

Comparison of applications of sand and polyacrylamide for separating the impact of the physical and chemical properties of sodic soils on the growth and nutrition of cotton (*Gossypium hirsutum* L.)

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Abstract

In Vertosols sodicity can affect the nutrition of cotton crops. However it is not known whether this results indirectly through the effects of poor soil structure on root growth and activity, or more directly as an effect of soil solution sodium ions on nutrient uptake. To separate these factors we investigated whether adding sand (25, 50 and 75% w/w) or polyacrylamide (PAM) (0.00005%, 0.001% and 0.2% w/w) to sodic and non-sodic soil would overcome the impacts of sodicity on soil physical characteristics in a pot experiment. Treatment effects on soil chemical properties were assessed through in situ measurement of soil solution composition. Soil physical properties were assessed by measurement of bulk density and water stable aggregates. As the proportion of sand in the soil increased, total soil solution nutrient concentrations decreased significantly and soil bulk density increased. This indicates that the addition of sand to sodic soils is an unsuitable method of counteracting the impacts of sodicity on soil physical characteristics in pot experiments. In contrast, increasing PAM application did not significantly affect the soil solution nutrient composition, except in the case of P, which showed a small decrease as PAM increased. Also, increasing PAM application to the soil increased the percentage of water stable aggregates, and increased infiltration and soil hydraulic conductivity. This indicates that the addition of PAM to sodic soils may be a suitable method of overcoming the impacts of sodicity on soil physical characteristics in pot experiments, although care is needed when interpreting P results.

Introduction

Almost 30% of the Australian landmass and 80% of the irrigated agricultural area in Australia are occupied by sodic soils (Rengasamy and Olsson 1993). It has been estimated that the loss in agricultural production occurring as a result of soil sodicity in Australia may cost up to \$6.75 billion annually. Sodicity affects the growth and nutrition of plants in a number of ways. Sodicity causes structural deterioration of the soil, reducing hydraulic conductivity and increasing susceptibility to surface crusting, hard setting and waterlogging (Levy, Shainberg et al. 1998). These factors can limit plant productivity and alter nutrient uptake by reducing seedling emergence and root growth. Sodic soils have reduced redox potential, high soil pH and maintain higher soil solution sodium (Na^+) concentrations (Curtin and Naidu 1998). These factors can limit plant productivity and alter nutrient uptake by changing nutrient availability to plant roots. A combination of both the physical and chemical impacts of sodicity has been shown to induce nutrient deficiencies and toxicities in plants (Curtin and Naidu 1998). In order to better understand this issue, there is a need to quantify the relative contribution of the physical aspects of sodicity to nutrition problems in crop plants.

A number of authors (Allison 1956; Bernstein and Pearson 1956; Carr and Greenland 1975; Chang and Dregne 1955; Wright and Raiper 2000) utilised synthetic soil conditioning agents, such as vinyl acetate-maleic acid copolymer and polyacrylamide (PAM) to ameliorate the soil structure of sodic soils in pot experiments and improve crop growth. PAM is an anionic polymer commonly used in irrigated agriculture for improving water infiltration and reducing soil erosion and runoff. PAM has been shown to improve the structure of sodic soils, increase the percentage of water stable aggregates and hydraulic conductivity and reduce surface crusting (Wallace, Wallace *et al.* 1986a). PAM is attracted to the surface of the soil via van der Waals and coulombic forces, where it increases particle adhesion through flocculation (Sojka and Surapaneni 2000). It is unclear however, whether PAM application may change nutrient availability and soil water retention characteristics (Falatah 1998; Wallace, Wallace *et al.* 1986b). In this paper, two experiments are reported, in which various proportions of sand and PAM were used to overcome structural problems in sodic soils. In situ sampling and analysis of the soil solution using inductively coupled plasma optical emission spectroscopy (ICPOES) and ion chromatography (IC)

allowed a comparison of ion concentrations in the soil solution following amendments with sand and PAM.

Materials and Methods

Two sodic and two non-sodic soils were used in these experiments. The characteristics of these soils are outlined in Table 1.

