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Effect of physical amendments on salt leaching characteristics for reclamation

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A B S T R A C T

Saline-sodic soils may be reclaimed through the addition of amendments to alter the soil pore system and hydraulic functions, therefore allowing salts to be leached from the soil. For the purpose of investigating the suitability of specific amendments for improving leaching and reclamation, soil percolation column studies were conducted to assess the influence of amendments on cation exchange, the potential for the release of cations and changes in hydraulic conductivity of the soil. A fine textured saline-sodic soil amended separately with 20% wood chips (wt/wt), 40% fine sand (wt/wt) and 2.5% bentonite (wt/wt) was used for this study as well as a non-amended soil as a control. The impact of amendments was evaluated by continuous leaching of the soil substrates with deionized water until the hydraulic conductivity and leachate chemistry stabilised. The bentonite amended soil had a greater increase ($15.9\ \mathrm{cmol_c\ kg^{-1}}$) in exchangeable $\mathrm{Ca^{2+}}$ and a higher reduction in exchangeable $\mathrm{Na^{+}}$ ($12.29\ \mathrm{cmol_c\ kg^{-1}}$) after the final leaching due to a greater rate of cation exchange for this soil substrate. The bentonite amended soil also had a greater reduction (92%) in $\mathrm{Na^{+}}$ content compared with the other soil substrates. The hydraulic conductivity of all soil substrates improved during leaching although the hydraulic conductivity of bentonite amended soil reduced after three pore volumes of leaching. This study suggests that a slower water movement (an increased percolation time) and a greater rate of cation exchange were associated with the greater leaching efficiency. Therefore, addition of bentonite improves and accelerates the reduction of salinity and sodicity.

1. Introduction

Salinization, predominantly by Na (sodium) salts, affects approximately 30% of the land area in Australia (Rengasamy, 2006) often as a result of anthropogenic activities such as agriculture (Bennett et al., 2009), land clearing, mining and oil and gas extraction (Merrill et al., 1990). Saline-sodic soils typically indicate a poor soil structure associated with the reduction in soil hydraulic conductivity, infiltration, aggregate stability and aeration (Ben-Hur et al., 2009; Rengasamy and Olsson, 1991; Shainberg and Letey, 1984; So and Aylmore, 1993). The poor physical conditions of the saline-sodic soils and high salinity can limit plant establishment and land revegetation (Bernstein, 1975; Hoffman and Shannon, 2007; Parida and Das, 2005; Shannon et al., 1994). Therefore, reclamation of salt affected lands appears necessary to create favourable conditions for plant establishment and land revegetation.

Leaching, which is a typical strategy for reclaiming saline soils, involves the dissolution of soluble salts in the soil profile, displacement of the saline solution by water and consequently the removal of salts from the soil (Al-Sibai et al., 1997). Where a source of calcium exists in the soil, cation exchange can occur followed by hydrolysis during the displacement and leaching (David and Dimitrios, 2002; Marwan and Rowell, 1995). Changes in the soil chemistry associated with increases in the electrolyte concentration of the soil solution and decreases in the exchangeable sodium percentage (ESP) coincide with an increase in the hydraulic conductivity of the soils (Ezlit et al., 2013; Loveday, 1976; Marchuk and Rengasamy, 2012; McNeal and Coleman, 1966; Quirk and Schofield, 1955; Reading et al., 2012; Sumner, 1993).

