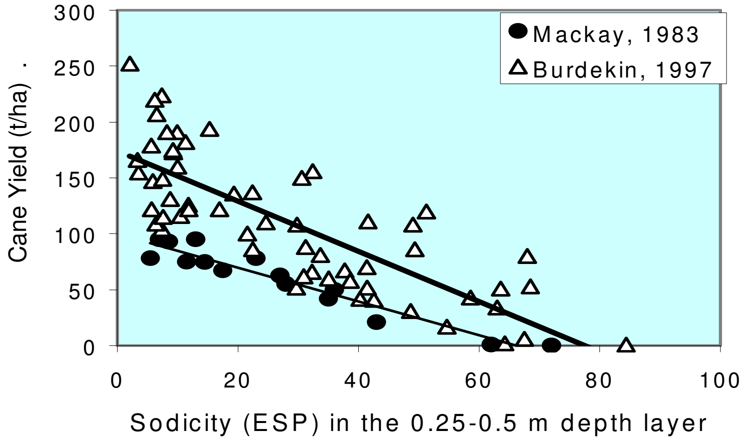


Figure 6 Relationship between cane yield and sodicity (ESP) in the 0.25-0.5 m depth layer at Mackay and Burdekin

The results of this study were included in the paper by Nelson and Ham (2000) (Appendix 8), which incorporates the linkage with the 'tool kit' for the identification of sodic soils (Nelson 2000, 2001).

5.0 OBJECTIVES 3 and 4 - Test commercially available products and other ameliorants by placement methods for relative effectiveness and determine the mechanisms/extent of action of the ameliorants and reasons for their longevity of operation

5.1 Test commercially available products – Irrigation management to increase productivity

5.1.1 Methods and materials

As the result of the workshop discussions, a replicated trial to examine the impact of changing the frequency of irrigation was established on a sodic soil in the Burdekin. The site was typical of the sodic soils of the area having increasing sodicity with depth (Table 5) and rising sharply at the topsoil/subsoil interface.

Table 5 Soil properties at trial establishment

Depth (mm)	pH	SEC (dS/m)	ESP
0-150	6.17	0.199	12.85
150-300	6.81	0.276	15.53
300-450	7.45	0.453	22.01
450-600	8.02	0.662	25.23
600-750	8.49	0.883	26.32

The trial was established as a randomised complete-block design with four irrigation scheduling treatments and five replicates. Each plot was six rows wide and 30 m long, with the centre four rows being used for cane- and sugar-yield determination. The layout of the trial is shown in Appendix 3. The irrigation schedules were to replace crop-water use on a daily, 3-day, 7-day and ‘conventional’ irrigation frequency (which ranged from 9-14 days). Irrigation applications for the first three treatments were scheduled using a mini-pan, which was correlated with a class A evaporation pan. The fourth ‘conventional’ schedule was run at the grower’s normal practice for irrigating the remainder of the un-ameliorated section of the field. Rainfall data were collected to allow adjustment of irrigation as appropriate.

Subsurface trickle irrigation was used to irrigate the whole trial. The system was automated to control the water application using a multi-station controller to regulate the hydraulic control valves. Adjustments to the controller settings to apply the required volumes were made based on the mini-pan evaporation. Correct applied water volumes were confirmed by checking with an in-line water meter. Water applied was filtered via a sand filter and then a disc-filter system to remove the fine suspended material present in the irrigation channel supply. Regular reverse flushing of the sand filter and disc cleaning was necessary to ensure desired flow.

5.1.2 Results and discussion

The greatest impact on production was found typically in ratoon crops (Figure 7). No significant cane or sugar yield or CCS differences occurred in the plant crop, but highly significant ($P \leq 0.01$) cane-yield differences were obtained in the first- and third-ratoon crops. Cane yields in the second-ratoon crop just failed to reach significance ($P \leq 0.05$), but exhibited the same trend as the other ratoon crops. Significant differences in CCS levels were found only in the second-ratoon ($P \leq 0.01$) and third-ratoon ($P \leq 0.05$) crops, whilst for sugar yield, significant differences were recorded for the first- ($P \leq 0.05$), second- ($P \leq 0.05$) and the third- ($P \leq 0.01$) ratoon crops (Appendix 2).

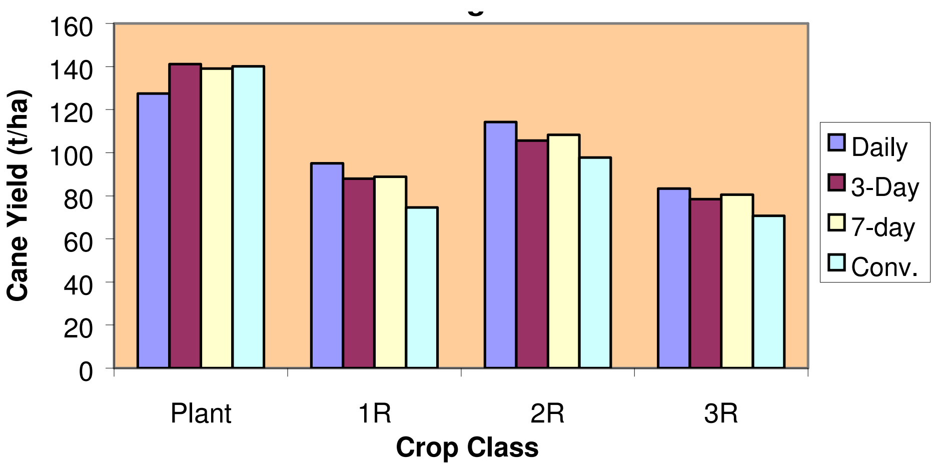


Figure 7 Crop yields in response to irrigation frequency

This apparent lack of response can be attributed to the prevailing rainfall pattern during the crop's growth, and the lower yields reflect the effect of prolonged waterlogging during that time (Figure 8). Throughout the rapid growth period of the second-ratoon crop, an 'abnormal' rainfall pattern persisted with rain in excess of 10 mm falling, on average, at intervals of 6.9 days with a range of 1-16 days. Figure 8 shows the rainfall pattern for the period from harvest of the first-ratoon crop to the end of the rapid growth of the second-ratoon crop. This does not include falls of <10 mm, which also added to the wet conditions, making access to the site particularly difficult given the soil type. Access to the site to alter the irrigation settings in accord with the rainfall pattern was also very difficult, but was largely effected through the co-operation of the farmer. The result of this was that irrigation demand in accordance with the treatments was largely maintained, enabling meaningful yield data to be obtained.

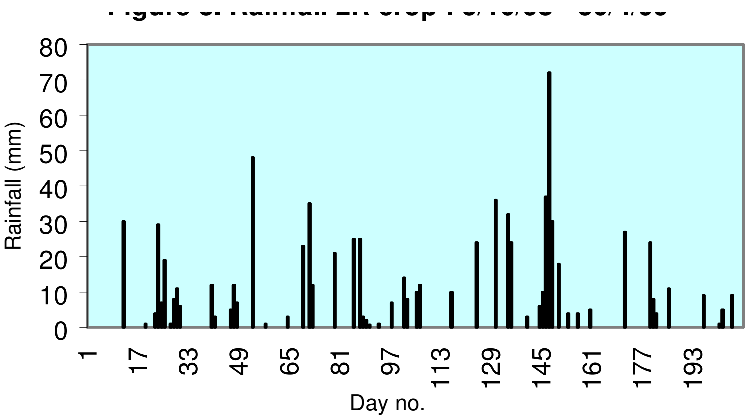


Figure 8 Rainfall in the second-ratoon crop 5 October 1998-30 April 1999

The grower ploughed out this field following the harvest of the third-ratoon crop.

5.1.3 Conclusions

The trial has indicated that significant cane yield improvement can be expected from more frequent irrigation. In practical terms, shortening the irrigation cycle to about 6-7 days would seem to be a manageable target for furrow irrigation on these soils, while gaining significant yield improvement from changed farm practice in a non-ameliorated environment.

5.2 Test ameliorants by placement methods for relative effectiveness and determine the mechanisms/extent of action of the ameliorants and reasons for their longevity of operation

A series of trials was established in Mackay, Proserpine, Burdekin and on the Atherton Tableland to test a range of the commercially available ameliorants. Treatments were chosen in relation to the established type of alkalinity and were not the same across regions. The site originally chosen at Sarina was later abandoned when it became apparent that sodicity was not a significant problem. Crops across regions varied from being rainfed to irrigated.

5.2.1 Methods and materials

At all trial sites, soil samples were collected from the trial area for nutrient analysis. Base fertiliser requirements were applied in accordance with BSES recommendations to ensure that nutrient supply was not a limiting factor.

All soil samples taken for chemical analysis in this series were collected, air-dried, ground to pass a 2 mm round-holed sieve and stored in airtight plastic containers. Samples for aggregate stability analysis were collected as core samples from the respective depth intervals in two randomly chosen replicates of the trials, crumbled to assist air-drying, thoroughly mixed, sub-sampled and stored pending analysis for aggregate stability (Gradwell and Birrell 1979).

5.2.1.1 Mackay trials

Mackay trials were established on *acid* sodic soil sites as shown by the establishment data in Table 6. Both trials were planted to the variety Q124. Plots in the trials were 20 m long by six rows, with the centre four rows weighed for yield determination and sampled for CCS analysis. Each trial contained three replicates in a randomised complete-block design. Yield data were collected using the BSES weighing unit.

Table 6 Soil establishment data for Mackay trials

Parameter	Bussey (#1)		Craig (#2)	
Soil depth (mm)	0-250	250-500	0-250	250-500
ESP	5.7	14.2	13.75	28.12
pH	5.2	5.8	5.89	6.49
EC (dS/m)	0.1	0.1	0.07	0.15

Treatments applied to each site are set out in Table 7. A mill mud/mill ash mix was included at one site, but not the other where trash retention was applied. Both sites had limited irrigation available, with trial #1 having sufficient for one irrigation for crop establishment or a single later application (in spring), whilst site #2 had sufficient water for three irrigations.

Table 7 Treatments applied in the Mackay trials

Treatments	Trial #1	No.	Trial #2	Treatments	Trial #1	No.	Trial #2
Control + Trash	Yes	1	Yes	Ash 50 t/ha	Yes	7	Yes
Gypsum 2.5 t/ha	Yes	2	Yes	Ash 150 t/ha	Yes	8	Yes
Gypsum 5 t/ha	Yes	3	Yes	Ash 450 t/ha	Yes	9	Yes
Gypsum 7.5 t/ha	Yes	4	Yes	Control + Trash*	Yes	10	No
Gypsum 10 t/ha	Yes	5	Yes	Mud/Ash 150 t/ha	No	10	Yes
Gypsum 2.5 t/ha/yr	Yes	6	Yes				

*Second replicate of this treatment was included to allow for other treatments that were not eventually applied.

