# BENTONITE TREATMENTS CAN IMPROVE THE NUTRIENT AND WATER HOLDING CAPACITY OF SUGARCANE SOILS IN THE WET TROPICS

By

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**KEYWORDS: Cation Exchange Capacity, Low Fertility Soils, Nutrient Cations, Bentonite Clays, Plant Available Water.**

## Abstract

THE Queensland 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 and improving the fertility of these soils. In a light textured Red Kandosol and a medium textured Red Ferrosol the basic CEC at soil pH was increased significantly by adding bentonite. The increases in surface charge are permanent and the correlation between the amount of bentonite applied and the change in CEC was linear. Significant increases in CEC of >1.0 cmol(+)/kg were achieved in both soil types at application rates of 20 t/ha and CECs >4.0 cmol(+)/kg were achieved at application rates of 50 t/ha. Bentonite at rates as low as 10 t/ha significantly increased the concentration and retention of applied nutrient cations. At application rates of 20 t/ha and above, natural sodium bentonite additions complemented by conventional nutrient management effectively maintained adequate levels of exchangeable Ca, Mg and K in soils under sugarcane over a full growing season (62 weeks), while nutrients in the untreated controls became deficient through leaching after just four weeks. Bentonite also increased the plant available water (PAW) content of soils. At an application rate of 30 t/ha the PAW content of a Kandosol was increased by 22%. Overall, the addition of natural bentonites at rates of 20 to 50 t/ha seems an effective means of permanently improving the availability of nutrients and PAW in low fertility sugarcane soils.

## Introduction

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, an obvious 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 too 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 is 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 factor of increasing soil CEC, bentonite can also improve the retention and availability of nutrients, enhancing agricultural productivity and improving fertiliser use efficiency (Noble *et al.*, 2001, 2002, 2004a, 2004b, 2005; Croker *et al.*, 2004) A further benefit of bentonite is that it has the capacity to increase plant available water (PAW) as a function of increasing porosity (Suzuki *et al.*, 2005; Soda *et al.*, 2006).

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). 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 a result of high cost in the case of beneficiated bentonites, and low availability of suitable waste bentonites in the wet tropics, the use of such bentonite types appears at this stage unfeasible.

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 both light textured loams and medium textured clays to improve them for sugarcane production?' In answering this question this paper explores the influence of natural bentonite treatments on CEC, levels and retention of exchangeable nutrient cations and water holding capacity of a Red Kandosol and a Red Ferrosol soil.

## Materials and methods

### Analytical methods

The analytical methods used in activities conducted as part of this study are briefly described in this section. Basic exchangeable cations were determined by atomic absorption spectrometry after replacement with 0.1 M $BaCl_2$-$NH_4Cl$ 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). 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 Kandosol and –20 kPa for the 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.

### Bentonites

Four different types of natural bentonite (three sodium bentonites; Trubond, Arumpo and Volclay 5D, and one calcium bentonite; Volclay Calcium) were investigated in this study (Table 1). All four bentonites are raw natural forms mined from deposits in southwest Queensland (Mantuan Downs and Miles deposits) and the Upper Hunter in New South Wales (Cressfield and Pooncarie deposits).

**Table 1**—Selected chemical properties of the natural bentonite types investigated.

| Bentonite type | pH (1:5) | Exchangeable cations (cmol(+)/kg) | | | | $CEC_B$ (cmol(+)/kg) |
|---|---|---|---|---|---|---|
| | | Ca | Mg | K | Na | |
| Trubond | 7.65 | 10.2 | 19.2 | 1.17 | 26.7 | 57.3 |
| Arumpo | 5.42 | 1.16 | 38.4 | 3.46 | 30.6 | 73.6 |
| Volclay 5D | 7.84 | 11.1 | 18.2 | 1.09 | 36.9 | 67.3 |
| Volclay Calcium | 9.65 | 21.3 | 25.6 | 1.36 | 22.6 | 70.9 |

### Soils

Two contrasting sugar-producing soils from Mourilyan and Wangan in the Innisfail region of North Queensland were chosen for investigation in this study. The Mourilyan soil was 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 Wangan soil was a medium textured clay loam classified as a Red Ferrosol (Isbell, 2002) or a Mundoo soil (Murtha, 1986). Selected chemical characteristics of both soils are presented in Table 2.

