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Research Paper

Irrigation with brackish water changes evapotranspiration, growth and ion uptake of halophytes

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ABSTRACT

Water shortage due to low precipitation, less river flows and high evaporation, and salinity stress related to use of brackish groundwater for irrigation are prevalent in the arid and semi-arid southwestern United States. The brackish groundwater desalinated using a reverse osmosis (RO) system produces a highly concentrate waste and creates a disposal problem. The objectives of this greenhouse study in pots were to assess irrigation water salinity induced changes to the evapotranspiration (ET), volumetric leaching fractions (LF), soil salinity, and dry biomass yields of two halophyte species (*Hordeum vulgare*, and *xTriticosecale*). Plants were arranged in a completely randomized design and four irrigation treatments (EC = 0.8, 5, 8 and 10 dS/m) were applied for 90 days during the two seasons. No significant differences were observed in the saturated hydraulic conductivity and soil water retention of sandy loam soil irrigated with different brackish waters. Total ET obtained from water balance was higher for plants irrigated with control than brackish waters only in season one. An increase in irrigation water salinity increased soil salinity and mean leaching fraction (LF) while mean ET decreased. There were no differences in dry biomass yield for both species in season 1, and very small differences in season 2. The sodium uptake primarily from irrigation water confirmed that both species were halophyte, can be grown with RO concentrate, and used as a salt substitute in animal fodder. However, in order to prevent soil salinization, RO irrigation should be done intermittently or until vegetation establishment in nonagricultural areas.

1. Introduction

There is a critical need of finding out ways to efficiently and properly use available water and augment water for irrigation through the use of nontraditional waters in the Western USA to maintain irrigated agriculture in the future. Water scarcity and salinity related abiotic stresses are generally known to be crucial for sustaining agriculture production in arid and semi-arid areas of the world. New Mexico faces the problem of declining surface water for irrigation caused by low precipitation, low river flows, and high evaporation (Flores et al., 2016). Brackish groundwater (BGW) is used to supplement the irrigation shortfalls (Baath et al., 2017) but about 75% of the aquifers in NM are brackish (EC > 3 dS/m; Lansford et al., 1990; WRRI, 1997). Prolonged application of brackish groundwater without treatment could exacerbate soil salinity with consequences for agriculture sustainability.

There are only two desalination facilities located near Las Cruces, Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico and Kay Bailey Hutchison Desalination (KBHD) Facility in El Paso, Texas. Both use reverse osmosis (RO) to desalinate BGW to produce fresh water, however, the process also produces a high saline (and/or sodic) waste (UNEP International Environmental Technology Center, 1998). The safe disposal of resulting RO concentrate, with EC ≥ 8 dS/m, is expensive, which makes the feasibility of an inland desalination system challenging (Soliz et al., 2011). Deep well injection and evaporation ponds are often used to dispose of the concentrate, resulting in loss of precious water (Gonzalez-Delgado et al., 2011). Reuse of RO concentrate to irrigate salt tolerant plants can be done in the water scarce arid and desert areas (Flores et al., 2015). The halophytes can also be grown for various purposes (Panta et al., 2014) including as a salt substitute in animal fodder. Halophyte farming,

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with proper plant selection and irrigation protocols, can also play an important role in reducing soil salinity problems (Noaman and El-Haddad, 2000; Keiffer and Ungar, 2002), improving air quality by controlling dust emission, increasing soil organic C, and food security.

Water scarcity is threatening food security in arid and semi-arid regions worldwide (Duan and Fedler, 2013). The increasing world population will require additional food, and drinkable water. However, soil salinization is one of the most crucial problems for crop production in arid and semi-arid regions (Ladeiro, 2012). Therefore, there is a need for more experimental studies on the potential of halophyte irrigation using wastewater after treating brackish and saline waters.