Soil samples for chemical analysis were collected from each plot for analysis after each harvest, whilst samples for additional physical analysis were collected from selected treatments in trial #1after harvest of the last crop at that site.

Trash blankets were retained at both sites.

5.2.1.2 Proserpine trials

The initial trial (Proserpine #1) in variety Q124 at Proserpine was centered on gypsum and mill mud. Treatments were gypsum at 2.5, 5, 7.5 ,10 t/ha and 2.5 t/ha annually or mill mud at 50,100,150 and 200 t/ha compared to an untreated control in a randomised complete-block of three replicates. The trial field was irrigated with a lateral-move overhead irrigation system, newly installed. A subsequent trial established in another field on this farm the following year was abandoned after very poor germination from repeated waterlogging of the field in a particularly wet year.

At another farm, a trial (Proserpine #2) was established in 1999. This trial incorporated a different range of treatments and was established in the rust-resistant variety Q138. Included in the treatments were gypsum at 2.5 t/ha annually, 5 and 10 t/ha, agricultural lime at 2.65 and 5.3 t/ha, gypsum 5t/ha + 2.65 t/ha agricultural lime (equivalent calcium amounts from each source), molasses at 10 t/ha, agricultural lime 2.65 t/ha + molasses at 10t/ha and N-Cal (a 12.2% $CaCl_2$- 5%N solution) at 1250 L/ha (= gypsum 5 t/ha according to manufacturers). This was a three replicate randomised complete-block design of 10 treatments, including an untreated control. Soil samples were collected from individual plots at establishment and after each harvest.

5.2.1.3 Burdekin trials

A trial to examine the rate of ameliorant application by placement position was established on an alkaline soil in the Jardine area of the Burdekin (Burdekin #1). Eight treatments were included in the four-replicate trial, with each treated plot being 25 m by four rows wide. The trial area was cultivated with a multi-type grubber four times during land preparation for planting. Replicates were separated from each other by a 20 m gap in order to allow room for 'leading-in' the subsurface placement equipment. Treatments included an untreated control, 5, 10, 15 and 20 t/ha of surface-applied Winton gypsum and three treatments of 5 t/ha surface-applied Winton gypsum with either 5 t/ha micro-fine gypsum, 0.95 t/ha elemental powdered sulfur, or 2.8 t/ha sulfuric acid applied at the interface of the A and B soil horizons. The sulfuric acid was uniformly distributed from a constant head system through winged tynes fitted with flow spreaders. The solid products were air-blown through specially modified winged tynes to provide uniform distribution at the interface. The layout of the trial is shown in Appendix 6. Soil samples were collected from individual plots at establishment and after each harvest for chemical analysis, with additional samples from selected plots for physical analysis. All products were incorporated by discing into the surface 125 mm soil.

A second large replicated trial was established in conjunction with a grower's testing of a range of products to overcome a poor growth problem (Burdekin #2). Three replicates of applications of: 1)normal fertilizer; 2) 1 +10 t gypsum/ha; 3) 250 t mud-ash/ha + 0.5 normal fertilizer; 4) 3 + 10 t gypsum/ha; and 5) 250 t mud-ash/ha + 1 were established as 100 m long plots in the top, middle and bottom sections of the field. Soil sampling was confined in a zone 5 m wide either side of a predetermined transect across the trial plots, in an effort to reduce the soil variability that would be the consequence of whole-of-plot random sampling.

5.2.2 Results and discussion

From the analysis of sodic soils, both in the general field-crop situation and in smaller areas used for trials as in this study, the spatial variability of sodicity can be quite high. Consequently, this variability can have a substantial impact on the results obtained from soil analysis in such trials (although the impact of this is minimized through blocking). The columnar subsoil structure commonly associated with these soils can influence the results from randomly sampled plots within trial sites, especially when these plots are re-sampled after each crop harvest for several years.

This variability encountered is well illustrated by the ESP values obtained from e.g. the 0-250 mm and 250-500 mm depths of trial #1 at Mackay at establishment (Table 8).

Table 8 ESP values at trial #1 establishment, Mackay

Trial area	0-250 mm				
Rep. 3	4.7 6.5	8.5 10.4	7.9 11.2	4.7 5.6	2.5 3.4
Rep. 2	8.0 7.7	4.5 4.9	4.8 6.2	3.0 4.1	3.7 3.3
Rep. 1	9.1 4.7	8.2 4.0	4.5 3.7	5.4 4.0	6.6 4.3
	250-500 mm				
Rep. 3	11.7 18.0	19.0 26.4	18.0 24.3	13.1 16.1	5.9 11.3
Rep. 2	15.9 18.3	10.1 12.1	9.1 13.7	12.4 8.9	11.7 8.1
Rep. 1	24.1 13.2	16.9 11.5	12.9 11.7	15.6 10.4	12.1 14.3

5.2.2.1 Mackay trials

Two factors mitigated against obtaining more reliable yield results from these trials: two abnormally wet seasons, and the outbreak of orange-rust disease in the variety Q124, which was planted at both sites.

Both trials showed some significant yield responses (Appendix 4) and some marked changes in ESP values as a result of treatments, which were centered on gypsum or mill ash applications with only one mill mud/mill ash treatment. Changes in ESP of the soils occurred following establishment, as illustrated by results from trial #1 (Bussey’s) (Figure 9). Gypsum treatments provided the major change, especially where rates of 5 t/ha or greater were applied, but changes were initially confined to the topsoil (Figure 9). The initial increase in ESP of the subsoil could be attributed in part to the displaced sodium from the topsoil being confined to this subsoil layer in the short term. Ash treatments were not as effective in consistently reducing sodicity in either depth interval. These changes are further illustrated by the progressive ESP changes relative to the control treatments in trial #2 (Craig) (Figure 10).

Treatment	No.
control (untreated)	1
2.5t Gypsum	2
5t Gypsum	3
7.5t Gypsum	4
10t Gypsum	5
2.5t Gypsum/year	6
50t ash	7
150t ash	8
450t ash	9
control (untreated)	10

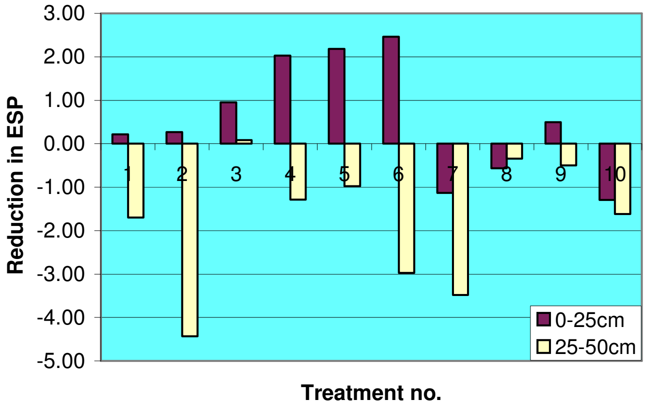


Figure 9 Change in ESP from 1996 to 1998 in Mackay trial #1

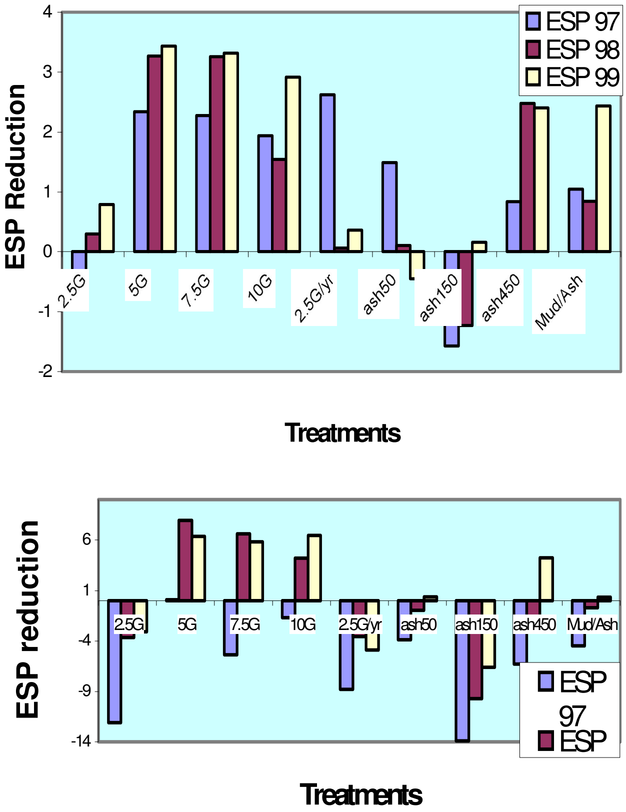


Figure 10 Mean change in ESP relative to the Control in Mackay trial #2 in the 0-250 mm (upper) and 250-500 mm levels (untreated controls not shown)

Yield results from both trials (Figures 11 and 12) show the response to treatments with mill ash at all rates having an advantage over most other treatments, persisting through to the later ratoons, although with diminished effect. Significant yield differences were obtained only in the plant and first-ratoon crops in trial #1and only in the plant crop of trial #2 (Appendix 4). However, the rankings of the treatments changed over time, with gypsum treatments rising in the ranking. This was in line with the changed soil aggregation measured.

