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First and second-year assessments of the rapid reconstruction and re-vegetation method for reclaiming two saline–sodic, coastal soils with drip-irrigation

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ABSTRACT

Soil salinity, sodicity and saline groundwater are major constraints to the cultivation of landscape plants along oceanic coasts. A sustainable approach for reclaiming saline–sodic soils in coastal environments is evaluated. Soil tillage, phased saline water management based on soil matric potential under drip-irrigation, and the installation of a gravel–sand layer were used. Field trials using the method showed that the proposed approach had the advantages of considerable water conservation, more effective salt leaching and successful re-vegetation with desired species. Severely saline soils became non-saline within the 0–40 cm soil profile after one year and non-saline to moderately saline within the 0–120 cm depth after two years. The approach can rather quickly create an attractive landscape and maintain good plant growth. Plants representing nearly 30 landscape species, including some sensitive to salinity were proposed. Plantings showed survival up to 90% after one and two years. This approach demands less water, improves the ecological environments, and will inspire development of coastal areas.

1. Introduction

Salinization and sodifacation of soils and ground waters may lead to serious ecological and environment problems in arid and semi-arid climates and is increasing steadily in many parts of the world (Akhter et al., 2004; Yu et al., 2010). Coastal regions face many of the same problems as lands in agricultural districts. Blowing sand reclamation and coastal wetland utilization present difficulties associated with environmental stability.

The accumulation of excess sodium (Na^+) in soil may cause numerous adverse phenomena, such as changes in exchangeable and soil solution ions and soil pH, destabilization of soil structure, deterioration of soil hydraulic properties, increased susceptibility to crusting, and imbalances of plant-available nutrients in the soil (Akhter et al., 2004; Khoshgoftarmanesh et al., 2003; Prichard et al., 1985; Qadir and Schubert, 2002). Saline–sodic soils can slake, disperse and swell under specific conditions when wet with rain or irrigation water: This can decrease soil water and air movement, plant-available water, root penetration, seeding growth and plant establishment, and can increase runoff, ponding, water-logging and erosion, and impedes seed bed preparation (Akhter et al., 2004; Oster et al., 1999; Sumner, 1993).

Amelioration of saline–sodic soils with chemical amendments is an established technology. Over time, gypsum (Ahmad et al., 1986; Gharaibeh et al., 2010; Hanay et al., 2004; Joshi and Dhir, 1990; Mahmoodabadi et al., 2013; Miranda et al., 2011; Sidhu et al., 2004; Vander Pluym et al., 1973), sulfuric/phosphoric acid (Gharaibeh et al., 2010; Mahmoodabadi et al., 2013; Yazdanpanah and Mahmoodabadi, 2013), fly ash (Angin et al., 2011), phosphogypsum (Agar, 2011), municipal solid waste (Hanay et al., 2004), polyvinyl-alcohol (Nawar and Petch, 1987) and organic matter (Mahmoodabadi et al., 2013; Miranda et al., 2011; Somani, 1981; Yu et al., 2010) have been used for soil reclamation. These amendments can effectively improve physical and chemical qualities of saline–sodic soil. For example, some amendment materials can supply calcium (Ca) which may replace excess exchangeable Na, which promotes the dissolution of calcite in calcareous saline–sodic soils, improves soil structure and aggregation, increases soil hydraulic conductivity, and promotes higher nutrient levels and greater cation exchange capacity. However, often the effects of

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chemical amendments are limited to shallow depths by shortages of raw materials, by the need to reclaim vast areas of saline lands, and by its contribution to potential pollution.

Use of salinity-tolerant plants has been recommended as a useful approach for soil reclamation and increased agricultural productivity (Ahmad et al., 1986; Akhter et al., 2004; El-Saidi, 2002; Helalia et al., 1992; Qadir et al., 1996; Sidhu et al., 2004). Rice (Ahmad et al., 1986), clover (Mehanni, 1987), amshot grass (Helalia et al., 1992), sesbania (Qadir et al., 1996), barley (Khoshgoftarmanesh et al., 2003), kallar grass (Akhter et al., 2004), a rice–wheat system (Nayak et al., 2008), *Suaeda maritima* and *Sesuvium portulacastrum* (Wang et al., 2013), and beet (Ammari et al., 2013) have been used for soil reclamation. Many studies have confirmed improvements in soil structure by growing salinity-tolerant plants (Helalia et al., 1992; Qadir et al., 1996, 2005; Qadir and Oster, 2002; Qadir and Schubert, 2002). As the length and biomass of the root system developed, improved soil water retention and decreased soil bulk density were observed. Phytoremediation also causes changes in the chemical properties of soils, such as decreased soil pH and increased calcite dissolution through root activity, resulting in adequate Ca^{2+} levels in the soil solution that in turn replaced the exchangeable Na^{+}.

Phytoremediation is a technology that can improve plant-nutrient availability, extend the depth of the ameliorated zone, and may promote stability of soil aggregates and soil hydraulic properties (Gharaibeh et al., 2011; Qadir and Schubert, 2002). However, biological methods for utilization or vegetative bioremediation of salt-affected soils are limited by the growth environment and salinity tolerance of plants, and are usually combined with chemical amendments and/or leaching methods in reclamation of highly saline–sodic soils. Most plants used for soil reclamation in the above studies were annual, shallow-rooted crops or herbaceous plants (Ahmad et al., 1986; Akhter et al., 2004; Ammari et al., 2013; Helalia et al., 1992; Mehanni, 1987). In order to create an attractive landscape, a variety of plant types should be used.