**Table 2**—Selected chemical characteristics of the soils used in this study, measured in bulk samples collected prior to the establishment of field trials.

| Soil samples | pH (1:5) | Org. C (%) | Ca | Mg | K | Na | $CEC_B$ |
|---|---|---|---|---|---|---|---|
| | | | | (cmol(+)/kg) | | | |
| Red Kandosol | 6.6 | 1.14 | 0.98 | 0.25 | 0.05 | 0.02 | 1.32 |
| Red Ferrosol | 5.1 | 1.8 | 0.85 | 0.37 | 0.07 | 0.02 | 1.31 |

### Activity 1—Effect of bentonite type and rate of application on CEC and pH

Each bentonite type was added to a 1000 g air dried, sieved (<2 mm) sample of both the Red Kandosol and the Red Ferrosol in the laboratory. Bentonites were applied to soils at rates of 10, 20, 40, 60, 80, 100 and 120 g/kg, which, assuming a bulk density of 1 $Mg/m^3$ and an incorporation depth of 10cm, are equivalent to field rates of 10, 20, 40, 60, 80, 100 and 120 t/ha.

Following addition, bentonite was thoroughly mixed with soils and each sample was subdivided into four 250 g sub-samples to yield four replicates of each treatment. pH was immediately measured for all replicates of each treatment, and basic cation exchange capacity ($CEC_B$) determined over a two-week period. A one-way analysis of variance (ANOVA) was used to determine the statistical significance and standard error of the resulting means. Spearman's correlation coefficient was used to measure the strength of the relationship between the rate of bentonite addition and change in CEC.

### Activity 2—Effect of bentonite on nutrient concentration and retention

Trubond sodium bentonite was applied directly to soils in the field at Mourilyan and Wangan. Bentonite was applied at rates of 0, 10, 20 and 30 t/ha overall. The treatments were applied in a band 20 cm wide along rows in 15 m sections, resulting in application rates of 0, 75, 150 and 225 t/ha in the bands themselves. In total there were four replicates of each treatment, including an untreated control, at each of the two sites. Following surface application, bentonite was incorporated into the top 10 cm of soil within rows using a rotary hoe before sugar cane (Variety Q166 on the Kandosol and Q186 on the Ferrosol) was planted in September 2007.

Fertiliser was applied at planting and along the rows of the newly emerged crop four weeks after planting. All treatments, including the untreated control, at both sites received a total of 120 kg N/ha as ammonium nitrate, 20 kg of P/ha as superphosphate, 100 kg of K/ha as muriate of potash, and 434 kg of Ca/ha and 75 kg of Mg/ha as a calcium-magnesium blend (Mirriwinni Lime Blend 5). At four weeks and 62 weeks after fertiliser application, four soil samples were collected from 0–20 cm depth in the profile from each treatment at both sites and analysed for basic exchangeable cations.

### Activity 3 – Effect of bentonite on texture, permeability, water holding capacity and bulk density and porosity

Soils from the field trials described in Activity 2 were also analysed for particle size distribution, bulk density, particle density and saturated hydraulic conductivity to investigate the effect of Trubond bentonite on soil texture, porosity and water holding capacity, in both the Red Kandosol and the Red Ferrosol. A disturbed 1 kg soil sample and an undisturbed 100 mL soil core were collected from 0–10 cm depth in each of the four replicates of each treatment (0, 10, 20 and 30 t/ha bentonite) for analysis at both field sites.