Treatment	No.
control (untreated)	1
2.5t Gypsum	2
5t Gypsum	3
7.5t Gypsum	4
10t Gypsum	5
2.5t Gypsum/year	6
50t ash	7
150t ash	8
450t ash	9
control (untreated)	10

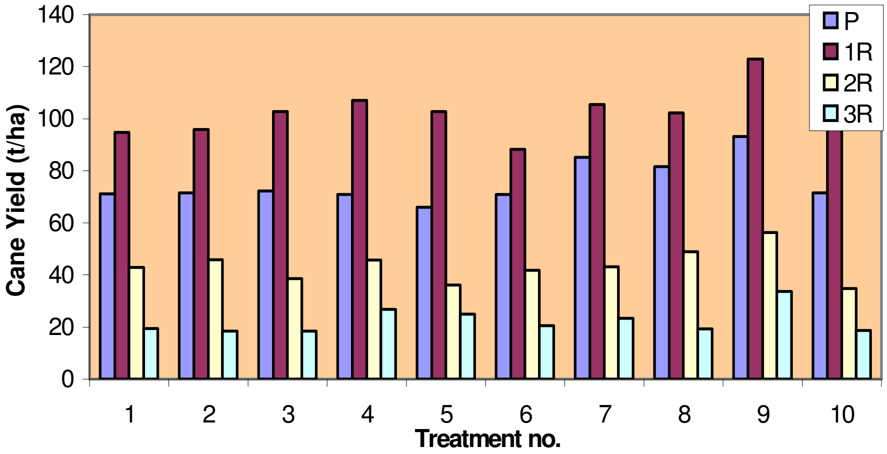


Figure 11 Crop yields in Mackay trial #1

Treatment	No.
control (untreated)	1
2.5t Gypsum	2
5t Gypsum	3
7.5t Gypsum	4
10t Gypsum	5
2.5t Gypsum/year	6
50t ash	7
150t ash	8
450t ash	9
150t mud/ash	10

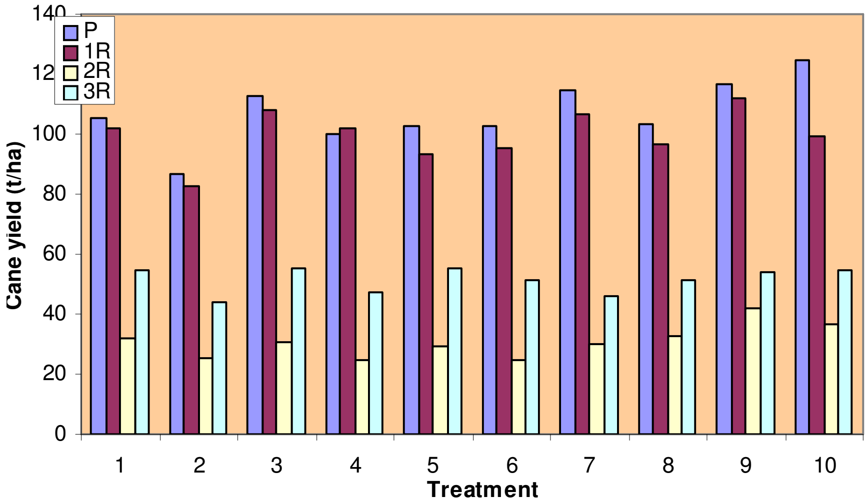


Figure 12 Crop yields in Mackay trial #2

The deceasing yield with increasing ESP relationship, similar to that obtained in previously reported work (Nelson and Ham 2000), was maintained even with decreases in ESP due to the treatments applied. Despite this, the overall reduction in ESP at the initiation of consecutive crops was illustrated by the data from trial #2 (Figure 13). The rate of reduction of yield per unit of ESP rise was reduced in the later crops, despite their lower yields.

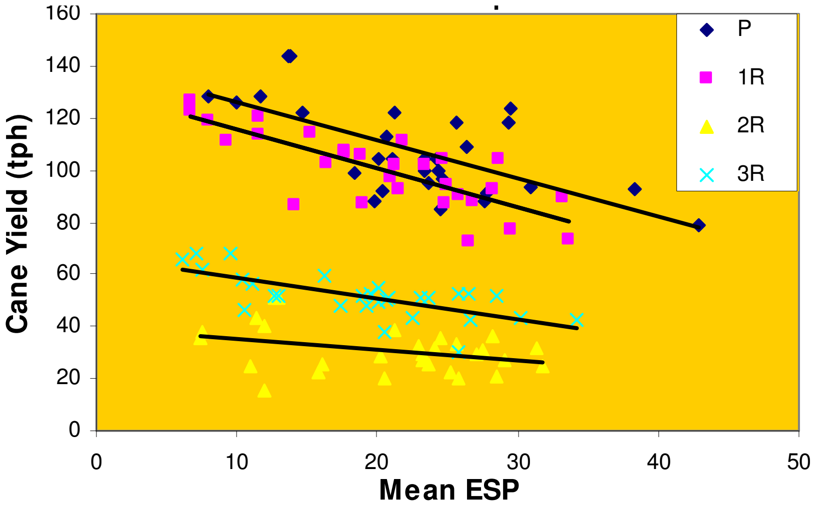


Figure 13 **Relationship between cane yield and mean ESP (0-500 mm) in different crops of Mackay trial #2**

However, for a positive reduction in ESP, the yield increment is small, poorly related and not always consistent with the trend shown in Figure 14. Further data analysis e.g. total yield for crop cycle versus total change in ESP, to try to develop more definitive relationships, has not provided better correlations, although this has been complicated by the impact of disease on crop yields in this instance.

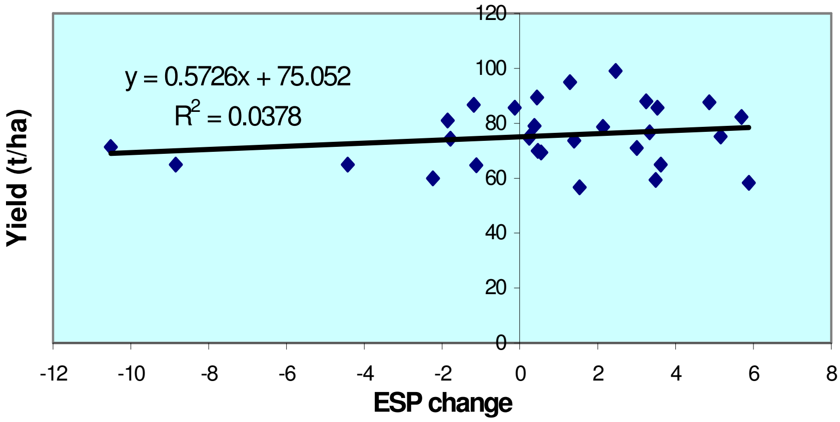


Figure 14 **Relationship between cane yield and change in ESP at 250-500 mm**

Although crop yield responses were not of the magnitude as might have been expected from changes in ESP, measurement of changes in soil physical structure has clearly demonstrated the change due to ameliorant application. It was found that the mean weighted diameter (MWD) of aggregates in the plots that received gypsum at 10 t/ha had increased by 7.0% and by 61.1% compared with the control (untreated soil) in the 0-250 mm and 250-500 mm intervals, respectively (Figure 15) at the end of the crop cycle. Aggregation had been improved by this treatment. In contrast, the MWDs in the high ash treatment (450 t/ha) were reduced by the presence of the ash by 36.6% and 18.3% for the respective depth intervals. This can be attributed to the high volume of fine, particulate material incorporated into the soil, which maintained a loose, friable soil condition adding to available soil moisture storage in the shorter term, but not resulting in improved stable soil structure. The individual nature of the small particles of mill ash material has contributed to the reduction in MWD.

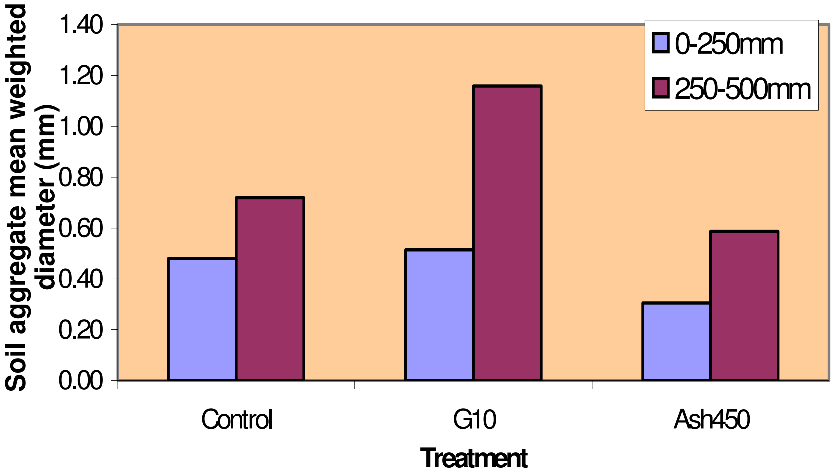


Figure 15 **Aggregate distribution as the mean weighted diameter (MWD) in Mackay trial #1**

5.2.2.2 Proserpine trials

The initial Proserpine trial (#1) was also centred on gypsum and mud/ash treatments at a range of rates per hectare. Although the plant crop showed some significant responses to treatments, there was doubt about the reliability of the results, as some of the plots had suffered considerable cultivation and irrigation damage. The first-ratoon crop had developed a reasonable crop, and was harvested to retrieve any useful information (Figure 16); the three higher rate mud/ash treatments produced significantly ($P \leq 0.05$) higher yields (t/ha) of cane and sugar than all other treatments; it is not possible to attribute this to soil property changes alone. The lowest rate mud/ash treatment and gypsum at 7.5 t/ha also gave significant ($P \leq 0.05$) cane yield increase over the control and lowest rate gypsum treatments, but for sugar yield 7.5 t/ha gypsum out-yielded the lower rate gypsum treatments and the control whilst 10 t/ha gypsum and low rate mud/ash was superior to the low rate single application of gypsum ($P \leq 0.05$). However, the onset of a severe rust infection in the Q124 curtailed the collection of further useful data.

Treatment	No.
control (untreated)	1
2.5t Gypsum	2
5t Gypsum	3
7.5t Gypsum	4
10t Gypsum	5
2.5t Gypsum/year	6
50t mud/ash	7
100t mud/ash	8
150t mud/ash	9
200t mud/ash	10

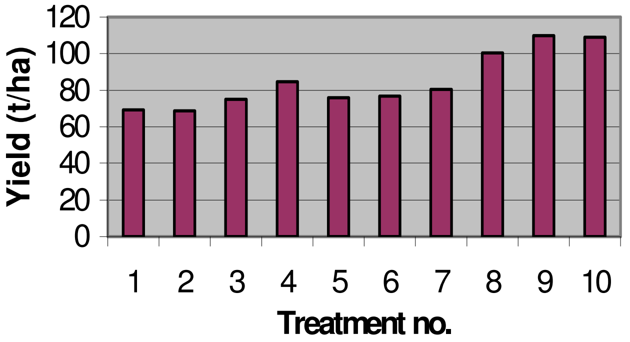


Figure 16 First-ratoon crop yields in Proserpine trial #1

In the trial established on a low salinity, acid sodic soil (Table 9) at Proserpine (#2), no significant differences ($P<0.05$) were found in the crops for any parameter, but the general trend for cane and sugar yield favoured the higher rates for gypsum and lime treatments with or without molasses (Figure 17; Appendix 5). Treatments containing molasses performed poorly in the plant crop but seem to have improved substantially in the first- and second-ratoon crops.