A common practice for reclaiming salt-affected soils is leaching of soils to move excess soluble salts from upper to lower soil depths or out of the root zone (Bennett, 1990; Jury et al., 1979; Khoshgoftarmanesh et al., 2003; Misra and Mahapatra, 1989; Valdivieso, 1984). Continuous ponding of water on the soil surface is the most frequently used method for salt leaching. Recently, a partial ponding method of leaching was found to save water and time compared to total ponding, because the local hydraulic head gradient is greater under partial ponding conditions (Siyal et al., 2010). However, traditional leaching (continuous or partial ponding) practice might not be feasible due to shortage of water resources, lack of good quality irrigation water, absence of adequate drainage, and increased demand on water resources by other vital economic sectors. These procedures fail to reclaim highly dispersed, hard, sodic and saline–sodic soils due to their low profile permeability (Nayak et al., 2008; Sumner, 1993). Although saline water can be used as an alternative to freshwater and leaching salt with saline water can save time and water in the reclamation of saline–sodic soils, irrigation with low electrolyte concentration has been most favored (Gharaibeh et al., 2009; Vander Pluym et al., 1973; Steppuhn, 2001). With either choice, salt build-up would probably occur during periods of low precipitation, warm temperatures, and insufficient leaching (Khoshgoftarmanesh et al., 2003). In addition, the use of saline water in leaching salt is limited by the salinity tolerance of the reclamation plants.

Reclamation under an unsaturated soil moisture flow has been demonstrated to save more water and be more effective in leaching salt than saturated moisture flow (Selassie et al., 1992). Drip-irrigation, when designed with suitable dripper flow rates according to the soils texture, is an effective irrigation technique for improving water-use efficiency (Kang, 1998; Wan et al., 2012). Drip-irrigation has also been shown useful for the reclamation of saline soils (Kang et al., 2010; Liu et al., 2012; Sun et al., 2013; Wan et al., 2012; Wang et al., 2013), and is regarded as the most promising irrigation system for use with saline water (Malash et al., 2008; Meiri et al., 1992). It applies water precisely and uniformly at high frequencies, maintains high soil matric potential (SMP) in the root zone and thus compensates for the decreased osmotic potential caused by irrigation with saline water, and constant high total water potential can be maintained for crop and plant growth (Goldberg et al., 1976; Kang, 1998).

There is a dearth of information on reclamation in the field, where the plants must face actual conditions. Under field conditions, salinity is a dynamic property of root zones resulting from evaporation of the soil solution, water extraction, selective plant uptake from plant roots and replenishment by irrigation or rainfall (Tanji, 2002). Meanwhile, environmental conditions such as temperature, light intensity, humidity, and wind speed can considerably affect plant responses to salinity (Niu and Cabrera, 2010; Zollinger et al., 2007).

In China, most oceanic, saline coastal wastelands are not used, and the native vegetation typically consists of only reed [*Phragmites australis* (Cav.) Trin. Ex Steud] and suaeda (*Suaeda glauca* Bge.) (Fig. 1). With rapid industrialization and urbanization in coastal saline regions, there is an urgent need to improve such landscapes to meet the demands of cities and industrial districts. Presently, the main method of vegetation rehabilitation in these environments is to replace saline soil with non-saline soil for depths ranging as deep as 100 cm. But this method is unsustainable due to the shallow and saline groundwater (Sun et al., 2012b). Moreover, available sources of non-saline soil are limited due to the laws of basic farmland protection. Therefore, a simple and sustainable method is needed. Our authors' group propose a rapid approach to vegetation landscape reconstruction in saline coastal soils using drip-irrigation, and the method is improved and assessed in this study.

2. Methods

Vegetation landscape reconstruction in saline coastal soils was tested in a two-step approach. First, soils were treated to mitigate multiple environmental growth-limiting factors, such as poor soil structure and low soil infiltration. Second, water–salt regulation using drip-irrigation was accomplished in order to provide a good root zone environment with suitable water, fertilizer, gas and temperature conditions.

2.1. Step 1: Soil treatments

This step mainly included: soil removal, laying the gravel and sand layer, soil backfilling, land leveling, and vegetation planting.

2.1.1. Soil removal

A certain depth of undisturbed soil in the saline–sodic land, which was selected for reconstructing the landscape, was excavated using a large backhoe (Fig. 2a). The bottom of the excavation was maintained at a tilt angle between 5 and 10 degrees to facilitate drainage. The removed soil was air-dried naturally. The depth of the soil excavation was determined by the needs of the landscape plants and the groundwater level. The excavation bottom should be above the groundwater table.

2.1.2. Laying the gravel–sand layer

A 15-cm thick layer of gravel (particle size of 3–5 cm) was laid in the bottom of the excavation and then covered with a 5-cm thick layer of sand (particle size 0.2–0.4 cm), to reduce capillarity of the soil (Fig. 2b and c). Plastic tubing was placed at the edge of the low end of the gravel–sand layer to discharge the leached saline water.