## Results and discussion

### Cation exchange capacity

All bentonite types effectively increased soil CEC. In both the Kandosol and Ferrosol the change in soil CEC was positively correlated with the rate of bentonite addition. In the Red Kandosol, for every 20 g (i.e. 20 t/ha) of bentonite added there was a corresponding mean increase in CEC of 1.21 cmol(+)/kg (Figure 1). At the highest rate of application of 120 g/kg of soil, CEC was raised from 1.3 cmol (+)/kg in the control to a mean of 9.58 cmol(+)/kg.
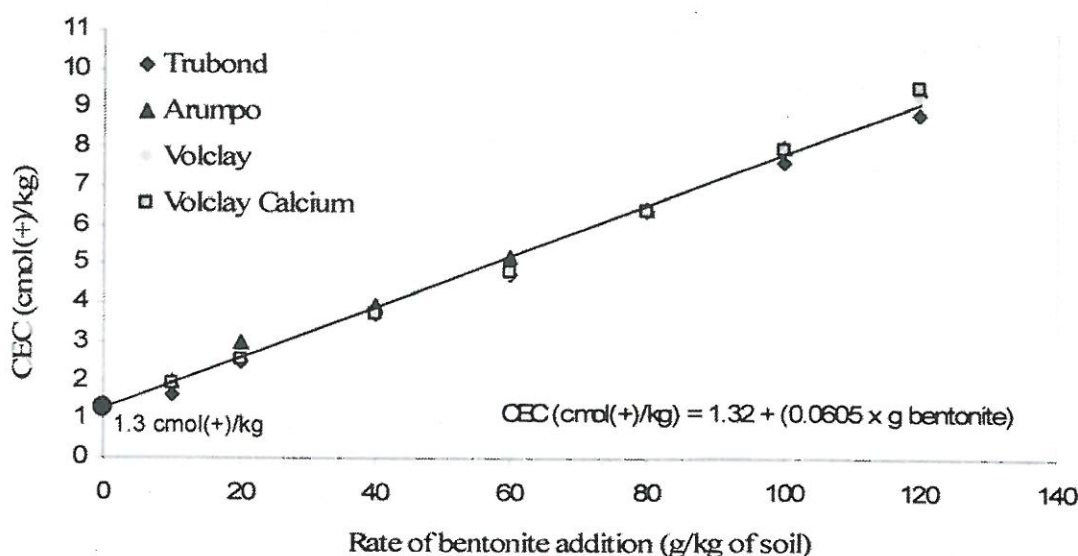
Fig. 1—The relationship between increasing rates of bentonite addition on the cation exchange capacity of a Red Kandosol in Activity 1.

The response was very similar in the Ferrosol, where according to the regression equation CEC (cmol(+)/kg) = 1.25 + (0.0575 x g bentonite addition) there was an increase in charge of 1.15 cmol(+)/kg every 20 g of bentonite added.

At a bentonite application rate of 50 g/kg of soil, equivalent to a field application rate of 50 t/ha (assuming a bulk density of 1 $Mg/m^3$ and an incorporation depth of 0.1m), mean CECs of 4.2 cmol(+)/kg and 4.3 cmol(+)/kg were achieved respectively in the Ferrosol and the Kandosol.

Considering that a CEC of >4 cmol(+)/kg is accepted as being moderate for sugar producing soils in the wet tropics (Schroeder *et al.*, 2006), these results suggest that at rates of 50 t/ha and above, natural bentonites can effectively be used to raise CEC in both Ferrosols and Kandosols to levels that can enhance soil fertility.

The fact that there was significant correlation (P < 0.05) between the different bentonite types and soil CEC suggests that small differences in the CEC (±8 $cmol_c$/kg) of the raw bentonites applied to soils do not significantly affect the overall soil CEC. This is an important finding from an economic viewpoint as the price of bentonites products rises considerably with the CEC value of products.

### pH

Soil pH was increased through bentonite addition. In the Ferrosol, pH was increased from 5.1 in the control to pH 6.7 by the application of 120 g/kg of natural sodium bentonite (Figure 2).

A rate of only 20 g/kg soil bentonite, equivalent to a field rate of 20 t/ha, was necessary to increase the soil pH above 5.5 and into the optimal pH range (pH 5.5–7) for the availability of most nutrients (Reuter and Robinson, 1997).