Table 9 Means of soil properties at establishment in Proserpine trial #2

Depth (mm)	pH	ESP	Conductivity (dS/m)*
0-250	5.53	21.2	0.162
250-500	5.94	24.4	0.388

*1:5 soil:water suspension

Treatment	Number
control	1
G5	2
G10	3
G2.5 annual	4
lime 5.3	5
G5+lime2.65	6
N-cal(=G5)	7
lime2.65+mol.10	8
molasses10	9

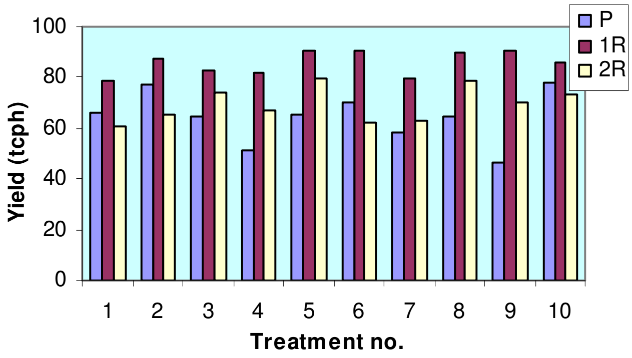


Figure 17 Crop yields in Proserpine trial #2

Whilst significant yield effects were absent in these crops, some impact on the crop appears to be supported by the water-extraction patterns for four of the treatments during the rapid growth phase of the first-ratoon crop. A sample of these extraction/accession patterns is shown in Figure 18. The gypsum and molasses treatments (each at 10 t/ha) have improved both water entry to and extraction from the soil by the crop compared with the control treatment, whilst the pattern for the lime treatment is more erratic. An improvement in structural stability of sodic soils by the application of molasses and gypsum, either alone or in combination, was reported by Suriadi *et al.* (2002) and these yield results suggested a time lag in this effect occurred in this study. These data (Figure 18) have been collected from only one replicate of the trial using an EnviroSCAN, in conjunction with the Rural Water Use Efficiency Initiative. The impact of changes in soil water availability on stalk elongation (Figure 19) was similar to the crop response found by Ham *et al* (1995) to the application of gypsum to a sodic, alkaline soil. The growth in the control treatment lagged behind the other three treatments, although any differences between them are much less pronounced. Data in Table 10 show the changes for the ESP values by treatment over the crop cycle. It is apparent that gypsum at 10 t/ha has had the greatest effect in the profile to 0.5 m. Reductions in ESP by gypsum at 5 t/ha, lime at 5.3 t/ha, molasses at 10 t/ha and gypsum-lime mixture are similar, but a little less, while lime at 2.65 t/ha is less again, especially in the 0.25-0.5 m interval. These data further support the evidence on improved soil aggregation being the result of reduced ESP with its associated soil structural benefits, eg improved soil water availability. It was notable that lime in this acid soil environment could provide similar benefits to gypsum even if at a slightly lower magnitude. The impact of molasses opens a path for further close field examination of its possible benefits.

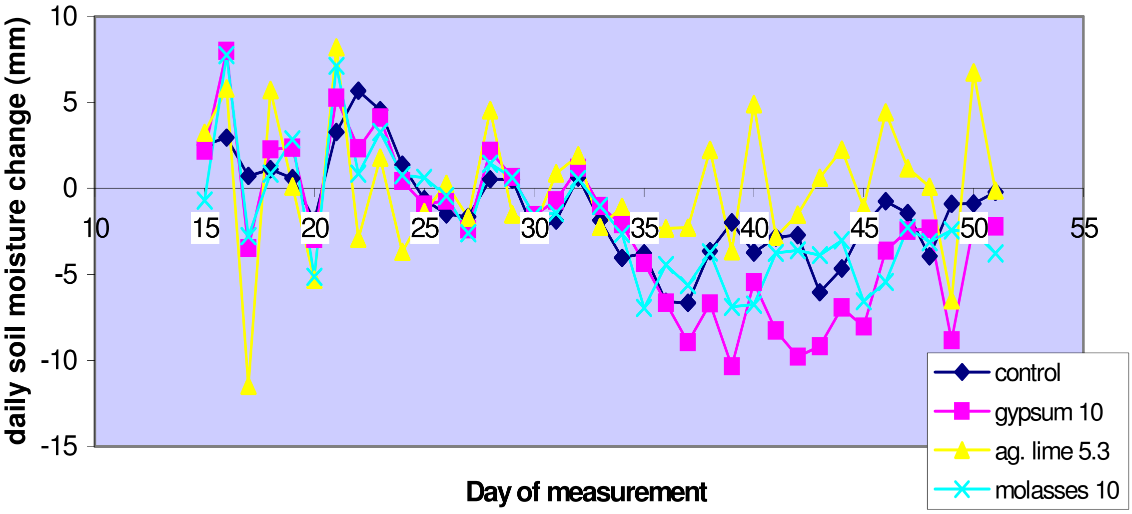


Figure 18 Changes in soil moisture in the first-ratoon crop of Proserpine trial #2

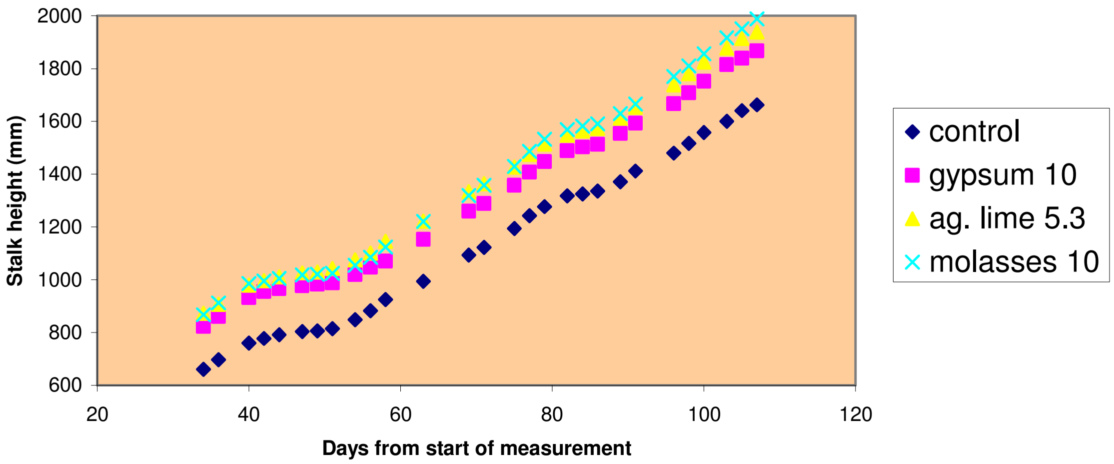


Figure 19 Stalk elongation over 75 days in Proserpine trial #2

Table 10 Mean changes in ESP by treatments over the crop cycle in Proserpine trial #2

Treatment*	Soil depth	
	0-250 mm	250-500 mm
Control	-8.59	2.32
G5	-7.05	-5.2
G10	-11.17	-6.32
G2.5 annual	-15.91	-0.94
Lime 5.3	-7.02	-3.89
G5+lime2.65	-4.67	-6.95
N-cal(=G5)	-1.28	-0.22
Lime2.65+mol.10	-6.18	1.23
Molasses10	-5.04	-7.53
Lime2.65	-6.38	-1.26

*no. = tonnes product/ha; - change =fall, + change =rise

5.2.2.3 Burdekin trials

Yield data from Burdekin trial #1 are shown in Figure 20.

Yield data from this trial are disappointing and less than that from similar commercial crops in the district. This can be largely attributed to crop management. Despite requests/advice to increase irrigation frequency on this low-water-availability soil, irrigation practice was below that desired and it is considered that the magnitude of the responses to the respective treatments have been masked to some degree. In addition, the drying-off schedule for the crops was extended in each instance in the ratoon crops to a later round of harvesting, but without further irrigation or rainfall. The lower than desirable irrigation frequency could be expected to have had an impact on the rate of reaction of the applied products. This also added to difficulties in soil sampling because of the extremely dry condition of the soil.

Treatment	No.
control	1
10tG/ha	3
15tG/ha	4
20tG/ha	5
5tG/ha	2
5tG/ha+0.95tS/ha	7
5tG/ha+2.8tSulfuric/ha	8
5tG/ha+5t.microG/ha	6

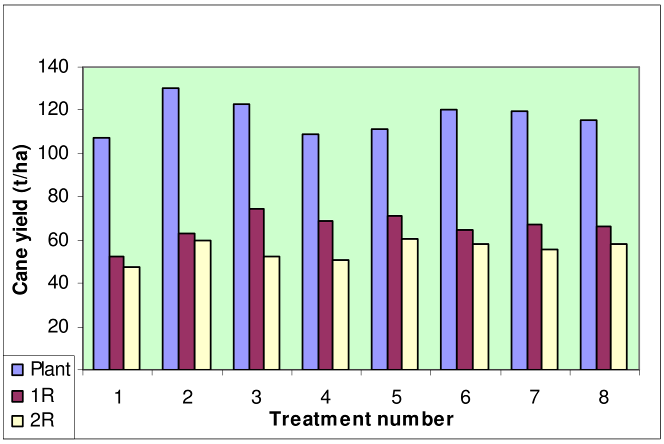


Figure 20 **Cane yields of different crops in Burdekin trial #1**

Although there were no significant differences for any character in these crops, there were changes in the relative rankings of the respective treatments, with the highest rate of gypsum and the interfacial placement treatments moving up the yield listing over time (Appendix 7). The salinity produced by the gypsum application rates may also have had an impact on crop yield as soil EC (1:5 soil:water) was sufficiently high (Figure 21) to expect a slight reduction in crop yield (Schroeder and Kingston 2000).

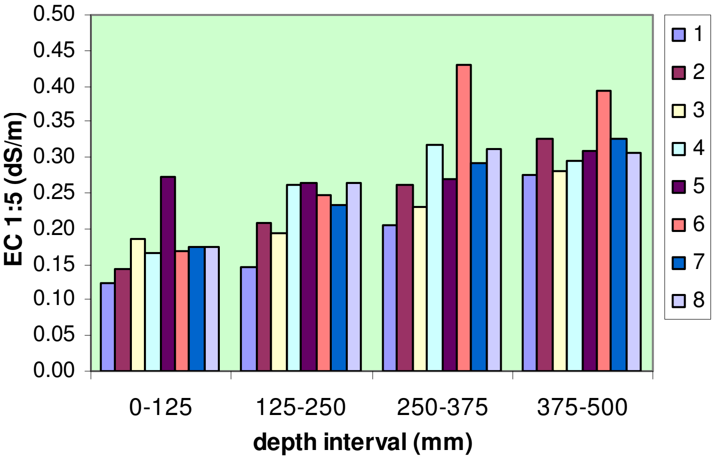


Figure 21 **Mean soil EC values at the start of the first-ratoon crop of Burdekin trial #1**

However, by the end of the second-ratoon crop, the impact of the dissolved gypsum on EC had dissipated except for small rises in the 375-500 mm interval of treatments 1, 2, 4, 7 and 8 (Figure 22).