Table 1: Characteristics of the soils used in the sand and PAM Experiments

Soil type ^a	Treatment	Collection Site	Crop Rotation	Clay ^b %	pH ^b	EC ^c (dS/m)	CEC ^d (cmol/kg)	ESP %	Colwell P ^f (mg/kg)
Grey Vertosol	Non-sodic + Sand	'Moreton Plains' Moree	Cotton-Cereal	27	7.7	1.0	29.9	2.3	27
Grey Vertosol	Sodic + Sand	'Moreton Plains' Moree	Cotton-Cereal	36	9.0	2.2	32.7	14.6	17
Grey Vertosol	Non-sodic + PAM	'ACRI' Narrabri	Cotton-Cereal	52	8.1	0.7	42.0	2.1	42
Grey Vertosol	Sodic + PAM	'Mirrabooka' Narrabri	Cotton-Cereal	59	6.3	3.6	58.2	17.0	11

^a(Isbell 1996); ^bdispersion and sedimentation; ^c1:5 soil:solution ratio in H₂O; ^dsaturation extract; ^e0.1 M BaCl₂/NH₄Cl; ^f(Colwell 1966)

Each of the soils was air-dried and passed through a 10 mm sieve to remove large particles of organic matter. They were then passed through 4 mm sieve by rolling the soil on a board that had a 4 mm high ridge on each side to maintain a gap between the soil and the roller and thus prevent excessive disruption of the soil structure.

The first experiment aimed to determine the effect of increasing sand addition (0, 25, 50 and 75% w/w) on solution cation and anion concentrations in a sodic and non-sodic soil. Treatments were replicated four times. Each replicate consisted of 600 g of soil/sand mixture placed in a pot of 7 cm diameter and 15 cm height and the base of the pot was sealed with a plastic bag. One soil solution sampler was placed centrally in each pot. Deionised water was added to bring the soil/sand mixtures to the previously determined field capacity of 50% and allowed to equilibrate for at least 24 hours. Soil solution was extracted using a modified version of the method outlined by Menzies and Guppy (2000), using polyacrylonitrile, ultrafiltration hollow fibres. Soil solution collected in this way differs slightly from that obtained by centrifugal drainage methods as only solution from within the larger pores is extracted. It is proposed that this solution better represents that accessible to plant (Menzies and Guppy 2000). Soil solution cation and P concentrations were determined using ICPOES whilst anion concentrations were determined using IC (Dionex ICS2000). Significant differences ($P < 0.05$) between treatments were determined using two-way analysis of variance (Genstat 2003).

The second experiment aimed to determine the effect of increasing application rates of PAM (0, 0.00005, 0.001 and 0.2%) on soil solution cation and anion concentrations and soil physical properties. Each PAM treatment was mixed with 2 L of water and applied with a fine-mist sprayer to soil spread thinly on a large tray. The soil was then allowed to air-dry before being placed into the pots. Soil solution was collected as described above. The effectiveness of PAM at ameliorating the physical degradation of sodic soils was determined using water stable aggregate measurements. Two replicates of each soil/PAM treatment were used. The samples were first divided for analysis by passing them through an Endicott sample splitter. A modification of the Yoder wet sieving method (Whitbread 1996) was utilised to determine aggregate stability. A set of five 100 mm diameter sieves with 125, 250, 500, 1000 and 2000 μ m mesh screens were used. A 15 g sample of air-dry soil was placed onto the top of the sieves and immersed in distilled water at 22°C for 30 s before being sieved for 10 min through an amplitude of 17 mm at 30 cycles/min. The sieves were drained and dried at 40°C for 24 h before weighing. Differences in water stable aggregation following PAM application were determined using two-way analysis of variance (Genstat 2003).

Results

Sand Experiment

Addition of sand in increasing proportions resulted in a significant ($P < 0.001$) decrease in solution cation concentrations (Figure 1). Sodium concentrations reported for the sodic soil (0 and 25% w/w sand) were at the upper range of the detection limits for the ICPOES, and due to small solution volumes could not subsequently be diluted. Therefore caution is warranted in drawing comparisons with the non-sodic soil with respect to Na concentration in solution. The trend however remains similar, with decreasing cation concentration with increasing sand content in the soil. Addition of sand in increasing proportions also resulted in a significant ($P < 0.001$) decrease in the solution concentrations of nitrate (NO_3^-) and chloride (Cl^-) but increased the concentration of sulphate (SO_4^{2-}) and fluoride (F^-) ($P < 0.001$) (Figure 2).