The ability of bentonite treatments to effectively raise the pH of low pH soils to desirable levels for plant growth provides additional support for the technique.
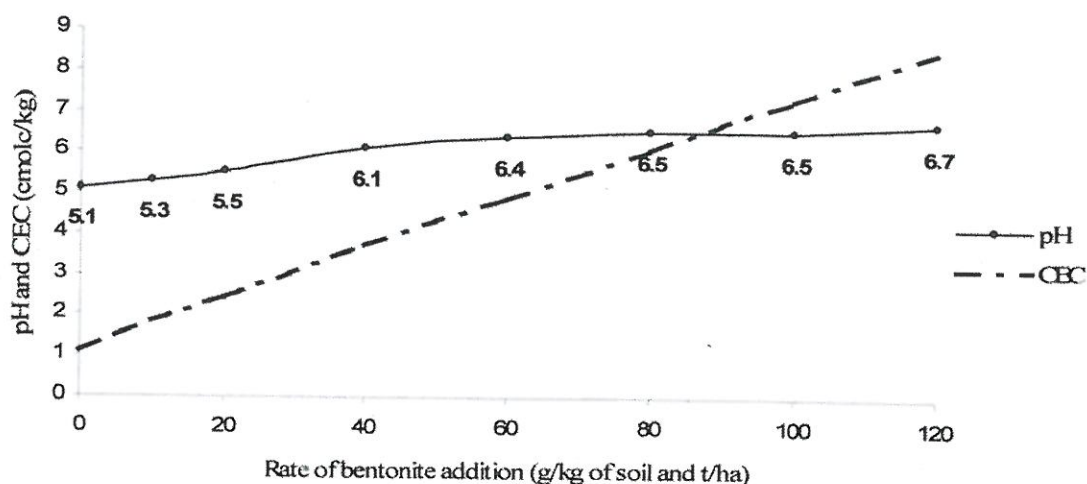
Fig. 2—The effect of rate of bentonite addition and soil CEC on soil pH in a Red Ferrosol treated with Trubond sodium bentonite in Activity 1.

### Concentration and retention of nutrient cations

The addition of bentonite alone can contribute to the level of exchangeable calcium (Ca) and magnesium (Mg) in soils. As can be seen in Figure 3, the contributions made to the levels of exchangeable Ca by the addition of bentonite at rates of 20 t/ha in the case of calcium bentonite, and 40 t/ha in the case of sodium bentonite, were adequate to allow sufficient levels of exchangeable Ca to be achieved in the Red Kandosol. However, as can be seen in the case of exchangeable Mg, the initial level of cations in the soil largely defines the overall level that will be achieved. In soils in which exchangeable Ca and Mg are severely deficient, bentonite alone, even at high rates of application, may be insufficient in achieving levels that would benefit sugarcane production.
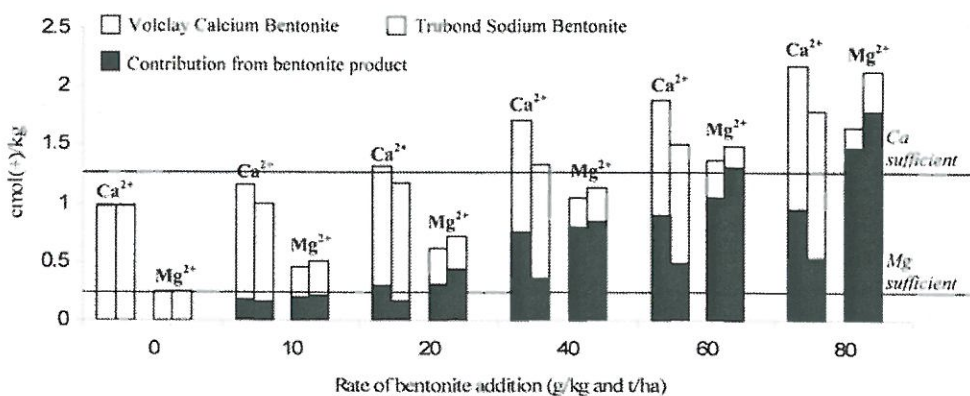


Fig. 3—The effect of the addition of calcium bentonite and sodium bentonite on the levels of exchangeable calcium and magnesium in a Red Kandosol in Activity 1. The contribution of exchangeable nutrients from bentonite additions alone is also shown.