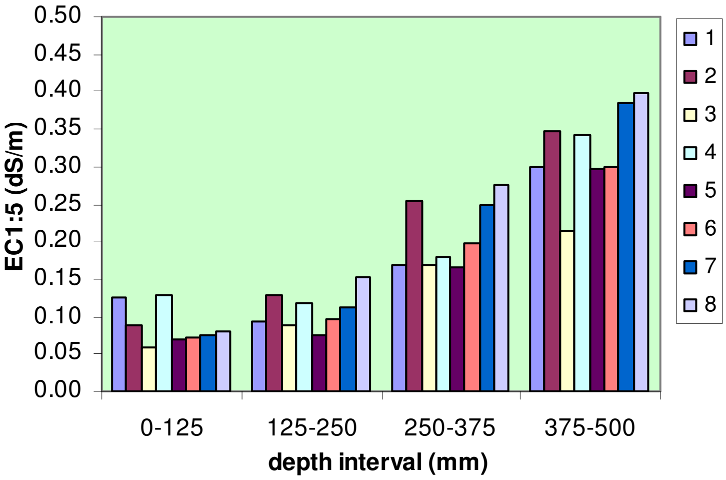


Figure 22 **Mean soil EC values at the end of the first-ratoon crop of Burdekin trial #1**

Changes in the mean ESP were variable. In the untreated plot, there was a displacement of sodium from the 0-375 mm interval by irrigation/rainfall, alone with a resultant increase in the 375-500 mm interval (Figure 23). There had been little to no change in the 0-250 mm zone with the reduction by the 5 t gypsum/ha confined to this zone, the displaced sodium accumulating in the 125-375 mm interval. All but gypsum at 20 t/ha and gypsum at 5 t/ha plus sulfuric acid at 2.8 t/ha had not reduced the ESP of the 375-500 mm interval. By far the greatest impact on ESP of the profile sampled was gypsum at 20 t/ha, indicating that the sodicity of the soil required high rates of application to reduce the ESP to an acceptable level of 6. Despite the reduction of ESP in the 0-125 and 125-250 mm zones to 3.7 and 5.2, respectively, for the 250-375 and 375-500 mm depth intervals, ESP values remained high at 13.8 and 17.8, respectively, although they each had been reduced by >11 units. That the gypsum+acid treatment had reduced ESP at 375-500 mm suggested that some dissolution of calcium carbonate nodules in the profile had taken place, but not to the extent anticipated. Although the ESP reductions in the 125-375 mm interval generally are not large, there has been an impact on soil aggregation in this zone. The MWD of aggregates for 0-375 mm for four of the treatments showed (Figure 24) that the effect of ameliorants has been greatest in the intervals in close proximity to the application. The improvement in aggregate size and wet stability in the 0-125 mm interval for the G10 and G5+S treatments is apparent and greater than for the G5+G5s treatment. The impact of the applied ameliorant in the 125-375 mm interval for the G5+G5s treatment was much greater than for the other treatments (Figure 24), which was due to the solubilisation of ameliorant, both from above and at the surface/subsoil interface. A further contributing factor would have been that the ESP of the G5+G5s treatment were 2-4 and 5-6units higher in the 125-250 and 250-500 mm intervals respectively than the other treatments. This has resulted in their effects being more confined. A contributing factor to the different ESP values at these depths was undoubtedly the laser levelling operation carried out on the field during its development for production.

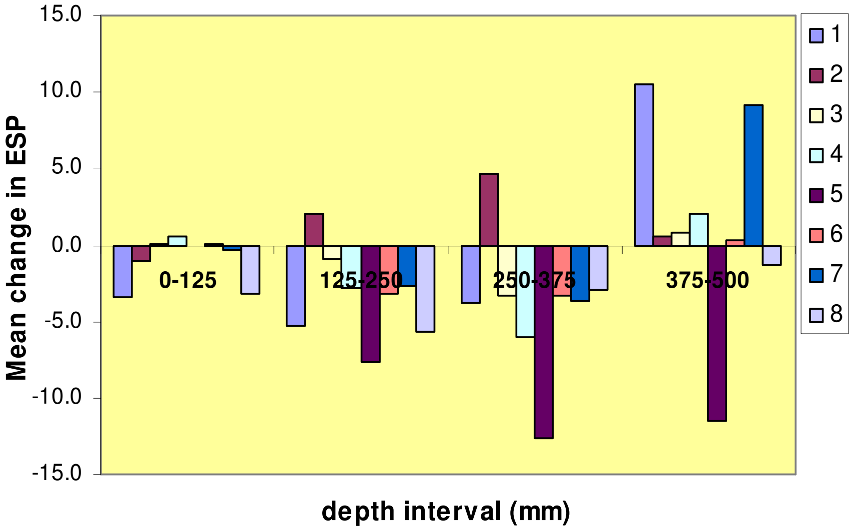


Figure 23 Mean changes in ESP over two crops in Burdekin trial #1

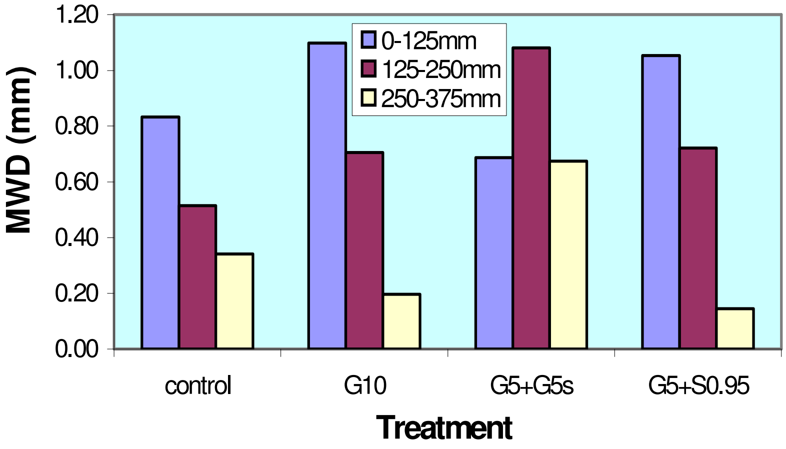


Figure 24 Treatment impact on MWD in Burdekin trial #1

Nonetheless, these data show that ESP reduction and improved soil structure, both in aggregate stability and wet strength, have been effected by the use of these ameliorants and would be expected to improve yields significantly under a suitable management regime. Distribution of ameliorant gypsum within the soil profile could be improved by the use of a dissolvenator (Ham *et al.* 1995), particularly if use was commenced early in the cultivated phase of crop production in both plant and ratoon crops.

The results of Burdekin trial #2 are summarised in Table 11. The trial was an opportunity to utilise an intended product application by the grower to gain further information on product efficacy. It was subsequently found that only the middle section of the block had a significant sodicity problem.

There were no significant responses ($P \leq 0.05$) to the treatments in the either crop Table 11). There were, however, significant differences ($P \leq 0.05$) between replicates in all cases in the ratoons; this reflects the difficulty in trying to use large plots in the very variable soil environment found in sodic soil field situations. No meaningful data was able to be collected in the second-ratoon crop due moderate to severe stool tipping of the variety (Q127) and variable canegrub damage across the trial.

Table 11 Yield data (t cane/ha) from plant and first-ratoon crops of Burdekin trial #2

Treatment	Material applied	Field position					
		Top		Middle		Bottom	
		Plant	1R	Plant	1R	Plant	1R
1	Normal fert.	166.3	145.1	128.2	118.7	114.1	132.2
2	1+ 10 t gyp.	191.5	147.9	140	119.8	122.9	132.3
3	250 t mud+1/2 fert	199.9	141.6	146	125.6	135.8	134.3
4	3+10 t gypsum	181.5	141.8	143.3	120.5	121.2	125.1
5	250 t mud+full fert	173.6	142	133.7	124.9	144.8	127.7

Only where gypsum applications were made in this trial were there consistent reductions in ESP (Table 12); establishment ESP values ranged from 7.7-17.5 in 0-125 mm, 16.9-23.9 in 125-250 mm and 23.9-43.0 in the 250-500 mm depth intervals. Whilst the absolute values of the ESP changes may be subject to the inherent sampling difficulties associated with sodicity, it was reasonable to conclude that the gypsum applications were effective in reducing ESP and producing the associated soil benefits, as was demonstrated in the other investigations reported earlier. The mill mud-ash mixture has not been effective in reducing ESP in the soil profile to 0.5 m.

Table 12 Mean changes in ESP by applied products during Burdekin trial #2

Treatment	Material applied	ESP change			
		0-125 mm	125-250 mm	250-375 mm	375-500 mm
1	Normal fert.*	3.56	0.34	6.03	3.37
2	Treat.1+ 10 t gypsum	-3.32	-3.32	-11.35	-11.45
3	250 t mud/ash+1/2 fert.	4.07	5.06	9.40	8.67
4	Treat.3+10 t gypsum	-9.50	-10.15	-3.09	-5.57
5	250 t mud/ash+full fert.	-0.71	-2.19	3.22	2.01

*based on soil analysis

5.2.3 Conclusions

Particular ameliorants used in the correct environment have been shown to improve soil properties. The mechanism for these changes has been an effective reduction in ESP of the soil accompanied by an increase in aggregate size, stability and wet strength. An increase in aggregate size was accompanied by an increase in soil water availability, similar to that reported by Ham *et al.* (1995). It was also shown that the use of relatively chemically inert material, eg mill ash, had an initial impact on crop production but did not prove effective in improvement of soil structure or the reduction of soil ESP.

