

Final Report

IMPROVING THE CATION RETENTION CAPACITY OF TROPICAL SOILS USING HIGH ACTIVITY CLAYS



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Executive Summary:

The Australian sugar industry largely relies on tropical soils that have low cation exchange capacities (CEC) and are prone to becoming deficient in Ca, Mg and K without appropriate management. Adding bentonite is an option for increasing the CEC, water holding capacity and fertility of these soils. This research project investigated if bentonite treatments could indeed be used to improve the fertility of low CEC sugar producing soils and enhance commercial cane yield. Two field trials conducted on old sugarcane producing soils in the Innisfail region in the Wet Tropics of far north Queensland over the 2006, 2007 and 2008 growing seasons showed that at rates of 10 - 30 t/ha banded additions of natural sodium bentonite improved soil properties and significantly raised sugarcane yields at final harvest. The best results were achieved with 20 and 30 t/ha rates of bentonite addition, in which cane yield was increased by up to 39.6 % in comparison to an untreated control. The main mechanisms responsible for the yield increase were found to be higher plant available water content (PAWC) and increased nutrient cation availability, which led to improved canopy development, greater radiation interception and overall enhanced growth and increased biomass accumulation within stalks. The results of the field trials were supported by five individual glasshouse trials that showed that various bentonite treatments could effectively be used to enhance soil CEC, nutrient cation levels and PAWC to bring about significant yield increases on a variety of low CEC soil types. Additional important information yielded by the glasshouse trials included the discovery that rates of above 80 t/ha bentonite had a detrimental impact on soil structure leading to reduced yields. Furthermore, the effect of increased PAWC as a result of bentonite treatment on yield was found to be much stronger than initially anticipated. An economic analysis assessing the feasibility of using bentonite treatments to improve soil fertility and increase cane yields has not yet been finalized. Preliminary results of this analysis suggest that bentonite treatment can indeed be an economically feasible option for increasing production and profitability in the long term in a permanent bed system under precision agriculture. Using an example from the Wangan trial where the cane yield in the 30 t/ha treatment was 97 t/ha compared to 75 t/ha in the control: assuming a sugar price of \$480/t and a CCS of 12.5, the return per hectare for the 30 t/ha treatment is \$772 higher than that of the control. At a bentonite cost of \$336 per tonne, the cost of a banded application at a rate of 30 t/ha is \$3360. Based on the increased return of \$772 per hectare, the investment in the bentonite product would be paid off after five seasons. However, caution must be applied, as due to the high product cost of bentonite, the technique is economically unfeasible both in the short term and in a conventional farm system where the ground is reworked after three to four seasons.

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1.0 Background:

In the wet tropics of far north Queensland, Australia, sugarcane, the region's largest agricultural industry, relies almost exclusively on production from highly weathered soils with low cation exchange capacity (CEC) that renders them with a limited capacity to retain and supply essential plant nutrients. Consequently, agricultural challenges posed to sugarcane production include low fertiliser use efficiency, low maximum yield potential and high risk of uncertainty over yield levels. Additionally, declining sugar yields are a reflection of a continuing steady decline in the fertility and productivity of low CEC soils under long-term sugarcane monoculture (Bramley *et al.* 1996). To maintain economic yields on these soils, the current practice is to regularly apply large amounts of fertiliser in accordance with research-based soil and plant criteria (Calcino, 1994; Schroeder *et al.*, 2006). However, as a direct consequence of low CEC, large quantities of nutrients are rapidly lost through leaching (Gillman *et al.* 1989) which raises questions about the economic and environmental sustainability of this type of production system.

Given that low CEC permits leaching of nutrients, a potential solution to enhancing nutrient retention is to raise the CEC of soils, and a variety of approaches are available. The most common practice is to raise soil pH by adding alkaline materials such as lime. However, this creates only small increases in CEC and these are relatively short lived as tropical soils possess a limited buffering capacity. According to Croker *et al.* (2004), the only way to increase the CEC of tropical soils over the long term is to apply materials with a high CEC.