In respect to potassium (K) levels, the contribution made to exchangeable K by bentonite additions was in this study found to be negligible (>0.02 cmol(+)/kg) at all rates tested (0 to 120 t/ha). Consequently, for bentonite treatments to be effective in enhancing the fertility of soils, additional nutrients, in particular K, need to be applied.

Figure 4 demonstrates the effect of natural sodium bentonite (Trubond) addition on soil CEC and exchangeable Ca, Mg and K in a Red Kandosol and a Red Ferrosol in the field, four weeks and 62 weeks after fertiliser application. As can seen Figure 4a, soil CEC increased linearly in both soils with increasing rate of bentonite addition. In the treated soils the CEC remained stable even after 62 weeks, while that in the untreated controls decreased. This indicates that the enhanced retention of nutrient cations witnessed in the treated soils in comparison to the control was a function of increased CEC brought about by the addition of bentonite. Furthermore, these results give support to the permanence of the effect of bentonite on soil CEC.

Figure 4b illustrates the effect of bentonite treatments on the levels of exchangeable soil Ca 4 weeks and 62 weeks after the application of 434 kg/ha Ca to a Kandosol and a Ferrosol. Exchangeable Ca increased with the rate of bentonite addition in both soils (Figure 4b.). Four weeks after the application of lime, exchangeable Ca in the Kandosol was at an adequate level (> 1.25 cmol(+)/kg) in all treatments, however after 62 weeks the control had dropped to marginal levels (0.55–1.25 cmol(+)/kg) (Calcino, 1994).

In contrast, the level of Ca in the soils treated with bentonite remained adequate even after 62 weeks, demonstrating that the bentonite treatments were effective in enhancing the retention of exchangeable Ca. Probably as a result of a lower soil pH and initial exchangeable Ca in the Ferrosol (refer Table 2), exchangeable Ca was not adequate in the control and 10 t/ha treatments in this soil. However, at 20 and 30 t/ha rates of application the exchangeable Ca was significantly increased to adequate levels. At these rates the level of Ca remained high, with only 5% having been lost at 62 weeks indicating that an excellent level of retention was achieved.

The effect of bentonite treatment on exchangeable Mg four weeks and 62 weeks after the application of 75 kg/ha Mg was very similar to that of exchangeable Ca (Figure 4c). As in the case of exchangeable Ca the retention of exchangeable Mg was significantly improved with bentonite addition in both soils, particularly at rates of 20 and 30 t/ha. However, only at rates of 20 and 30 t/ha bentonite application is the effect sufficient to maintain adequate levels of exchangeable Mg in soils at 62 weeks.

The levels and retention of exchangeable K in both the Kandosol and Ferrosol were significantly increased through bentonite additions (Figure 4d). In the Kandosol, a 10 t/ha rate of application of bentonite was sufficient to maintain exchangeable K at adequate levels up to 62 weeks after the application of 100 kg/ha K. In contrast to exchangeable Ca and Mg however, the retention of exchangeable K in both soils did not improve with increasing bentonite application from 20 t/ha to 30 t/ha.

### Water holding capacity

Application of bentonite increased the clay content of soils, decreased the bulk density and increased the porosity. At an application rate of 30 t/ha, the clay content was increased from 11 to 25% in the Kandosol and from 53 to 57% in the Ferrosol. In the Kandosol the bulk density decreased from 1.56 to 1.44 $Mg/m^3$ and the porosity increased from 0.42 to 0.48 $m^3/m^3$. In the Ferrosol, the changes in bulk density and porosity were less

pronounced; with the bulk density decreasing from 1.23 to 1.22 Mg/m$^3$ and the porosity increasing by 3% from 0.51 to 0.54 m$^3$/m$^3$. The saturated hydraulic conductivity of both soils remained relatively constant in spite of the increase in porosity, suggesting that the increase in porosity was associated with an increase in the volume fraction of pores smaller than macropores.