Of the materials tested, gypsum proved to be most effective across all soil environments, with encouraging results from earth lime in an acid environment. Molasses and lime/molasses results indicate that a time lag, greater than for other products, may occur before a positive response results. The impact of elemental sulfur and sulfuric acid applied at the surface-subsoil interface in an alkaline system was very limited. However, micro-fine gypsum applied in this way had an immediate positive impact on adjacent soil, the overall impact being bolstered by a simultaneous surface application and incorporation of gypsum. This subsurface method of application was slow and accompanied by difficulties in maintaining uniformity of application. It may well be more efficient to use a dissolvenator, where possible, in full or supplementary irrigation situations, to achieve deep gypsum distribution, especially during the cultivated stage of crop growth. In the case of mill mud/ash applications, the effect on crop production of any ameliorative benefit is difficult to separate from the added nutritional benefits of the mud component.

6.0 OUTPUTS

Outputs from the project are:

1. a detailed assessment of the chemical and physical properties of ameliorative products available from Mackay north;
2. a simple, rapid method to test the relative performance of ameliorative products;
3. an optimal irrigation management method for use on non-ameliorated sodic soils;
4. the quantified strong linkage between soil sodicity and crop production in an irrigated environment;
5. the impact of a range of soil ameliorants on crop production;
6. the effect of a range of soil ameliorants on soil chemical and physical properties;
7. an interlinking of this study with the development of the ‘tool kit’ for identification of sodic soils (Nelson 2000, 2001);
8. an interlinking of this study with the development of the model *Gypsy* (www.clw.csiro.au/products/gypsy/). This allows the estimation of the influence of a gypsum addition on cane yield and cash flow on neutral-alkaline soils, using the relationships between yield and sodicity, and the effect of gypsum on sodicity. The inputs are cation exchange capacity and exchangeable sodium percentage for the 0-25 cm and 25-50 cm depth layers, cost and quality of the gypsum, price of cane, and a discount rate. The output is a cash-flow analysis, with a graph showing net benefit against gypsum rate.

7.0 EXPECTED OUTCOMES

Much of the information from this and preceding investigations has been delivered to the industry at the farm level, with the result that production increases, estimated in excess of 100,000 tonnes cane worth >$2.5 million annually, have been achieved in the Burdekin alone. Definition of the extent of losses due to sodicity allow the overall cost to the industry to be calculated with some certainty and set parameters for the use and benefits from amelioration of these soils. Additional information on product quality from this investigation will enable a reduction in cost of amelioration by allowing selection of best quality and effective products, ensuring they are delivered at competitive prices. In an adverse-price environment, the best management of irrigation of sodic soils will provide a low-cost improvement to production without amelioration. The findings on soil properties will add to the understanding of the behaviour of these soils in response to amelioration, and these results will be applicable to other crops in other soil environments across Australia and overseas.

Community benefits will come from several fronts including:

1. the environment, especially water quality, will have reduced loading from farm run-off, since the changes in soil properties as a result of amelioration will reduce soil dispersion and movement to water bodies and the Great Barrier Reef lagoon;
2. the increased income generated in the community by the increased production from previously sodic soils;
3. an increase in irrigation efficiency on these soils; and
4. a small increase in local jobs, as distributor networks for the products develop or have developed.

8.0 FUTURE RESEARCH NEEDS

Several issues remain to be resolved from this study. In particular:

1. the longevity/durability of the impact of successful amelioration to enable the assessment of declining efficacy or reversion caused by the repeated application of waters containing residual bicarbonate or high sodium content;
2. the impact of repeated ameliorant additions to soils on deep drainage properties of the soils and, hence, on issues such as irrigation efficiency, nutrient leaching, particularly where there are underlying aquifer systems as in the Burdekin;
3. the interaction between soil amelioration using gypsum and shallow watertables (<2 m and often saline);
4. the potential for the manipulation of saline-sodic irrigation waters to provide a satisfactory pathway for the introduction of calcium sources to enhance the Na-Ca exchange for amelioration;
5. field efficacy of molasses, alone or in combination with gypsum or lime, in acid or alkaline environments, and
6. whilst the efficacy of gypsum applied in the irrigation water in furrow irrigation systems has been measured, no similar evaluation has been conducted for application through overhead irrigation systems.

Further detailed discussion of these research needs is contained in a paper by Surapaneni *et al* (2002).

During the course of this study, a range of other materials claimed to have ameliorative properties has been released in the marketplace with little or no supporting evidence regarding their efficacy. It may be warranted to test some of these more fully in a field situation after an initial appraisal.

9.0 RECOMMENDATIONS

Extensive dissemination of the information in this report has already taken place. Product composition and properties have been advised to individual suppliers of the products and to BSES extension staff for use in their normal advisory role. Individual growers contemplating product use have also been advised in relation to ameliorant properties. In relation to irrigation management, information on the impact of irrigation frequency on sodic soils on crop production has been widely disseminated through shed meetings, the RWUE Adoption program, to individual growers and more recently through the CSR Productivity Initiative meetings in areas affected by sodicity. Outcomes of these investigations were also provided at the CRC Sugar training workshops for the use of the Sodic Soil Toolkit, so that positive management could be applied where the toolkit was used to identify potential problem areas. These workshops were conducted in major centres of the industry.

Future actions should include

- Disseminate the information on the variation of product quality widely throughout the Australian industry, thereby allowing best choice of most effective product and price. This can be done most effectively through local networks, eg Cane Productivity Initiative, district newsletters, extension staff.
- Promote the use of the simple test of product quality to permit selection of the most economic and effective product for application.
- Examine new products now available and make an assessment of their applicability to the sodic soil situation and evaluate them in the field for their impact on crop and soil.

10.0 PUBLICATIONS ARISING FROM THE PROJECT

Nelson PN and Ham GJ. 2000. Exploring the response of sugar cane to sodic and saline conditions through natural variation in the field. Field Crops Res. 66, 245-255 (Appendix 8).

Surapaneni A, Olsson KA, Burrow DP, Beecher HG, Ham GJ, Stevens RM, Hulugalle NR, McKenzie DC and Rengasamy P. 2002. Tatura Sodicity Conference: knowledge gaps in sodicity research for major agricultural industries. Aust. J. Exper. Agric. 42, 379-387 (Appendix 9).

11.0 ACKNOWLEDGEMENTS

The analytical expertise of Mr. Michael Haysom and his staff at BSES Indooroopilly was an integral part of this project. Assistance of BSES Technical Staff, in particular, John Jackson, Bob Brandon and Kimberley Mallon is gratefully acknowledged. Support of and assistance by colleagues, Paul Nelson and Mandy Jeppesen in particular, enhanced the work undertaken in these investigations.

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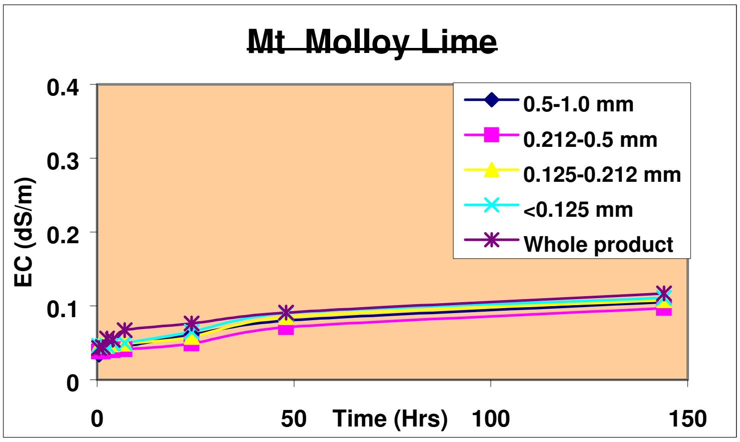
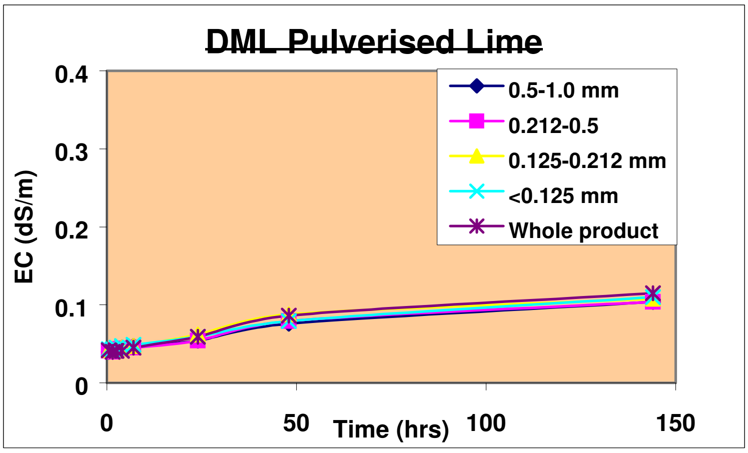
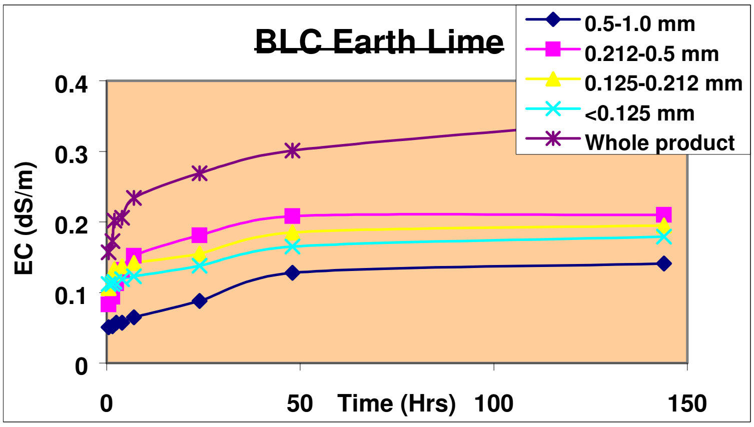
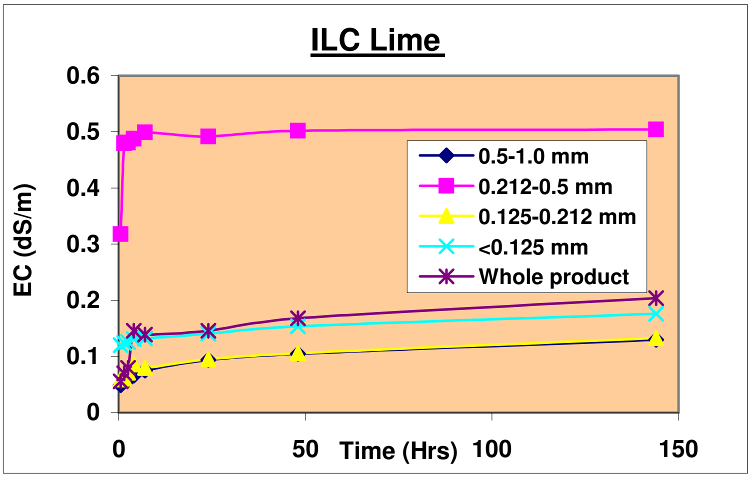
Suriadi A, Murray RS, Grant CD and Nelson PN. 2002. Structural stability of sodic soils in sugarcane production as influenced by gypsum and molasses. Aust. J. Exper. Agric. 42, 315-322.