Increasing the proportion of sand also increased soil solution phosphate (PO_4^{3-}) at the highest (75% w/w) sand application. In these solutions, the sum of the total cation concentrations was greater than the sum of the total anion concentrations by a factor of between two and four in the non-sodic soil and between four and eight in the sodic soil, indicating that not all of the significant anionic species were accounted for. Carbonate anionic species are likely to be present in these soils, considering the pH (non-sodic soil 7.7 and sodic soil 9.0). Ion chromatography is not sensitive enough to detect carbonate concentrations by conductivity and hence carbonate is usually determined by titration. However, the small volumes of solution collected (< 10 mL) precluded carbonate determination on these samples.

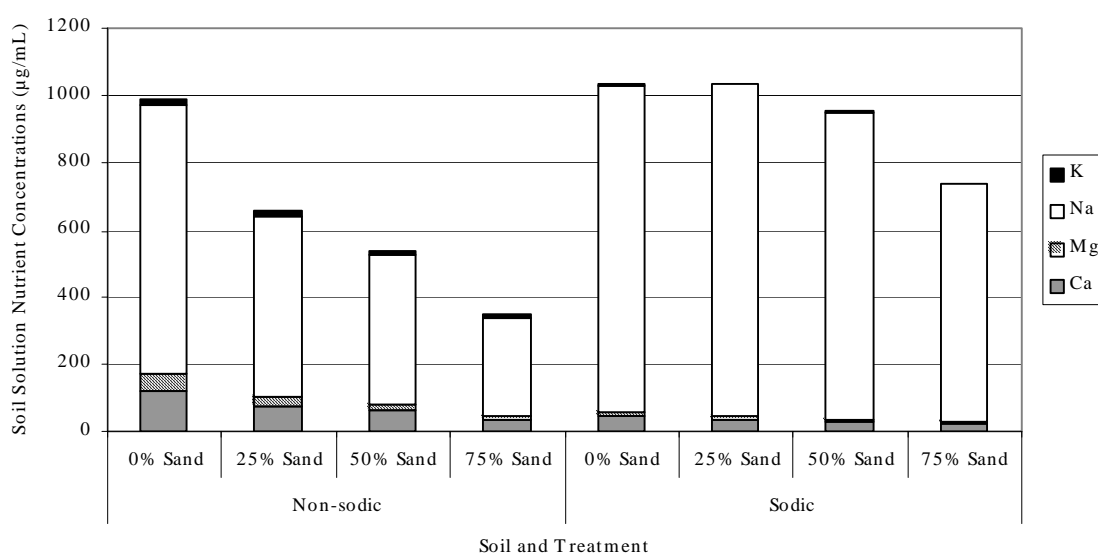


Figure 1. Soil solution cation concentrations in a sodic and non-sodic grey Vertosol following the addition of sand in increasing proportions. Values are the means of four replicates; CV was less than 10%.

PAM Experiment

Addition of PAM to a grey vertosol in increasing proportions has no significant effect on the soil solution concentrations of the measured cations or anions (Figures 3 and 4). However, soil solution P concentrations were an exception to this pattern. As the amount of PAM applied to the soil increased, there were significant decreases in both total solution P ($P = 0.031$) and the PO_4^{3-} in the soil solution ($P = 0.028$). In the sodic soil, the P concentration in the soil solution was very low and PO_4^{3-} not measurable, even without the addition of PAM. There was also an increase in the concentration of zinc in the soil solution in the highest PAM treatment, although the relationship between PAM application rate and zinc concentration was hardly significant ($P = 0.071$).