Addition of organic matter is one such option but it decomposes rapidly under the warm, wet conditions of the tropics. Consequently the amount required to maintain adequate levels of CEC is beyond the means of the average farmer (Noble *et al.* 2000). A much more efficient solution may be to add bentonite to soils. 'Bentonite' is the common term used to describe mixtures of high CEC clays consisting predominantly of smectite minerals, usually montmorillonite. When applied to low CEC soils, bentonites can bring about significant increases in the CEC simply as a consequence of their high net permanent negative charge. As a result of increasing soil CEC, bentonite can also improve the retention and availability of nutrients, enhancing agricultural productivity and improving fertiliser use efficiency (Berthelsen 2002; Berthelsen and Davis 2004; Berthelsen *et al.* 2005; Berthelsen *et al.* 2003; Berthelsen *et al.* 2004; Croker *et al.* 2004; Noble 2005; Noble *et al.* 2001; Noble *et al.* 2005; Noble *et al.* 2004a; Noble *et al.* 2004b; Noble *et al.* 2002; Soda *et al.* 2006; Suzuki *et al.* 2005) A further benefit of bentonite is that it has the capacity to increase plant available water (PAW) as a function of increasing porosity (Soda *et al.* 2006; Suzuki *et al.* 2005).

To date, research on the use of bentonites as soil conditioners has been largely confined to light textured soils. Light textured soils are undoubtedly important for sugarcane production in the wet tropics, but clay loams such as Ferrosols occurring on undulating low basaltic and alluvial fans account for approximately 30 % of the sugarcane producing soils in the wet tropics (Murtha 1986; Murtha *et al.* 1994; Murtha and Smith 1994; Schroeder *et al.* 2006). Furthermore, the bulk of the previous research has focused on the use of engineered cation-beneficiated bentonites and waste bentonites as opposed to raw natural bentonites. As natural bentonites have a lower cost than beneficiated bentonites these have a greater potential of being an economically feasible means of improving soil fertility and enhancing commercial sugarcane production.

In light of the promising results of previous work in the field the major question that this study asked was: 'Are natural bentonite treatments an effective and environmentally beneficial means of modifying the chemical and physical properties of low CEC soils to improve these for sugarcane production and ultimately raise commercial sugarcane yields?' In answering this question, the research explored the influence of natural bentonite treatments on the physical and chemical properties of low CEC sugarcane producing soils, and subsequently plant yields (including

commercial sugarcane production). Additionally, the economic feasibility of treatment in the current economic climate was also evaluated.

2.0 Objectives:

2.1 Major objectives

The major objectives of the research project were to:

- Improve farm profitability and industry performance by improving fertiliser use efficiency in permanent bed farming systems on low CEC soils.
- Improve the ability of soils with low CEC to retain Ca, K, Mg and N by applying high activity clays.
- Minimise environmentally detrimental aspects of fertiliser application, by improving the retention of NH_4 and NO_3 in soils prone to a loss of N.
- Understand the mechanisms whereby HAC additions influence soil properties and crop growth

2.2 Research questions

Major Research Question: Is bentonite treatment an economically viable means of enhancing sugarcane production on low CEC soils of the tropics?

Specific Research Questions:

1. To what extent can bentonite increase the CEC and enhance the retention of Ca, K, Mg and N in low CEC soils?
2. How does bentonite addition influence PAWC in low CEC soils?
3. Does the effectiveness of bentonite in enhancing production vary with soil type?
4. What are the interactions between bentonite addition and inorganic nutrient management?
5. Can bentonite influence yield and commercial cane sugar content (CCS)?
6. Is the use of bentonite in a permanent bed system an economically viable option for increasing commercial sugar productivity?

3.0 Methodology:

A variety of research activities including field trials, glasshouse trials, laboratory analysis, and cost benefit analysis were employed to answer the research questions posed by this study.

3.1 Field trials

The most important activity of project was two field trials conducted in the Innisfail region of North Queensland; one at Wangan and one at Mourilyan. The Wangan and Mourilyan study sites are underlain by two contrasting low CEC soil types common to the Innisfail region. The soil at Wangan is a medium textured clay loam classified as a Red Ferrosol (Isbell 2002) or a Mundoo soil (Murtha 1986). The soil at Mourilyan is a light textured sandy clay classified as a Red Kandosol under the Australian Soil Classification (Isbell 2002) and as a Brosnan soil according to Murtha (1986). The major nutritional factors identified as negatively impacting on sugarcane yield on these soils are very low levels of available K, P, Si and to a lesser extent Ca, Mg and Zn (Schroeder *et al.* 2006).

