

Impacts of sodic soil amelioration on deep drainage

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Abstract

Groundwater tables are rising beneath irrigated fields in some areas of the Lower Burdekin in North Queensland, Australia. The soils where this occurs are predominantly sodic clay soils with low hydraulic conductivities. Many of these soils have been treated by applying gypsum or by increasing the salinity of irrigation water by mixing saline groundwater with fresh river water. While the purpose of these treatments is to increase infiltration into the surface soils and improve productivity of the root zone, it is thought that the treatments may have altered the soil hydraulic properties well below the root zone leading to increased groundwater recharge and rising water tables. In this paper we discuss the use of column experiments and HYDRUS modelling, with major ion reaction and transport and soil water chemistry-dependent hydraulic conductivity, to assess the likely depth, magnitude and timing of the impacts of surface soil amelioration on soil hydraulic properties below the root zone and hence groundwater recharge. In the experiments, columns of sodic clays from the Lower Burdekin were leached for extended periods of time with either gypsum solutions or mixed cation salt solutions and changes in hydraulic conductivity were measured. Leaching with a gypsum solution for an extended time period, until the flow rate stabilised, resulted in an approximately twenty fold increase in the hydraulic conductivity when compared with a low salinity, mixed cation solution. HYDRUS modelling was used to highlight the role of those factors which might influence the impacts of soil treatment, particularly at depth, including the large amounts of rain during the relatively short wet season and the presence of thick low permeability clay layers.

Key Words

Sodic soils, amelioration, gypsum, deep drainage

Introduction

In Australia, over 80% of the irrigated soils are sodic and irrigation management is closely linked with management of soil sodicity (Rengasamy and Olsson 1993). Sodic soils typically exhibit poor soil structural stability, low plant available water contents and low infiltration rates. Most of the irrigated soils in Australia need reclamation of sodicity, at least for the soil layers in the root zone (Rengasamy and Olsson 1993). When soils are successfully ameliorated, the leaching flux is expected to increase relative to surface runoff potentially increasing deep drainage rates (Rengasamy and Olsson 1993).

Sodic soils are prevalent in the Lower Burdekin irrigation area in North Queensland, Australia (Figure 1). While there are adequate supplies of fresh water for irrigation, there is a lack of sub-surface drainage and a number of areas have problems due to rising groundwater tables. Applications of gypsum or irrigation waters with increased salinity have been used to improve soil structural stability and hydraulic properties, but there is now a concern that the whole soil profile may be affected thus enhancing recharge and impacting groundwater tables. To assess the likelihood of this occurring, the expected magnitude, depth and timing of increases in soil hydraulic conductivity in response to these treatments needs to be determined.

Methods

Soil Properties

The soil used in this study was collected from an irrigated sugarcane field in the Lower Burdekin. The soil used was collected from the B horizon, 0.6 to 1.1 metres below the ground surface, by digging a soil pit and obtaining soil from the wall of the pit. The soils are clay soils with high sodicity levels (Table 1). The Exchangeable Sodium Percentage (ESP) of these soils places them in the strongly sodic category based on Australian soil classifications (Northcote and Skene 1972).



Figure 1. Location of the Lower Burdekin in North Queensland, Australia.

Table 1. Soil properties for the soils used in these experiments based on five samples from the same site.

| Sample | pH [†] | Exchangeable | Exchangeable | Exchangeable | ESP [‡] | CEC | Clay |
|--------------------|-----------------|-----------------------|-------------------------|----------------------|------------------|-----|------|
| | | Calcium (meq/100g) | Magnesium (meq/100g) | Sodium (meq/100g) | | | |
| A | 8.8 | 11.1 | 14.3 | 5.2 | 17.3 | 30 | 66 |
| B | 8.8 | 10.2 | 13.6 | 4.9 | 16.9 | 29 | 69 |
| C | 8.8 | 10.9 | 14.2 | 5.4 | 18 | 30 | 70 |
| D | 8.9 | 11 | 13.9 | 5.2 | 17.3 | 30 | 68 |
| E | 8.9 | 11.1 | 13.6 | 4.2 | 14.6 | 29 | 67 |
| Mean | 8.8 | 10.9 | 13.9 | 5 | 16.8 | 30 | 68 |
| Standard deviation | 0.1 | 0.4 | 0.3 | 0.5 | 1.3 | 1 | 2 |

[†] pH = pH of 1:5 soil solution extract

[‡] ESP = Exchangeable Sodium Percentage

[¶] CEC = Cation Exchange Capacity

Column leaching experiments

Column leaching experiments were used to investigate changes in hydraulic conductivity for sodic clays from the Lower Burdekin, in response to changes in applied solution chemistry. The soil columns were prepared by oven drying the soil, grinding it, sieving it to obtain the <2 mm fraction and packing it into columns with 5.4 cm diameter and 4 cm height. The soil columns were wet from the bottom using the percolating solution. Hydraulic conductivity was then determined by measuring the flow rate whilst continuing to apply the percolating solution using a constant head apparatus.