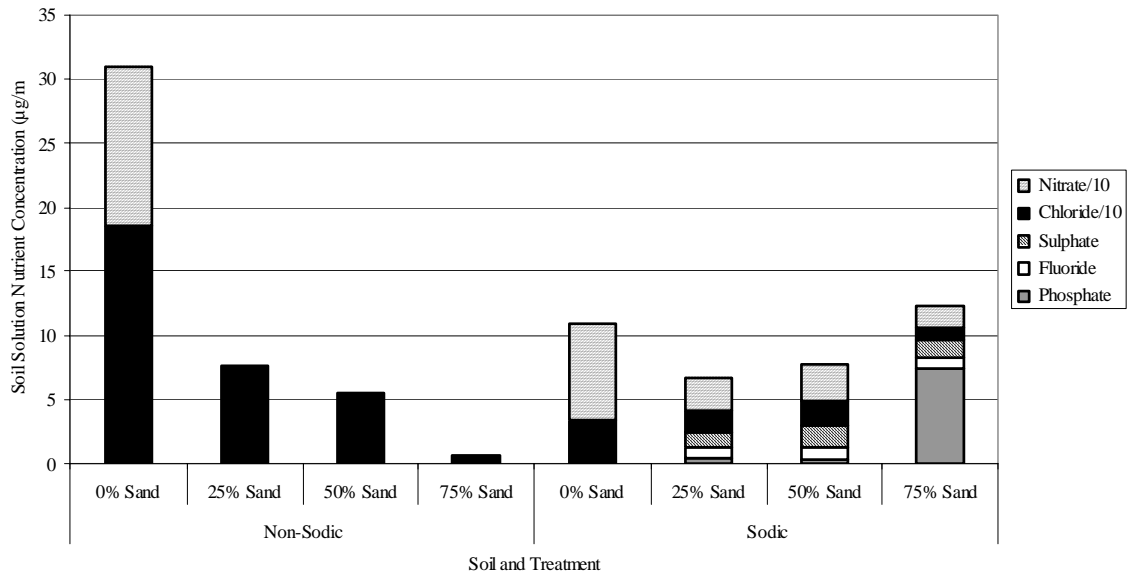


Figure 2. Soil solution anion concentrations in sodic and non-sodic grey vertosol following the addition of increasing proportions of sand. Values are means of four replicates; CV was less than 20%.

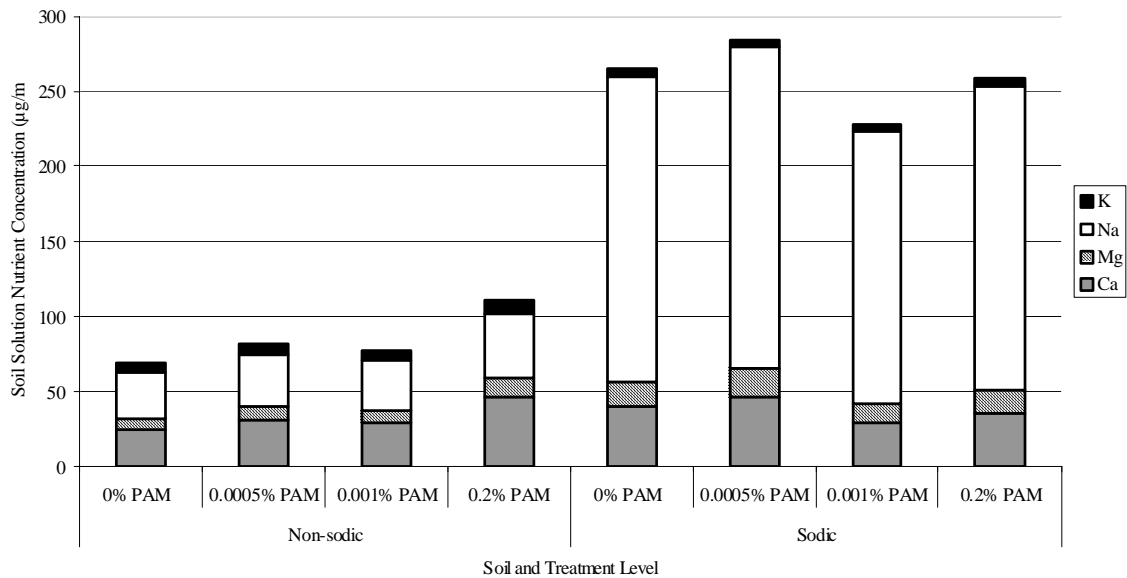


Figure 3. Effect of PAM on Soil solution cation concentrations in a sodic and non-sodic grey Vertosol following the addition of PAM. Values are means of four replicates; CV was less than 14%.