APPENDIX 1 - Balance of product solubility curves





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0.5
0.4
0.3
0.2
0.1
0
0
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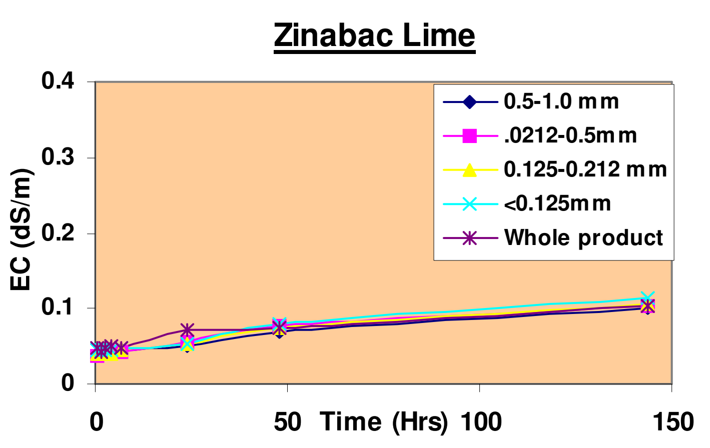
Whole product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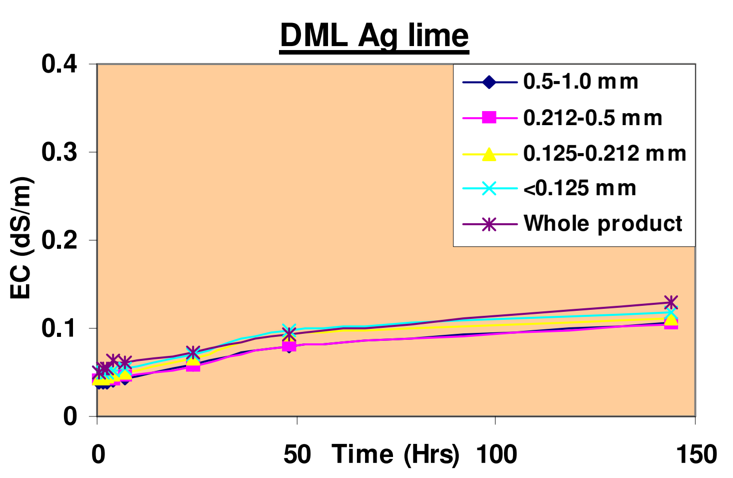
Whole product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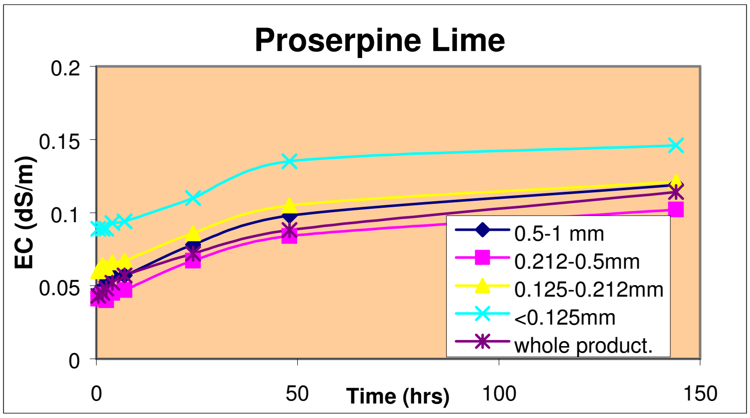
Whole product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0.1
0.05
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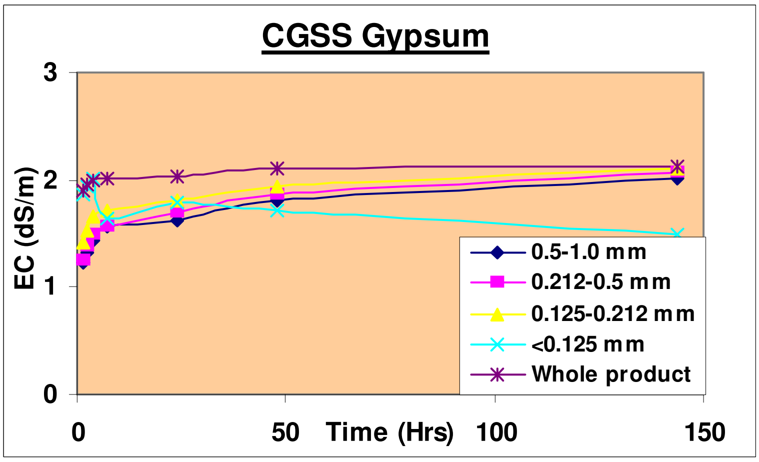
whole product.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2
1
0
0
50
Time (Hrs)
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150
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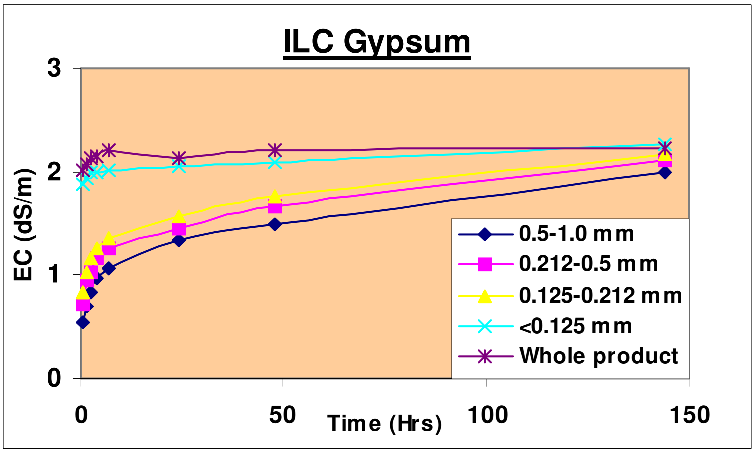
0.125-0.212 mm
<0.125 mm
Whole product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EC (dS/m)
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2
1
0
0
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Time (Hrs)
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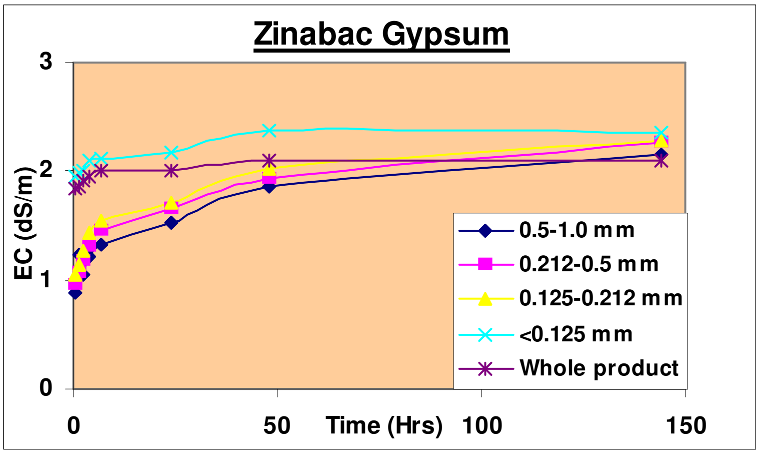
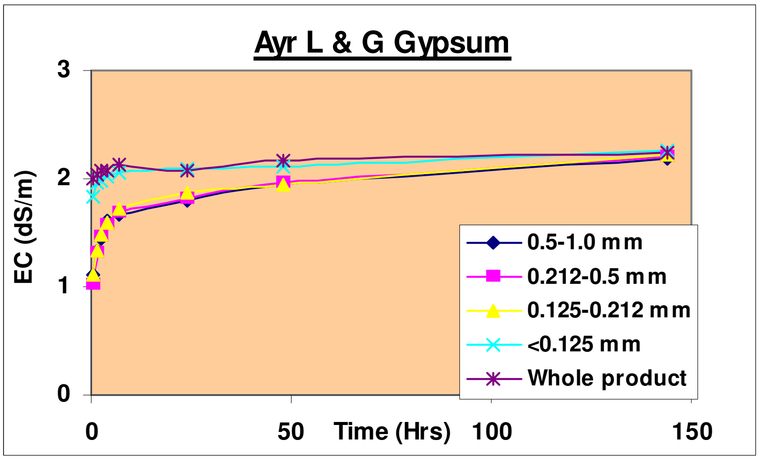
<0.125 mm
Whole product


Zinabac Gypsum
EC (dS/m)
3
2
1
0
0
50
Time (Hrs)
100
150
0.5-1.0 mm
0.212-0.5 mm
0.125-0.212 mm
<0.125 mm
Whole product


Ayr L & G Gypsum
EC (dS/m)
3
2
1
0
0
50
Time (Hrs)
100
150
0.5-1.0 mm
0.212-0.5 mm
0.125-0.212 mm
<0.125 mm
Whole product

APPENDIX 2 – Sodic soil irrigation trial summary data

Cane Yield (t/ha)

Treat. No.	Plant	1R	2R	3R
1	127.5 a	95.1 b	114.2 d	83.3 g
2	141.1 a	88.0 b	105.7d	78.5 g
3	139.1 a	88.9 b	108.3 d	80.5 g
4	140.1 a	74.6 c	97.8 d	70.7 h
	*	**	*	**

* Means followed by the same letter are not significantly different (P≤0.05)