Increased porosity and smaller pores brought about by bentonite applications increased the water holding capacity of soils. Water retention curves demonstrated that a significant increase in PAW could be achieved in the Kandosol with addition of bentonite. For the control treatment, field capacity, wilting point and PAW contents were 0.14, 0.05 and 0.09 m$^3$/m$^3$ respectively.
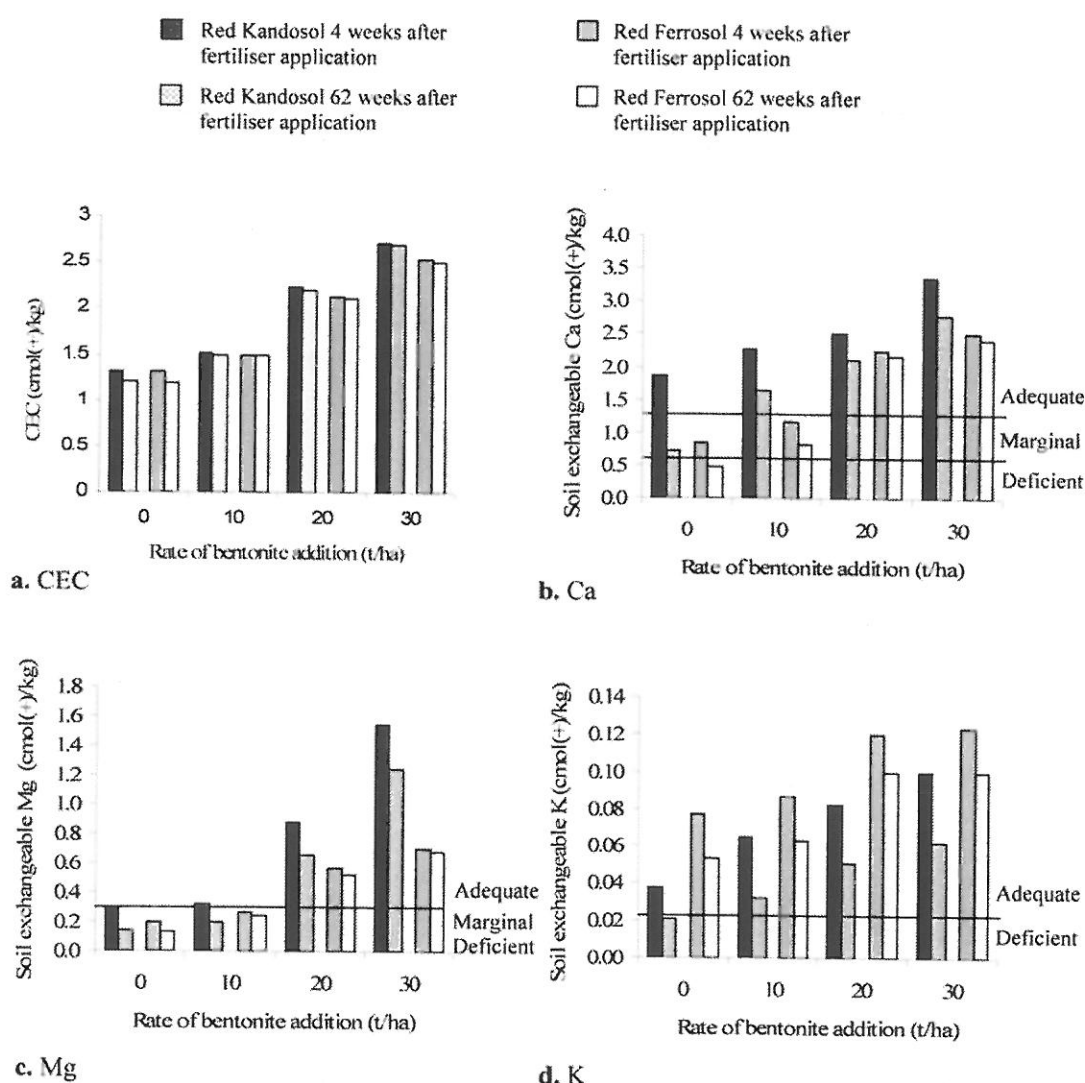