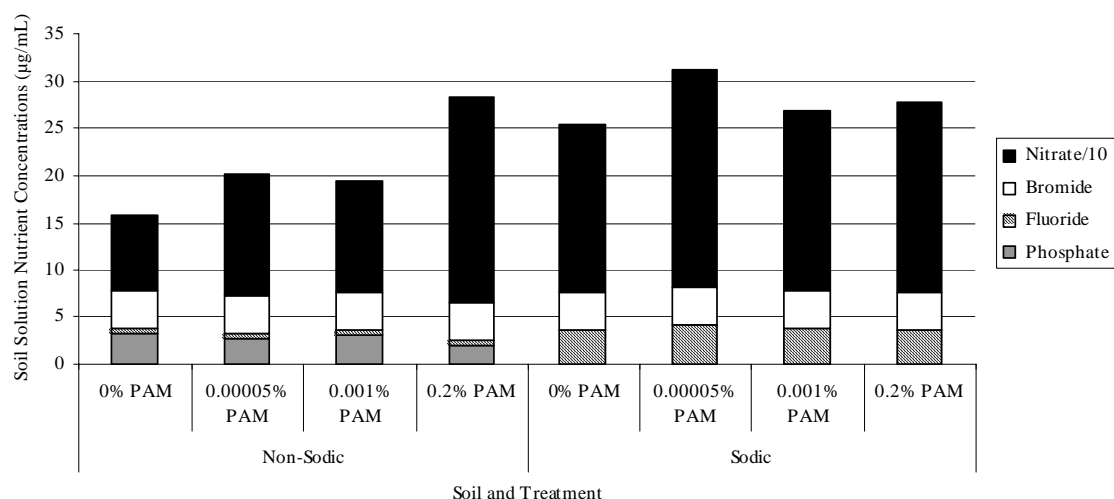


Figure 4. Effect of PAM on Soil solution anion concentrations in a sodic and non-sodic grey Vertosol following the addition of PAM. Values are means of 4 replicates; CV was less than 20%.

The results of the water stable aggregate analysis, which was determined on the PAM treated soil, are outlined in Table 2. Sodicity had a negative effect on soil structure, with the sodic soil having significantly less water stable aggregates than the non-sodic soil ($P < 0.001$). PAM had a positive effect on soil structure, improving %WSA with each increase in application rate ($P < 0.001$). The amount of PAM needed to improve the structure of sodic soil to that of the non-sodic soil was approximately 0.001% w/w. However, the highest rate of PAM did not increase the %WSA of the sodic soil to the same level as the %WSA of non-sodic soil at the highest PAM rate.

Table 2. The effect of sodicity and PAM on water stable aggregation in a sodic and non-sodic grey Vertosol. Values are means of two replicates; CV was less than 1.5%.

Soil	Treatment	Water Stable Aggregates (%)
Non-Sodic	0% PAM	49.4
Non-Sodic	0.00005% PAM	52.9
Non-Sodic	0.001% PAM	63.0
Non-Sodic	0.2% PAM	78.8
Sodic	0% PAM	21.8
Sodic	0.00005% PAM	26.1
Sodic	0.001% PAM	47.3
Sodic	0.2% PAM	62.3

Soil Properties

Significant differences were detected between both the cation and anion concentrations in the sodic and non-sodic soils. In the Moree soils used for the sand experiment, the sodic soil had significantly lower soil solution concentrations of Ca, Mg, K, P and S ($P < 0.001$) and significantly higher concentrations of Na ($P < 0.001$) than the non-sodic soil. In the Narrabri soils used for the PAM experiment, the sodic soil had significantly lower soil solution concentrations of Mg ($P = 0.021$), K and P ($P < 0.001$) and significantly higher concentrations of Na and S ($P < 0.001$). In both sets of soils there was also a significant decrease in the concentration of phosphate anions in the soil solution of the sodic soils, as compared with the non-sodic soils ($P < 0.001$).