Leaching plays an important role in reclamation of saline-sodic soil where gypsum exists in the soil (Oster et al., 1996). However, salt leaching can be limited due to poor soil physical conditions associated with a reduction in hydraulic conductivity and potential for infiltration. Therefore, remediation strategies are required to improve infiltration and soil hydraulic conductivity and thus enhance salt leaching. In instances where the low hydraulic properties in saline-sodic soils prevent high rates of throughflow and leaching, application of amendments to the surface soil may foster reclamation by improving and stabilising

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the pore system, accelerating the leaching of Na^+, decreasing salinity and decreasing the exchangeable sodium percentage (ESP) (Harris et al., 2005; Hussain et al., 2001; Mahmoodabadi et al., 2013; Rahman et al., 1996; Ranjbar and Jalali, 2011; Tejada et al., 2006) and thus facilitating plant establishment. This approach may require the application of inorganic amendments such as sand (Hamdi et al., 1963; Rahman et al., 1996) or organic amendments like plant residue (Belden et al., 1990; Harris et al., 2005; Mahmoodabadi et al., 2013; Ranjbar and Jalali, 2011; Tejada et al., 2006). The soil hydraulic conductivity and the extent of cation exchange, which can be altered by amendments, control the suitability of specific amendments for reclamation.

Several studies have investigated the effect of the addition of sand (Hamdi et al., 1963; Rahman et al., 1996) and plant residue (Li and Keren, 2009; Mahmoodabadi et al., 2013; Ranjbar and Jalali, 2011; Tejada et al., 2006) on physico-chemical properties of the saline-sodic soils. However, the influence of the amendments on the magnitude of cation exchange, the release of cations from the soil and changes in hydraulic conductivity during leaching has not been well understood, despite the fact that these are significant factors in the saline-sodic soil reclamation. In previous studies, the effect of solution chemistry, such as solutions with differences in salinity concentrations (EC), sodicity (SAR) or gypsum concentrations, on changes of soil hydraulic conductivity (Frenkel et al., 1992; Jayawardane, 1979; Mace and Amrhein, 2001; McNeal and Coleman, 1966; Naghshineh-Pour et al., 1970; Prather et al., 1978; Pupisky and Shainberg, 1979; Reading et al., 2012) and cation exchange (Ghafoor et al., 2004; Jalali et al., 2008; Reading et al., 2012) were investigated. However, in arid and semi-arid regions, particularly in remote parts of Australia, soil leaching is constrained to rainfall as the only water source for leaching due to the lack of energy and alternative water resources. Therefore, evaluation of leaching soil substrates with non-saline water is an efficient and cost-effective possibility to simulate leaching by rainfall under purely natural conditions. This approach enables to investigate the success of the application of an amendment strategy in principle and its potential to achieve a positive outcome for reclamation. Such a feasibility study is essential prior to upscaling to conditions of affected soils in (semi)arid climates.

The main objectives of this study are to understand the influence of amendments on cation exchange, leaching of cations from saline-sodic soil substrates and changes in hydraulic conductivity during leaching by non-saline water to predict the consequences of the application of amendments for reclamation.

2. Materials and methods

The soil used in this study was collected from a site near Eromanga in South West Queensland, Australia (26°27′05.12″ S, 143°25′43.77″ E) impacted by activities associated with oil extraction. The soil was affected by leakage from a series of ponds containing brine, a by-product of oil production. The salt affected and at the time of the study bare soil requires reclamation to provide favourable conditions for revegetation and phytostabilisation, e.g. establishment of halophytes, salt tolerant species, which can be used as fodder for livestock.

The soil (18% clay, silt 60%, sand 22%; Silty loam) was classified as saline-sodic soil based on the Australian soil classification (Northcote and Skene, 1972). The soil was non-calcareous and classified as a sodosol. X-Ray Diffraction analysis indicated that the soil contains gypsum (17 wt%).

2.1. Column preparation

Column experiments were used to investigate the reclamation potential of different strategies at a small scale. The soil was collected by creating a shallow trench to a depth of 20 cm. Rayment and Lyons (2011) suggested that bulk soil should be dried at ≤40 °C whereas drying temperatures between 30 and 35 °C have been recommended in Metson (1961). In this study, the collected soil was dried at 35 °C, and then it was sieved to pass 2 mm.