Two sets of experiments were conducted to determine the changes in soil hydraulic conductivity that occur when a) a saturated gypsum solution and b) mixed cation solutions of varying salinity are applied. In the first set of experiments, a saturated gypsum solution was applied and the primary aim was to determine the potential for increases in hydraulic conductivity in response to gypsum applications. A low salinity irrigation water surrogate was used for comparison with the gypsum solution results.

As the measured field bulk densities were approximately 1.9 g/cm³, much higher than the bulk densities typically used in laboratory experiments with repacked columns, the influence of bulk density was also investigated by using columns packed at two bulk densities, 1.3 g/cm³ and 1.4 g/cm³. Five replicates were used for each of these bulk densities.

The second set of experiments was designed to determine the influence of salt concentration on hydraulic conductivity after the methods of McNeal (1968). Measurement of hydraulic conductivity at two salt concentrations was recommended by McNeal (1968). In this study, 100 meq/L and 50 meq/L solutions containing calcium chloride, magnesium chloride and sodium chloride were used with three replicates for each salt concentration.

For both sets of experiments, the leaching was continued until a stable flow rate was achieved. The electrical conductivity, pH and cation concentrations of the leachate solutions were measured to determine when chemical equilibration with the applied solution had occurred.

HYDRUS modelling

HYDRUS-1D models were set up using the properties of the sodic clays used in the column experiments to determine whether the trends observed in the laboratory could be simulated using HYDRUS. Subsequent modelling efforts focused on determining the influence of the initial soil sodicity and hydraulic conductivity on deep drainage rates after amelioration. In addition, the influence of large amounts of rain during the wet season on soil properties and deep drainage rates was investigated.

Results

The bulk density of the repacked columns had a significant effect on the maximum hydraulic conductivity when saturated gypsum solutions were applied. The maximum hydraulic conductivity for the columns packed at 1.3 g/cm³ was approximately five times greater than the maximum hydraulic conductivity for the columns packed at 1.4 g/cm³ (Figure 2). The variability in the measurements was also significantly greater. The standard deviation for the columns packed at 1.3 g/cm³ was approximately ten times greater than the S.D. for the columns packed at 1.4 g/cm³.

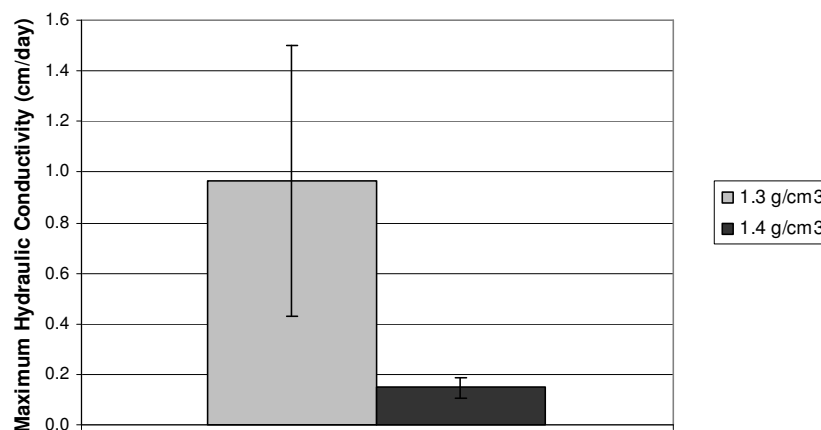


Figure 2. Maximum hydraulic conductivity with gypsum applied to soil columns packed at two different bulk densities. The mean and the standard deviation of the measurements are shown.

The maximum hydraulic conductivity measured for the columns leached with a saturated gypsum solution was approximately half of the maximum hydraulic conductivity measured for the columns leached with a 100 meq/L mixed cation salt solution, but approximately four times the maximum hydraulic conductivity measured for the columns leached with a 50 meq/L mixed cation salt solution (Figure 3). For the columns leached with a saturated gypsum solution, there was a gradual increase in hydraulic conductivity during the leaching period. This increase in hydraulic conductivity is due to the combined impacts of electrolyte effects and reductions in soil sodicity. The final hydraulic conductivity for the soil columns leached with a saturated gypsum solution was approximately twenty times larger than the final hydraulic conductivity for soil columns leached with a low salinity irrigation water surrogate.

