



# Effect of gypsum and rice straw compost application on improvements of soil quality during desalination of reclaimed coastal tideland soils: Ten years of long-term experiments

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## ABSTRACT

The objective of this study was to investigate the effectiveness of applying gypsum and rice straw compost on improvements in soil quality during the desalination of previously reclaimed coastal tideland soils. The four treatments were control (without amendment), gypsum, rice straw compost, and gypsum + rice straw compost. The experiments were carried out in a completely randomized design with three replicates. Saturated electrical conductivity ( $EC_e$ ) and exchangeable sodium percentage (ESP) values of soils treated with gypsum, or gypsum + rice straw compost, reached the salinity and sodicity classification limits of  $4 \text{ dS m}^{-1}$  and 15% (US Salinity Laboratory Staff, 1954), respectively, after eight years of leaching experiments. However, despite 10 years of leaching experiments, neither the control nor the rice straw compost alone treatment reached the salinity and sodicity classification limits. The addition of gypsum and rice straw compost resulted in a reduction in soil bulk density and a corresponding increase in soil porosity in highly saline-sodic soils ( $p \leq 0.05$ ). The results of mean weight diameter (MWD) showed that the application of soil amendments increased MWD significantly ( $p \leq 0.05$ ); the highest MWD was observed for the gypsum + rice straw compost treatment and was twice the magnitude of the control.

## 1. Introduction

Reclaimed coastal tidelands are composed of saline-sodic soils that are characterized by high pH, electrical conductivity, soluble sodium carbonate, and exchangeable sodium percentage (ESP) values, and poor organic matter (Cho et al., 2003; Son et al., 2016). The highly soluble and exchangeable salts have a profound impact on chemical and physical properties of soils, as well as plant growth (Greene et al., 1988; Bauder and Brock, 1992; Bauder and Brock, 2001; Ha et al., 2008; Gama et al., 2009). These salts have been shown to cause specific ions to accumulate into plants over a period of time, which leads to ion toxicity or ion imbalance, and a continuous osmotic phase that prevents water uptake by plants due to the osmotic pressure of the saline soil solution (Munns and Tester, 2008). Saline-sodic soils are subject to severe structural degradation and show poor soil-water and soil-air interactions (Rengasamy and Olsson, 1991). Swelling and dispersion of sodic aggregate destroy soil structure, reduce soil porosity and permeability, and increase soil strength, even at low suction (Rengasamy,

1982; Clark et al., 2007; Ahmad et al., 2015).

Reclamation of saline-sodic soils is imperative in many areas where degradation of land and water resources is occurring (Lebron et al., 2002). The chemical mechanisms involved in the reclamation of saline-sodic soils have been well documented. However, the changes in physical properties that occur during early desalination of saline-sodic soils, as well as the impact on aggregate formation and stability, have not frequently been considered. To use newly reclaimed tidelands as arable land necessitates desalination for many years. During the initial period, high salinity may lead to an increase in soil sodicity and deteriorating soil structure. Specifically, the action of  $\text{Na}^+$  ions may cause various negative impacts, such as destabilization of soil structure and increased susceptibility to wind or water erosion (Qadir and Schubert, 2002; Zamani and Mahmoodabadi, 2013; Zhao et al., 2013; Arjmand Sajjadi and Mahmoodabadi, 2015).

Gypsum and compost have been used extensively to reclaim saline-sodic soils to reduce physical degradation. It is well known that applying gypsum and compost to saline-sodic soils improves soil

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physical conditions by promoting flocculation, enhancing aggregate stability and increasing the infiltration rate (Lebron et al., 2002; Ekwue and Harrilal, 2010; Mazaheri and Mahmoodabadi, 2012). Therefore, understanding the effects of applying gypsum and organic matter on reclaimed coastal tidelands may be of critical importance to optimize arable land management strategies and promote sustainable agriculture (Son et al., 2016). The objective of this study was to investigate the effectiveness of applying gypsum and rice straw compost to improve salinity, sodicity, and soil aggregate of soil quality during desalination of reclaimed coastal tideland soils.

## 2. Materials and methods

### 2.1. Experimental soil

Soils used in the lysimeter experiment were collected at depths of 0–30 cm from reclaimed coastal tidelands located in Gyehwa-myeon, Buan-gun, and Jeollabuk-do, South Korea (35°79'45"N, 126°63'77"E) (Son et al., 2016). The soils have thin, dark gray, silt loam Ap horizons. They were formed in recently reclaimed fluvio-marine plain alluvium with a high salt content (NIAST, 2000). The physico-chemical properties of the soils before and after leaching experiment are presented in Table 1.

### 2.2. Lysimeter setup and soil amendment application

A detailed description of the lysimeter setup procedure was previously provided by Son et al. (2016). Our research was conducted using a completely randomized design with three replicates at an experimental farm operated by Chonbuk National University (South Korea) from 2006 to 2015. Twelve cylindrical lysimeters were laid in the vicinity of a research greenhouse. The size of the lysimeters was 0.95 m × 1.07 m (inner diameter × height). A 5 cm layer of gravel and sand was placed in the bottom of each lysimeter to facilitate leaching. The culvert facilities were buried at soil depths of 65–70 cm using corrugated pipe with a diameter of 50 mm. In each lysimeter, 70 cm of soil were uniformly packed and then stirred to prevent layering to obtain a uniform bulk density of 1.25–1.30 kg m<sup>-3</sup>.