As the intention of the study was to alter the soil physical properties to improve the conditions for leaching and exchange process, sieved soil was amended separately with different materials: 20% (wt/wt) red gum tree wood chips (<2 mm; EC: 0.55 dS/m; pH: 4.37), which contained 2.7 g kg^{-1} Ca, 0.5 g kg^{-1} Na, 0.4 g kg^{-1} Mg, 0.6 g kg^{-1} K, 40% (wt/wt) washed fine sand (~100–300 μm; EC: 0.08 dS/m; pH: 7.48) and 2.5% (wt/wt) sodium based bentonite (trugel, Sibelco; CEC = 80 $cmol_c$ Kg^{-1}). Data provided by bentonite supplier (Sibelco, Australia) list the following composition: 63.8% (wt%) SiO_2; 13.6% (wt%) Al_2O_3; 2.8% (wt%) Fe_2O_3; 0.2% (wt%) CaO; 2.3% (wt%) Na_2O; 2% (wt%) MgO; 0.2% (wt%) K_2O. The bentonite type of clay was chosen because of its high shrink-swell potential (Alther, 1987) which can create drainable pore space in the soil after wet and dry cycles (Rayhani et al., 2007). The small size of wood chips (<2 mm), which was similar to the size of the sieved soil particles (<2 mm), was adopted to have a similar particle size as the soil matrix. The rates of the specified amendments were selected based on preceding studies where the effect of different rates of the specified amendments on saturated hydraulic conductivity of the saline-sodic soil (control) was determined (Appendix A). Results from these studies showed that soil amended with proportions of 40% fine sand (wt/wt), 20% wood chips (wt/wt) and 2.5% trugel (bentonite) (wt/wt) had the greatest influence in increasing the hydraulic conductivity than other tested concentrations, but also that of the non-amended soil (Appendix A). Furthermore, the selected rates of amendments were previously used in other studies which evaluated the revegetation of saline-sodic mine spoil (Belden et al., 1990), saline tailings (Huang et al., 2012) and saline soil (Rahman et al., 1996) under (semi)-arid climatic conditions.

Gypsum treatment was not used in this study since application of gypsum solution to the soil containing gypsum can result in increasing salinity and further preventing seed germination and plant establishment (Belden et al., 1990; Schuman et al., 1989). Gypsum was not removed from the soil since other studies (Belden et al., 1990; Quirk and Schofield, 1955; Rengasamy and Olsson, 1991; Sumner, 1993) showed that leaching saline-sodic soils with water or DI-water led to sodic soils which can limit seed germination and plant establishment. Furthermore, in our study, gypsum is one of the components of the soil.

The materials were homogenised using a shaker (Gerhardt Rotoshake; Gerhardt, Cologne, Germany) for 8 h and were then packed into columns. The soil cores were prepared by placing the materials into a set of 2 cylinders and then packing it into a lower cylinder (40 mm height and 56 mm diameter) using a loading frame to create a high degree of packing uniformity throughout the samples. The materials were packed to achieve an equal bulk density of 1.20 ± 0.02 g/cm^3. The bulk density of columns filled with 20% wood chips amended soil was 0.9 ± 0.02 g/cm^3 due to the low specific particle density of the wood chips. Three replicates were produced for each material.

All soil cores were subjected to three wet-dry cycles to consolidate the soil and stimulate the aggregate formation and to reach an equilibrium state in the packing density. Wetting was carried out using DI-water from the base of the soil cores to minimise any disruption caused by the application of water to the soil surface. Following the wetting for 24 h, all soil cores were allowed to dry at 35 °C in the drying oven for 7 days. The volume of water for wetting cycles was limited to prevent leaching effects prior to the experiment. The limited volume of water also prevented rapid dilution of salts prior to the beginning of the experiments. After three wet-dry cycles, the materials were used for saturated hydraulic conductivity and leaching tests.

2.2. Soil physical analyses

Saturated hydraulic conductivity of the soil samples was evaluated using a constant head permeability test (Klute and Dirksen, 1982). The hydraulic conductivity procedure test followed the method described