Fig. 4—The effect of natural sodium bentonite treatments in Activity 2 on (a) CEC, (b) exchangeable Ca, (c) exchangeable Mg and (d) exchangeable K in top soil (0–20 cm) in the field at four and 62 weeks after the application of fertiliser.

As can be seen in Figure 5, the field capacity and PAW consistently increased with increasing rates of bentonite addition while the wilting point remained relatively unchanged. At a 30 t/ha rate of bentonite application the field capacity was 0.19 $m^3/m^3$ corresponding to a 27% increase while the PAW content was 0.12 $m^3/m^3$ equivalent to 22% increase. The influence of bentonite on PAW in the Ferrosol was significantly less pronounced, as the field capacity changed little with increasing rates of bentonite addition and the wilting point remained relatively constant.

These results suggest that the effect of bentonite on water holding capacity to benefit plant growth may not be so important in heavier textured soils such as the Ferrosols. In contrast, in light textured soils such as Kandosols, where plants commonly experience moisture stress during the drier seasons, bentonite treatments can bring about significant improvements in the field capacity and PAW content to potentially enhance plant growth and reduce yield losses due to reduced soil water availability.
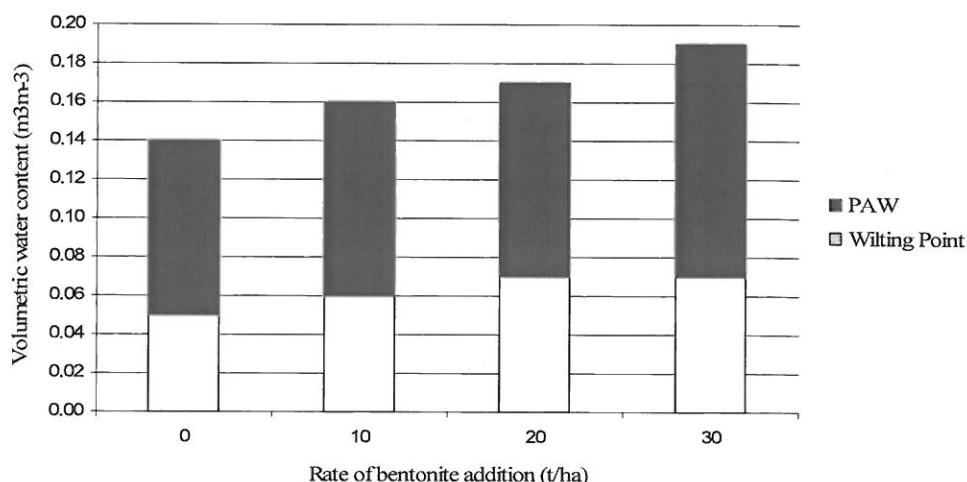


Fig. 5— The volumetric water contents in a Kandosol at field capacity, wilting point and PAW at bentonite application rates of 0, 10, 20 and 30 t/ha in Activity 3.

**Conclusion**

The low chemical fertility soils of the wet tropics support a large proportion of the Australian sugar industry and are thus an economically valuable resource. A potential solution for overcoming some of the economic and environmental challenges of cultivating these largely infertile soils lies in the use of bentonite.

Collectively, the results of this study demonstrate that natural bentonite treatments at application rates of between 20 and 50 t/ha can be used to effectively enhance soil CEC, and, together with conventional nutrient management, improve the levels and retention of exchangeable nutrient cations. This will significantly improve fertiliser use efficiency and minimise environmentally detrimental aspects of fertiliser application. Additionally, increased PAW achieved through the addition of bentonite has the potential to significantly enhance plant growth and yield due to improved soil water availability in rainfed systems on light textured soils.

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