Soil amendments are materials that directly or indirectly, through chemical or microbial action, furnish Ca<sup>2+</sup> to replace exchangeable Na<sup>+</sup>. The soil amendments used in this experiment were gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O) and rice straw compost (organic carbon: 52.2%, C/N ratio: 28.9, moisture: 40.5%). Application of the soil amendments in each treatment was as follows: (1) Control: neither gypsum nor compost was applied; (2) Gypsum: agricultural grade gypsum powder (passed through a #70 mesh sieve) was broadcast uniformly 93% GR at the soil surface layer (1.45 kg 500 kg<sup>-1</sup>) (Beyce, 1973); (3) Rice straw compost: rice straw compost was applied at a rate of 50 ton ha<sup>-1</sup> to the soil

surface; (4) Gypsum + rice straw compost: both gypsum and rice straw were applied as previously stated.

The desalination process was continued until both EC and ESP fell below the salinity and sodicity classification limits of 4 dS m<sup>-1</sup> and 15%, respectively, at a soil depth of 30 cm (i.e., rhizosphere zone) (US Salinity Laboratory Staff, 1954). After treating the soil amendments to the soil surface, leaching was initiated by natural rainfall. The EC of the natural rainfall was 0.12 dS m<sup>-1</sup> and the pH was 7.17. In May and October of each year during the experimental period, soil in the lysimeters was plowed to a depth of 30 cm using a hoe. All experimental lysimeters were kept under natural conditions until the end of experiment, without vegetation. The average annual temperature in the study area is 12.4 °C, and mean annual precipitation is 1240 mm, with 60% or more of the precipitation falling during the monsoon period (Fig. 1).

### 2.3. Soil analysis

Samples for determining physico-chemical properties and aggregate formation were collected at soil depths of 0–30 cm before the start of the experiment and again in October of each year. The collected soil samples were air dried, crushed, uniformly mixed, and sieved through a 2 mm sieve, and then analyzed according to methods described by US Salinity Laboratory Staff (1954). The chemical properties evaluated were as follows: pH, saturated electrical conductivity (EC<sub>e</sub>), soil organic carbon, cation exchange capacity (CEC), and exchangeable cations (Ca<sup>2+</sup> and Na<sup>+</sup>). The pH and EC<sub>e</sub> were measured in saturated paste and saturated paste extract, respectively. Soil organic carbon content was measured with ground, air-dried, soil samples using a carbon-nitrogen analyzer (PE-2400, USA). CEC was measured using the ammonium acetate method. Exchangeable cations were leached first with neutral 1 M ammonium acetate, and concentrations were determined by atomic absorption spectrophotometry (Perkin Elmer 2380, USA). ESP was estimated by direct determination of exchangeable Na<sup>+</sup> and CEC, and calculated as in US Salinity Laboratory Staff (1954) (Son et al., 2016). The physical properties assessed were as follows: soil texture, bulk density, and porosity. Soil texture was classified by the pipette method. To determine bulk density and porosity, samples were collected using 57.73 cm<sup>3</sup> steel cylinders. Bulk density was measured using dry soil. Soil porosity was calculated following Briggs (1977).

### 2.4. Aggregate stability analysis

Aggregate stability was determined following the principle that unstable aggregates will break down more easily than stable aggregates when dry aggregates are immersed in water (Kaewmano et al., 2009). For this study, the wet-sieving method described by Kemper and Rosenau (1986) was applied to determine aggregate stability and mean

**Table 1**  
Physical and chemical properties of the soils before and after leaching experiments.

Items	Before	After			
		Control	Gypsum	Gypsum + rice straw compost	Rice straw compost
Soil texture	Silt loam				
Bulk density (kg m <sup>-3</sup> )	1.33 ± 0.15	1.33 ± 0.10	1.26 ± 0.09	1.26 ± 0.12	1.30 ± 0.09
Organic carbon (%)	0.96 ± 0.06	0.97 ± 0.14	0.96 ± 0.10	1.59 ± 0.22	1.62 ± 0.15
CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	6.54 ± 0.62	6.61 ± 0.27	7.05 ± 0.33	7.11 ± 0.20	6.85 ± 0.16
pH (1:5H <sub>2</sub> O)	7.79 ± 0.18	7.82 ± 0.17	7.58 ± 0.18	7.42 ± 0.28	7.63 ± 0.34
EC <sub>e</sub> (dS m <sup>-1</sup> )	26.7 ± 1.5	14.2 ± 0.68	3.9 ± 0.61	3.5 ± 0.62	11.1 ± 1.3
CaCO <sub>3</sub> (g kg <sup>-1</sup> )	13.6 ± 1.1	12.2 ± 0.5	15.1 ± 2.3	14.9 ± 0.4	14.9 ± 0.6
Ex. - Na <sup>+</sup> (cmol <sub>c</sub> kg <sup>-1</sup> )	3.9 ± 0.2	2.8 ± 0.4	0.6 ± 0.2	0.8 ± 0.4	1.6 ± 0.2
Ex. -Ca <sup>2+</sup> (cmol <sub>c</sub> kg <sup>-1</sup> )	1.2 ± 0.3	1.2 ± 0.2	3.4 ± 0.3	2.7 ± 0.3	1.6 ± 0.2
Ex. - K <sup>+</sup> (cmol <sub>c</sub> kg <sup>-1</sup> )	1.5 ± 0.2	1.4 ± 0.4	1.3 ± 0.3	1.3 ± 0.2	1.2 ± 0.3
Ex. - Mg <sup>2+</sup> (cmol <sub>c</sub> kg <sup>-1</sup> )	2.7 ± 0.5	2.5 ± 0.4	2.4 ± 0.3	2.4 ± 0.3	2.4 ± 0.1
ESP (%)	43.9 ± 1.9	27.2 ± 2.0	13.4 ± 2.0	9.0 ± 1.8	20.2 ± 2.4

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