The Wangan trial was laid down in August 2006 and the Mourilyan trial one year later in July 2007. Soil fertility and yields were monitored in both the plant crop and first ratoon crop at Wangan over the 2006 and 2007 growing seasons. At Mourilyan only the plant crop over the 2007 growing season was studied.

GreenLight-RedLight Odyssey™ (GLRL) capacitance probes were installed in the control and 30 t/ha treatments at both trial sites to continuously measure soil water content at 10, 30, 50, 70 and 90 cm depth below the surface. Both trials were exclusively rainfed.

3.1.1 Wangan trial

A randomised block design was used and the original (conventional) row spacing of 1.52 m was maintained. The trial area consisted of 15 plots in total, each five rows wide (~7.5 m) by 15 m long. Plots were arranged in three rows (replicates) of five plots, separated by two metre long buffer zones. Datum areas in the center of each plot measuring three rows wide and 5 m long were used for manual yield measurements.

3.1.2 Mourilyan trial

A randomised block design was used and the original (conventional) row spacing of 1.63 m was maintained. The trial area consisted of 16 plots in total, each five rows wide (~8 m) by 15 m long. Plots were arranged in four rows (replicates) of four plots, separated by five metre long buffer zones. Datum areas in the center of each plot measuring three rows wide and 5 m long were used for manual yield measurements.

3.1.3 Bentonite treatment

A natural sodium bentonite called ‘Trubond™’, sourced from Unimin Australia Limited’s operating site near Miles in Queensland, was utilized in both trials. In both trials the bentonite was applied as a band 50 cm in width along the planting rows. Although a permanent bed system as such was not in place at either site, GPS precision farming technology allowed the bentonite to be applied directly to the previously existing cane rows. At Wangan bentonite was applied at rates of 0, 5, 10, 20 and 30 t/ha in a concentrated band. These application rates are equivalent to broadcast application rates of 0, 1.6, 3.3, 6.6 and 10 t/ha. At Mourilyan bentonite was applied in a band at rates 0, 10, 20 and 30 t/ha, equivalent to broadcast rates of 0, 1.6, 3.3, 6.6 and 10 t/ha. At Wangan each treatment was replicated three times, while at Mourilyan there were four replicates. At both sites, the bentonite was incorporated into the top 0.15m of soil.

All plots were planted to cane cultivar Q186 at Wangan and Q166 at Mourilyan using a billet planter approximately one month after the application of bentonite. At both sites fertiliser was applied to the plant crop at planting and along the rows of the newly emerged crop four weeks after planting. All treatments at Wangan and Mourilyan, including the untreated control, received a total of 120 kg N/ha as ammonium nitrate, 20 kg of P/ha as superphosphate, 100 kg of K as muriate of potash, and 434 kg of Ca/ha and 75 kg of Mg/ha as a calcium magnesium carbonate blend. At Wangan the ratoon crop was side dressed with 130 kg N/ha as ammonium nitrate, 20 kg of P/ha as superphosphate, and 100 kg of K as muriate of potash approximately four weeks after the plant cane was harvested.

3.1.4 Yield monitoring

Yield monitoring activities carried out at both trials over the growing season(s) consisted of periodic stalk/shoot counts, eight-month biomass harvest, final hand and mechanical harvest, and laboratory determination of moisture content, fibre and commercial cane sugar (CCS). Stalk population density (number of shoots or stalks per m²) was determined at 2, 4, 6, 8, 10, 32 and 52 weeks. A destructive biomass sample was taken from each plot at 8 months by hand harvesting the end 1 m section of each row at ground level (5 m² from each plot). The total fresh weight (\pm 0.1 kg) of stalks in each plot was recorded using a weigh cradle. Three 10-stalk subsamples were taken from each plot and partitioned into trash (defined as dead leaf and dead sheaths), green leaf blades, cabbage (defined as the growing point of the stalk plus green leaf sheaths), and millable stalk. After weighing in the field, yield components were fibrated and oven dried at 80°C for 48 h for the

determination of dry biomass. A 5-stalk sample was also taken from each plot for determination of specific leaf weight (SLW, leaf dry weight per unit area) and leaf area.