Whereas the column experiments have been used to determine the maximum effects of varying solution chemistry on hydraulic conductivity after continuous leaching of the soils, HYDRUS modelling has been used to simulate a range of scenarios applicable to field conditions. For example, the depth of the profile affected as a result of the combined effects of irrigation, sporadic gypsum applications and intermittent rainfall was investigated. The results of the HYDRUS modelling indicate that the initial soil sodicity and the initial soil hydraulic properties have a large influence on the changes in deep drainage rates that would be expected in response to different soil treatments (Figure 4). For high initial sodicity levels, i.e. exchangeable sodium percentages of equal to or greater than 33.8, less of the profile was ameliorated and the corresponding deep drainage rates were much lower.

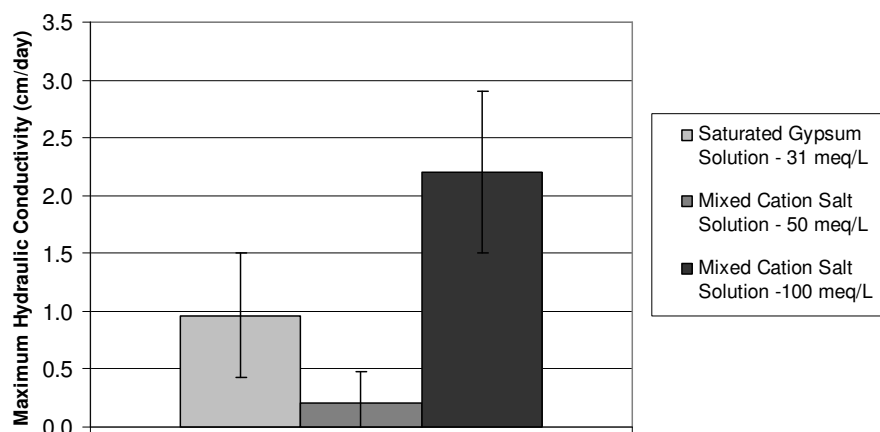


Figure 3. Maximum hydraulic conductivity with gypsum applied vs maximum hydraulic conductivity with mixed cation salt solutions applied. The mean and the standard deviation of the measurements are shown.

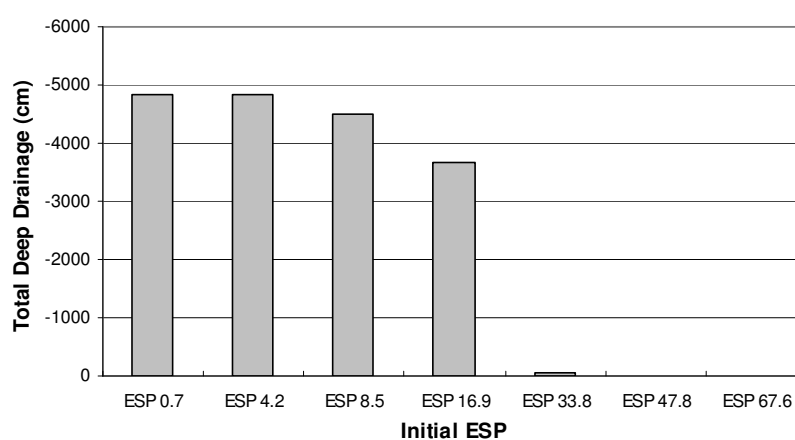


Figure 4. Impact of initial soil sodicity on total deep drainage rates after ten years of continuous gypsum applications.

Conclusion

The changes in hydraulic conductivity in response to gypsum applications and increased salinity waters were measured. Leaching with a saturated gypsum solution until the flow rate stabilised resulted in an approximately twenty fold increase in the hydraulic conductivity when compared with a low salinity, mixed cation solution. The maximum hydraulic conductivity when a 100 meq/L salt solution was applied was significantly higher than the maximum hydraulic conductivity when the saturated gypsum solution was applied.

Findings from the column experiments and HYDRUS-1D modelling are being used to improve understanding of the impact of long term treatment with gypsum or saline irrigation water on sodic soils. This is needed to test the validity of current practices in which water management in the Lower Burdekin is being informed by regional hydrology modelling with groundwater recharge estimated using static soil hydraulic properties.

References

- McNeal BL (1968) Prediction of the Effect of Mixed-Salt Solutions on Soil Hydraulic Conductivity. *Soil Science Society of America Proceedings* **32**, 190-193.
- Northcote KH, Skene JKM (1972) 'Australian Soils with Saline and Sodic Properties'. (CSIRO: Melbourne).
- Rengasamy P, Olsson KA (1993) Irrigation and Sodicity. *Australian Journal of Soil Research* **31**, 821-837.