** Means followed by the same letter are not significantly different (P≤0.01)

CCS

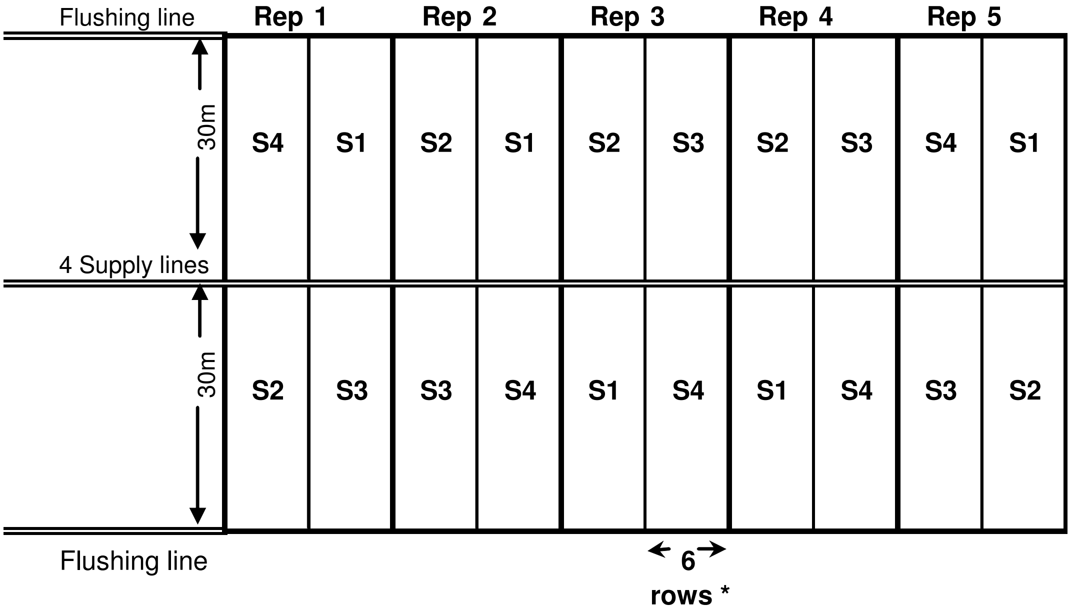
Treat. No.	Plant	1R	2R	3R
1	16.47a	16.53 b	17.10 d	16.74 g
2	16.77a	16.08 b	17.61 e	16.64 g
3	16.97a	16.13 b	16.98 e	16.10 gh
4	16.89 a	16.24 b	16.14 f	15.93 h
	*	*	**	*

Sugar Yield (t/ha)

Treat. No.	Plant	1R	2R	3R
1	21.04 a	15.71 b	19.54 d	13.95 g
2	23.65 a	14.16 bc	18.62 d	13.08 g
3	23.61 a	14.34 bc	18.33 d	12.96 g
4	23.67 a	12.12 c	15.77 e	11.27 h
	*	*	*	**

Treat. No.	Treatment
1	Daily replacement
2	3-day accumulated replacement
3	7-day accumulated replacement
4	conventional "furrow" frequency

APPENDIX 3 – Sodic soils irrigation trial layout



Rep 1		Rep 2		Rep 3		Rep 4		Rep 5	
S4	S1	S2	S1	S2	S3	S2	S3	S4	S1
S2	S3	S3	S4	S1	S4	S1	S4	S3	S2

Treatments - related to crop use.

S1 = daily replacment
S2 = 3 day accumulated replacement
S3 = 7 day accumulated replacement
S4 = "furrow" irrigation schedule

*** centre four rows harvested for yield data**

APPENDIX 4 – Yield data for Mackay trials

	Trial #1 Mackay (Bussey)				Trial #2 Mackay (Craig)			
Treatment no.	Plant	1R	2R	3R	Plant	1R	2R	3R
1	71.1	94.8	42.9	19.4	105.1	102.3	32.2	54.4
2	71.6	95.9	45.8	18.4	86.6	82.4	25.0	44.3
3	72.3	102.8	38.7	18.4	112.7	108.2	30.4	55.4
4	70.9	107.0	45.7	26.7	100.1	101.8	24.7	47.4
5	66.1	102.8	36.1	24.9	102.6	93.3	29.1	55.1
6	70.9	88.2	41.8	20.4	102.8	95.6	25.0	51.2
7	85.1	105.6	43.1	23.3	114.9	106.8	29.9	46.3
8	81.7	102.2	48.9	19.2	103.2	96.7	33.0	51.4
9	93.2	122.9	56.3	33.7	117.0	112.1	41.9	53.7
10	71.6	96.1	34.8	18.7	124.8	99.1	36.5	54.6
lsd (P<0.05)	13.89	n.s.	n.s.	9.21	18.46	n.s.	n.s.	n.s.

Treatments	Trial #1	No.	Trial #2
Control + Trash	Yes	1	Yes
Gypsum 2.5 tph	Yes	2	Yes
Gypsum 5 tph	Yes	3	Yes
Gypsum 7.5 tph	Yes	4	Yes
Gypsum 10 tph	Yes	5	Yes
Gypsum 2.5 tph/yr.	Yes	6	Yes
Ash 50 tph	Yes	7	Yes
Ash150 tph	Yes	8	Yes
Ash 450 tph	Yes	9	Yes
Control + Trash	Yes	10	No
Mud/Ash150tph	No	10	Yes

APPENDIX 5 – Yield data for Proserpine trials

Proserpine - 1R (Quod)

Treatment	treat.no.	t cane/ha	t sugar/ha
Control	1	69.3	11.36
Gyp 2.5t/ha	2	68.7	11.11
Gyp 5t/ha	3	75.0	11.92
Gyp 7.5 t/ha	4	76.0	12.72
Gyp 10t/ha	5	84.3	13.97
Gyp 2.5t/ha/ya	6	76.7	12.37
Mud-Ash 50 t/ha	7	80.7	12.75
Mud-Ash 100 t/ha	8	100.7	15.87
Mud-Ash 150 t/ha	9	110.0	17.07
Mud-Ash 200 t/ha	10	109.0	16.79
lsd (P<0.01)		10.4	1.489

Muller's trial

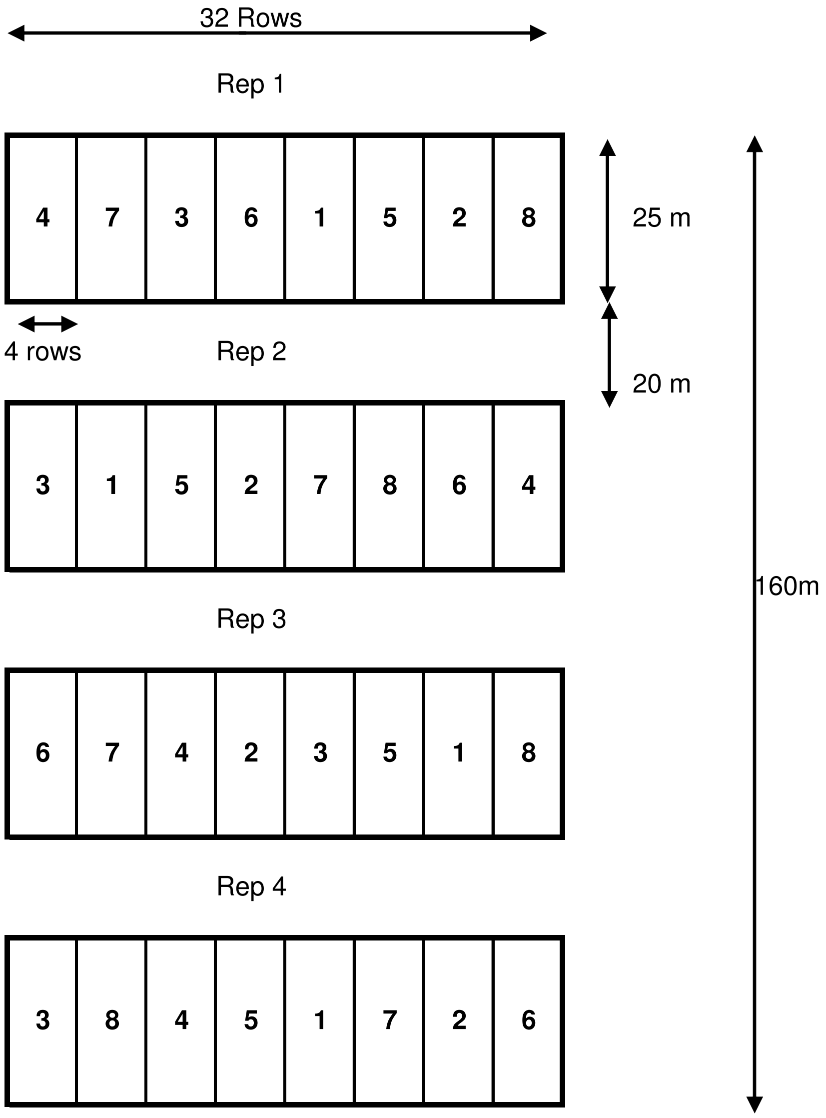
		tcph Plant	tcph 1R	tcph 2R
treat. no.	Treatment	65.9	79.0	60.5
1	control	77.3	87.1	65.2
2	G5	64.3	83.1	74.1
3	G10	51.5	81.7	67.2
4	G2.5 annual	65.7	90.3	79.6
5	lime 5.3	68.6	90.7	61.9
6	G5 + lime 2.65	58.3	79.2	62.7
7	N-cal (=G5)	64.9	89.7	78.8
8	lime 2.65 + mol. 10	46.4	90.8	70.1
9	mol. 10	78.2	85.7	73.6
10	lime 2.65			
lsd (P< 0.05)	n.s.	n.s.	n.s.	

G=gypsum; mol.=molasses; 5,10, etc = tonnes product/ha

APPENDIX 6 – Trial layout Burdekin #1

Appendix 6

Trial plan: product placement (Jardine).



Rep 1

4	7	3	6	1	5	2	8

Rep 2

3	1	5	2	7	8	6	4

Rep 3

6	7	4	2	3	5	1	8

Rep 4

3	8	4	5	1	7	2	6

Treatments	
1	Control
2	5 t/ha surface gypsum
3	10 t/ha surface gypsum
4	15 t/ha surface gypsum
5	20 t/ha surface gypsum
6	5 t/ha surface gypsum plus 5 t/ha gypsum(powder) at depth
7	5 t/ha surface gypsum plus 0.95 t/ha sulfur at depth
8	5 t/ha surface gypsum plus 2.8 t/ha sulfuric acid at depth

APPENDIX 7 – Yield data Burdekin trial #1

		Lando		
Treat. No.	Plant	1R	2R	Treatment
1	107.3	52.5	47.5	control
2	130.0	63.3	60.1	G5
3	122.8	74.7	52.6	G10
4	109.0	68.9	50.9	G15
5	110.4	70.9	60.4	G20
6	120.4	65.0	57.9	G5 + G5microfine-sub
7	119.4	67.1	56.0	G5 + 0.95t elemental sulfur-sub
8	115.8	66.7	58.0	G5 + 2.8t sulfuric-sub

G = gypsum; 5,10, etc= rate t/ha; sub = applied @ interface