The cane crop at both sites was harvested when mature at 12 months. The datum area was sampled by hand, to obtain precise yield measurements, and then within a few days the remaining cane standing in each plot was harvested mechanically. All the cane within the datum sampling areas (15 m²) in each plot was harvested at ground level by hand over two days. Total fresh weight (± 0.1 kg) was determined using a weigh cradle. Two 10-stalk subsamples were taken from each plot and partitioned into trash, millable stalks and cabbage, and the fresh weight and dry biomass determined as at 8 months. Five stalks randomly sampled from each plot were retained for SpectraCane analysis for the determination of CCS. Again a 5-stalk sample was taken from each plot for determination of SLW and leaf area. Within one day of the final hand harvest the remaining cane of the trial was harvested green using a mechanical harvester and BSES weigh truck.

The trash, green leaf, cabbage and millable stalk fresh and dry matter yields were determined on per hectare basis from the total fresh weight, the component proportion of the total above-ground material on a fresh weight basis, and the dry matter content of each component. The net above ground biomass was calculated as the sum of the dry weight of the individual yield components. Cane yield (t/ha) was calculated as the product of the total fresh weight in each datum sampling area and the proportion of millable stalks on a fresh weight basis. Sugar yield (t/ha) was calculated as the product of the mean cane yield (hand harvested) and mean CCS in each datum sampling area. The cane yields derived from the mechanical harvest of each plot were used primarily to provide a comparison to the hand harvest results.

Following the final harvest of the plant crop at Wangan, trash (previous crop residue) was retained and the existing stools allowed re-grow normally to produce the first ratoon crop. All activities conducted in the plant crop were repeated for the ratoon crop.

3.2 Glasshouse trials

Five individual pot trials were conducted in a glasshouse to further investigate the effect of bentonite treatments on soil properties and plant yield, and more particularly, to gain a better understanding of the importance of bentonite treatments in reducing nutrient losses via leaching and governing PAWC in soils. Unlike the field trials, the glasshouse provided a controlled environment in which watering could be regulated and microclimate effects (e.g. edge effects) eliminated. Under these controlled conditions, soils could be maintained at field capacity, and the leachate draining from pots collected, measured and analysed, allowing both nutrient losses to be quantified and nutrient and PAWC effects on plant yield to be separated.

Each of the individual glasshouse trials conducted as part of this investigation were specifically designed to provide information on an aspect of the research objectives of the project that could not to be conclusively determined in the field. Trial 1 was designed to investigate the effect of a wide range of low to high rates of bentonite application on soil properties in an effort to define an 'optimal' rate of bentonite addition. Trial 2 tested the effectiveness of different bentonite types in enhancing soil fertility and raising yields to determine if different bentonite types could be used to achieve the same results. Trial 3 trialled bentonite treatments on three contrasting low CEC soil types to ascertain if the response to bentonite treatment differed between soil types. In Trial 4, all pots were constantly maintained at field capacity to ensure that plants were never exposed to moisture stress, allowing the nutrient effect of bentonite treatments on yield to be separated from the PAWC effect. The final trial, Trial 5 investigated the effect of bentonite treatments on yield in a sugarcane variety developed for poor soils (Q200) and a variety suited to richland soils (Q230) to determine if the response to bentonite treatments differed with variety. In addition to addressing a specific research objective, each individual glasshouse trial also aimed to contribute to the general body of data by providing information on the effect of bentonite treatments on the physical (texture, hydraulic conductivity, stability) and chemical properties of soil (pH, charge characteristic), plant

yield, the leaching of N as NH_4 and NO_3 , and PAWC. More detailed methodology for the glasshouse trials can be supplied upon request (email: anna.satje@jcu.edu.au).

