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Leaching and reclamation of a biochar and compost amended saline–sodic soil with moderate SAR reclaimed water

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ABSTRACT

Remediating saline–sodic soils with organic amendments is increasingly seen as a cheaper and sustainable alternative to inorganic materials. The reclamation potential of biochar, biosolids and greenwaste composts applied to a saline–sodic soil was evaluated in a laboratory leaching experiment using moderate SAR reclaimed water. Treatments included biochar, biosolids co-compost, greenwaste compost (all applied at a 75 t ha^{-1} rate), gypsum (50% soil gypsum requirement), biochar + gypsum, biosolids + gypsum, greenwaste + gypsum and a non-amended control. All treatments were subjected to a one month incubation after which, soils were filled in columns and leached using reclaimed water until 7 PV of water had passed. Cumulative leachate losses of Na^+, Ca^{2+}, and Mg^{2+} were evaluated in addition to soil properties after leaching. Results show that leaching with moderate SAR water was effective in reducing the soil salinity and sodicity of all soils, irrespective of amendment application. However, incorporating biochar and composts significantly enhanced this effect. Salt leaching was higher in soils treated with organic amendments. Cumulative leachate losses of cations were significantly higher from biochar and compost treated soils compared to gypsum and unamended controls. Improvements in soil aggregate stability and saturated hydraulic conductivity were prominent in compost treated soils. After leaching, soil analyses indicated that organic amendments lowered significantly more soil EC_e, ESP and SAR than that of the control soils and saturated the exchange complex with Ca^{2+}. Soil pH was significantly reduced and CEC was significantly increased in only compost treated soils. Although individual organic amendment applications proved to be significant enough to remediate a saline–sodic soil, combined applications of gypsum and organic amendments were more effective in improving soil properties directly related to sodium removal including sodium leaching, hydraulic conductivity, ESP, and SAR, and therefore could have a supplementary benefit of accelerating the reclamation process.

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1. Introduction

Soil salinization is defined as an excessive accumulation of salts within the soil profile to the extent that it decreases plant growth. It has been one of the major environmental problems threatening agricultural productivity since ancient times (Rengasamy, 2006). Salt-affected soils are in general classified as; saline, sodic or saline–sodic, based on their respective electrical conductivity (EC_e) and sodium adsorption ratio (SAR) of the saturated paste extracts or the sodium on the exchange sites (exchangeable sodium percentage, ESP) (Richards, 1954). Saline soils are characterized by having high EC_e values (>4 dS m^{-1}) while saline–sodic soils have both high EC_e (>4 dS m^{-1}) and SAR (>13) of the saturation extract and an ESP > 15. Sodic soils are those which have low EC_e (<4 dS m^{-1}) but have high SAR's (>13) or ESP > 15 (Richards, 1954). Saline–sodic soils can be considered to be highly degraded and least productive due to their simultaneous effect of salinity and sodicity on soil physical, chemical and biological properties. High salinity retards plant growth by creating osmotic imbalances and specific ion toxicities. On the other hand, sodicity deteriorates soil physical structure by clay swelling and dispersion due to high concentrations of Na^+ in the soil solution or at the exchange phase, forming dispersed soils (Rengasamy and Olsson, 1991). Dispersed saline–sodic soils are compacted and have reduced water infiltration and hydraulic conductivity, which play a major role in water, air, and solute movement through the soil profile (Shainberg and Lety, 1984; Suarez et al., 2006). In addition to physical effects, chemical, biological and biochemical property deteriorations have been well reported in literature for saline and sodic soils (García and Hernández, 1996; Ghollarata and Raiesi, 2007; McClung and Frankenberger, 1985;

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Pathak and Rao, 1998; Rietz and Haynes, 2003; Setia et al., 2012; Wong et al., 2008).

Reclamation of a saline–sodic soil requires the removal of sodium from the soil exchange sites into soil solution by divalent cations (Ca^{2+} preferably) to promote soil flocculation. Subsequently, salts are leached from the soil profile (Abrol et al., 1988). Extensive research has been conducted over decades with respect to use of chemical amendments to provide Ca^{2+} to replace Na^{+} on the exchange sites (Brinck and Frost, 2009; Qadir et al., 2002). Gypsum ($CaSO_4{\cdot}2H_20$) is the most commonly used chemical amendment and its efficiency as a supplier of Ca^{2+} to offset Na^{+} on exchange sites has been long studied and is an established technology to remediate saline–sodic soils (Ghafoor et al., 2001; Mace and Amrhein, 2001; Oster et al., 1999). Other chemical amendments such as sulfur and sulfuric acid have also been used to remediate saline–sodic soils by facilitating native calcite dissolution to release required calcium into soil solution (Amezketa et al., 2005; Sadiq et al., 2007; Zia et al., 2007). Alternatively, phyto-remediation technique has gained attention as a less expensive alternative to chemical amendments. This technique works on the same principle of native calcite dissolution to supply soluble calcium by facilitating changes in root zone partial pressure of CO_2 by plants and thus helping to remediate calcareous saline–sodic soils (Qadir et al., 2007; Qadir and Oster, 2004).