Discussion

Sand Experiment

This experiment aimed to identify whether the addition of sand to soil is an appropriate method by which to separate the physical and chemical effects of sodicity on plant growth. The addition of increasing proportions of sand to the grey Vertosol increased soil bulk density, through better packing and settling of colloidal material. There was also a decrease in the soil solution concentrations of most major soil cations

(Ca²⁺, Na⁺, Mg²⁺, K⁺) and anions (NO₃⁻ and Cl⁻). Exceptions to this pattern were the anions, SO₄²⁻, F⁻ and PO₄³⁻, which increased with the addition of increasing proportions of sand. Therefore, as the addition of increasing proportions of sand to the grey Vertosol increases soil bulk density and causes a change in composition of the soil solution, it is unlikely that it will allow separation of the physical and chemical effects of sodic soil on plant growth.

PAM Experiment

This experiment aimed to identify whether the addition of PAM to soil is an appropriate method, by which to separate the physical and chemical effects of sodicity on plant growth. The addition of increasing proportions of PAM to a grey Vertosol had no significant effect on the soil solution concentration of major cations and anions in the soil solution. However the exception to this observation concerns soil solution P concentration. In the non-sodic soil P concentrations decreased with the addition of increasing proportions of PAM, while in the sodic soil no decrease was observed, perhaps because the P concentrations in the sodic soil were very low. The decrease in soil solution P concentrations showed no relationship to the increase in %WSA and as such is likely to be due to the PAM itself. Further investigation is necessary in order to determine the exact nature of this relationship before this method can be utilised in pot experiments that examine crop nutrition.

There was also an increase in the soil solution zinc concentration in the highest PAM treatment. Further investigation is also necessary to determine the nature of this relationship. However, it is unlikely that a direct relationship exists between PAM application rate and zinc concentration, because the zinc increase was only observed in the highest PAM treatment.

Soil Properties

An important outcome of these experiments is the significant differences that were detected between the sodic and non-sodic soils collected from sites in close proximity to each other. The significant increase in the concentration of Na⁺ ions and decrease in Ca²⁺, Mg²⁺ and K⁺ ions in the soil solutions of the sodic soils as compared to the non-sodic soils can be explained by cation exchange processes, particularly the preference of colloid surfaces for divalent over monovalent cations.

Also important to note is the significant decrease in the concentration of total solution P and PO₄³⁻ ions in the soil solutions of the sodic soils as compared to the non-sodic soils. This result contrasts with the work of earlier authors (Curtin, Syers *et al.* 1987; Gupta, Singh *et al.* 1990; Nelson and Oades 1998; Sharpley, Curtin *et al.* 1988) who observed that P should be more available in sodic soils due to an increase in clay surface negative potential leading to reduced sorption of P and due to the increased solubility of organic matter. Critical soil solution P concentrations for cotton in Vertosols have not been determined, however, P concentrations in the sodic soils remain above the 0.6 µM required for adequate wheat growth (Romer and Schilling 1986). Dorahy (2002) reported that critical Colwell P concentrations in NSW Vertosols were between 6-8.5 mg/kg, although his observations did not include sodic soils. Higher Colwell P values were observed in all soils used in these experiments (Table 1). Therefore, although there was a reduction in P concentration it did not fall below that likely to limit P nutrition.

Conclusions

The addition of sand to soil is an inappropriate method to separate the physical and chemical effects of sodic soils on plant growth. As the proportion of sand increased there was a corresponding change in the composition of the soil solution and increase in soil bulk density. In contrast, the addition of PAM to soil is a more appropriate method by which to separate the physical and chemical effects of sodic soils on plant growth. PAM increases the %WSA of the soil and had no effect on the soil solution composition, with the exception of slightly decreasing P concentration and slightly increasing Zn concentration. Further studies are needed to better quantify the nature of the relationship between soil PAM levels and P and Zn concentrations in soil solution.

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