3.3 Analytical methods

Standard analytical methods were employed in the analysis of soils, leaf samples, and leachate samples. The only analytical methods requiring further definition are those used to determine basic exchangeable cations and soil water characteristics. Basic exchangeable cations were determined by atomic absorption spectrometry after replacement with 0.1 M $\text{BaCl}_2\text{-NH}_4\text{Cl}$ as recommended by Gillman and Sumpter (1986). Soil pH was measured in distilled water at a soil:solution ratio of 1:5 for four replicates of each treatment. Particle size distribution was determined using a Malvern X (Mastersizer X) after samples were treated with a 30 % hydrogen peroxide (H_2O_2) solution and placed in a water bath at 60°C for three days to remove organic matter. Volumetric soil moisture content and bulk density were calculated after oven drying soil cores at 105°C for 48 hrs. Particle density was determined by the pycnometer method (Blake and Hartge 1986). Porosity was derived from bulk density and particle density. Saturated hydraulic conductivity was measured by the falling head method (Klute and Dirksen 1986). The matric potentials of samples were adjusted to -20, -10, -6, -5, -3, -2 and -1 kPa by the suction table method (Romano *et al.* 2002) and to -50 and -100 kPa by the pressure plate method (Dane and Hopmans 2002), and measured by the freezing point depression method (Suzuki 2004). Field capacity was determined as the soil moisture content at -10 kPa for the Mourilyan soil (Kandosol) and -20 kPa for the Wangan soil (Ferrosol), while the wilting point was determined at -1500 kPa. Plant available water (PAW) was determined as the difference between the field capacity and wilting point.

3.4 Statistical methods

The SPSS Statistics package no. 17 was used for the statistical analysis of data. Analysis of variance (ANOVA) was used to assess the significance of differences between the treatments. Regression analysis was used to further explore the relationships between treatments and variables.

4.0 Outputs:

The main results of the field trials have been presented to the industry in the publications listed below. At the present time the major project output, the final thesis, has not yet been completed. The final thesis is 30% complete with the two largest research components, the sugarcane field trials having been written up. Remaining chapters to be completed include the introduction, glasshouse trials, economic analysis, discussion and the conclusion.

5.0 Intellectual Property:

Other than the standard university regulations there is no intellectual property.

6.0 Expected Outcomes:

The results of this research have conclusively shown that bentonite treatments at rates ranging from 5 to 30 t/ha can significantly enhance the structural stability, water holding capacity, nutrient cation retention and Si content of low CEC sugarcane producing soils to bring about marked yield increases in sugarcane (up to a 39% increase in cane yield at a 30 t/ha rate of addition). Enhanced long-term soil fertility and higher cane yields translate to a higher level of farm sustainability and profitability. While the current cost of the bentonite product renders the use of bentonite treatment as a means of enhancing sugarcane productivity as economically unfeasible in a conventional

farming system, in a permanent bed system under precision agriculture, bentonite treatments, as shown by this study, have the potential to be economically viable. As more growers in the industry move to permanent bed farming systems it is expected that the use of bentonite to enhance soil fertility, reduce nutrient run-off and raise cane yields on low CEC soils will become common practice. An Australian bentonite production company 'Pacific Environmin Ltd' is already preparing to service this anticipated demand by developing a fleet of trucks capable of delivering bentonite to farms and applying this to paddocks as a banded treatment (similar to mill mud application).

7.0 Future Research Needs:

This study has clearly shown that bentonite treatments can significantly enhance the retention of nutrient cations, suggesting that the rate of current fertiliser additions may be able to be reduced. However, this study was unable to conclusively quantify if, and by how much, fertiliser additions could be reduced by without impacting on sugarcane yield. A future investigation focussing on this aspect of bentonite treatment could yield potentially valuable results that may lead to enhanced fertiliser use efficiency and a reduction in fertiliser application rates.

8.0 Recommendations:

Sugarcane growers relying on low CEC soils for production, particularly those in the Wet Tropics, should be encouraged to consider the use of bentonite treatments in a permanent bed system to enhance the long term fertility of their soils, raise cane yields and overall improve their farm sustainability and profitability. However, growers need to be cautioned that in many cases the use of bentonite may be economically unfeasible, particularly in the short term, and thus a careful and thorough farm specific cost benefit analysis must be completed before making the decision to utilise bentonite treatment.

9.0 List of Publications:

Satje A. and Nelson P.N. 2009. Bentonite treatments can improve the nutrient and water holding capacity of sugarcane soils in the wet tropics. *Proceedings of the Australian Society of Sugar Cane Technologists* 31, 166-176. Republished in *Sugar Cane International* Sep-Oct 2009 Vol 27 Issue 5 183-196.

Satje A. and Nelson P.N. 2008. Improving the cation retention capacity of tropical soils using bentonite (poster paper). *Proceedings of the Australian Society of Sugar Cane Technologists* 30, 590

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The Research Organisation is not a partner, joint venturer, employee or agent of SRDC and has no authority to legally bind SRDC, in any publication of substantive details or results of this Project.

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