Organic amendments including composts have long been studied for their effectiveness in improving soil properties such as soil structure, aggregate stability, hydraulic conductivity and other chemical and biological properties (Giusquiani et al., 1995; Haynes and Naidu, 1998; Ros et al., 2003; Tejada et al., 2009) when applied on degraded lands. Several studies have also reported the benefits of using organic materials to remediate salt-affected soils by improving their physical, chemical and biological properties (Lax et al., 1994; Liang et al., 2005; Tejada et al., 2006; Wahid et al., 1998; Walker and Bernal, 2008). Composts differ in their physiochemical properties based on the feedstocks from which they are made and could influence soil properties differently when used for reclamation (Lakhdar et al., 2009). The effects of two different composts, i.e., biosolids and greenwaste composts were evaluated in this study to reclaim a saline–sodic soil. Moreover, the benefits of combined applications of these composts and gypsum during the process of saline–sodic soil remediation and their effects on specific soil properties such as hydraulic conductivity and aggregate stability have been seldom studied. Besides, the effect of extremely stable organic materials, such as biochar, on the reclamation of saline–sodic soils has not been investigated.

Biochar, a carbonaceous organic material, is produced by slow pyrolysis of biomass under zero or limited oxygen conditions, in a closed furnace at temperatures ≤700 °C (Lehmann and Joseph, 2009). Interest in biochars is more recent with its use mainly focused to combat global climate change by sequestering atmospheric CO_2 into soil C (Chan et al., 2008). In addition to the C sequestration value, beneficial aspects of improved soil quality, nutrient enhancement and plant growth have also been reported when biochar is used as an organic soil conditioner (Glaser et al., 2002; Lehmann et al., 2006). However, the use of biochar as a potential soil amendment for salt-affected soils, in particular saline–sodic soils, has never been evaluated. Biochar was shown to improve soil physical properties such as bulk density, porosity, aggregate stability, and saturated hydraulic conductivity (Herath et al., 2013; Laird et al., 2010). Moreover, recent studies have reported that biochars can be rich in nutrients like Ca^{2+} and Mg^{2+} (Tsai et al., 2012) and may enhance their availability in soil when added as amendments (Laird et al., 2010; Rajkovich et al., 2012). Therefore, addition of biochar to a saline–sodic soil could aid in its remediation by adding Ca^{2+} and Mg^{2+}, improve aggregate stability, hydraulic conductivity, and potentially might enhance Na^{+} leaching.

Degraded water, defined as "water which has suffered chemical, physical or microbiological degeneration in quality", (O'Connor et al., 2008) such as agricultural drainage water, municipal treated waste water, water from animal and feed operations, are increasingly seen as alternative sources of irrigation water due to an augmented demand for high quality potable water in urban areas (Corwin and Bradford, 2008). In California and much of the Western United States, agricultural drainage and municipal treated waste water, termed as 'reclaimed water', are used mainly for agricultural irrigation to supplement the scarcity of fresh canal water and as an alternative for their disposal (Mandal et al., 2008; Wu et al., 2009). The chemical characteristics that determine the suitability of these marginal quality waters for irrigation are same as those of fresh waters given by Ayers and Westcot (1985). Important issues that constrain the use of these low quality waters for irrigation are salinity, sodicity, and specific-ion toxicities. Salinity (EC_{iw}) and sodicity (SAR) of the irrigation water are the principal water quality properties that determine the extent of soil degradation. Many studies have evaluated the effects of irrigation water salinity and sodicity on soil structure deterioration by clay dispersion and subsequent reduction in hydraulic conductivity (Frenkel et al., 1978; Grattan and Rhoades, 1990; Mace and Amrhein, 2001; McNeal and Coleman, 1966; McNeal et al., 1968; Quirk and Schofield, 1955). Reclaimed water from municipal treatment plants may contain higher EC and SAR values (Wu et al., 2009) than other fresh water resources. While the effects of water with high SAR's (>15) on soil properties have been well studied (Grattan and Oster, 2003; Jalali et al., 2008; Murtaza et al., 2006), the use of moderate SAR waters (SAR < 8) (Mace and Amrhein, 2001), especially to leach a saline–sodic soil treated with organic amendments for reclamation, is questionable and warrants study.

The main objective of this study was to compare and evaluate the effects of organic amendments (biochar and composts) and gypsum as individual and conjunctive applications on the reclamation potential of a saline–sodic soil, when leached with marginal quality reclaimed water. Our hypothesis is that the combined applications of gypsum and organic amendments and subsequent leaching with reclaimed water will accelerate the reclamation process beyond what is achieved when they are used separately. Moreover, the negative chemical effects of reclaimed water use on soil structure degradation will be negated due to the structural stability enhancements offered by organic matter additions.

2. Materials and methods

2.1. Soil sampling

Bulk saline–sodic soil samples (0–20 cm) were collected from an agricultural farm located on the west side of San Joaquin valley, California (36°22′57.2″N, 120°13′50.8″W). These soils had a history of being previously irrigated with saline–sodic drainage water as part of integrated on farm drainage management (IFDM), and were abandoned without any crop cultivation for more than a year due to poor soil performance. The soil has a clay loam texture and belongs to the Ciervo soil series (Fine, smectitic, thermic VerticHaplocambids). Bulk soils were air-dried and crushed to pass through a 2 mm sieve and were homogenized by thorough mixing. Sub samples were randomly collected from the bulk soil to analyze for their physical and chemical properties. Soil particle size analysis was conducted using the hydrometer method (Gavlak et al., 2003). Soil EC_e and pH measurements were made on saturated paste extracts following the method given by Richards (1954) using Oakton CON 6 conductivity meter (Oakton Instruments, IL) and Thermo Scientific Orion 3 star bench top pH meter (Thermo Scientific, Inc. MA). Soluble cations (Na^{+}, Ca^{2+}, and Mg^{2+}) were analyzed

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