Irrigation water salinity could subsequently cause seed dormancy which relies on physical defense to exclude predators and pathogens, and rapid seed germination to escape pathogens at the emergence stage (Dalling et al., 2011). Sustainable land application of RO concentrate for halophyte farming and using desalinated water for agriculture could decrease salinization of agriculture soils and lower nutrient loading in the river. However, guidelines on species selection (Picchioni et al., 2014) for forage, revegetation or rangeland management (Browning et al., 2006) and irrigation management for halophyte farming (Adhikari et al., 2012a; Baath et al., 2017) are not available for concentrate use. Ghermandi et al. (2013) reported increases in agricultural productivity with irrigation using desalinated water. However, a major concern with saline water application to the soil is the affect aqueous salts could have on the soil hydraulic properties. An increase in the sodium absorption ratio (SAR) in the soil is reported to decrease the soil hydraulic conductivity (McNeal et al., 1968; Adhikari et al., 2012b).

Decreases in biomass yield (about 6%) of some medicinal plants were observed between control and 10 dS/m, and reduced water uptake with increasing salinity was identified as one of the main causes (Muhammad and Hussain, 2010). Seedling establishment and growth of *H. vulgare* was low due to high electrical conductivity of irrigation water ranging from 8.7 and 11.7 dS/m (Bernstein, 1975; El-Dardiry, 2007). On the other hand, no changes in seedling establishment were reported by Flores et al. (2016) for halophytes grown in sand and irrigated up to 8 dS/m of natural irrigation water. However, irrigation water salinity is reported to increase soil salinity with attendant decreases in ET, plant growth, and biomass yields (Allen et al., 1998). Low soil salinity and high ET corresponds to higher biomass yields (Diaz et al., 2013). The reported relationships between soil salinity, ET and biomass yields for agricultural crops does not follow the same patterns for halophytes.

Halophytic species tolerate high soil salinity without a decrease in ET or biomass yield. In some cases, biomass yields are increased. Flores et al. (2016) showed that the ET was higher for plants irrigated with control water than saline water. In spite of the differences in ET, Flores et al. (2016) showed no differences in biomass yields for six halophytes grown in sand but some limitation for those grown in clay. In contrast, Panta et al. (2016) reported that biomass yield for Atriplex lentiformis was higher in clay than in the sandy loam soil. Irrigation with high salinity water could cause reductions in plants growth without showing signs of salinity toxicity (Bernstein, 1975). Sodium and chloride could cause ion toxicity and produce salt burns in leaves (Alvarez et al., 2012; Deb et al., 2013). Reductions in plant growth and functions are reported due to the exclusion of calcium and potassium when excess sodium is present (Hussain et al., 2015; Flores et al., 2017).

Most studies on quantifying the influence of saline irrigation water on soil, and plant growth and physiology are conducted by preparing solutions of different concentrations of various salt mixtures. These solutions have generally very high solubility as opposed to the natural BGW, used in this study, with a suite of chemicals with high to very low solubility. Natural BGW and saline RO concentrate of similar concentration and solubility will be used by growers interested in halophyte farming. In this study, it was hypothesized that halophyte plant species will grow better when irrigated with RO concentrate. The objectives of the experimental study were to evaluate salinity induced changes on (1) soil hydraulic properties, and (2) ET, LF, soil salinity, and dry biomass yield of halophyte species.

2. Materials and methods

2.1. Soil analysis

In the experiment, knowledge of soil physical properties is crucial because it plays an important role in regulating plant growth, air flow, compaction and irrigation water management. The soil for the experiment was collected from West Mesa, New Mexico, a potential site for halophyte farming. Also some halophyte plant species naturally grow in this area. Air-dried soil was sieved through a 4-mm sieve prior to sterilization in an oven at a temperature of 85 °C for 30 min. Subsequently soil samples were sieved through 2 mm sieve and particle size analysis was performed using the hydrometer method (Gee and Bauder, 1986). The soil bulk density was determined on intact cores (5 cm × 5 cm) as the ratio of the mass of dry soil to its total volume (Blake and Hartge, 1986). Replicated cores (4-each) were separately saturated with control, BGW, and RO2 concentrate (RO mixed with NaCl) and saturated hydraulic conductivity (Ks, cm/h) was determined by the constant head method (Klute and Dirksen, 1986).

$$K_s = \frac{Q}{At} * \frac{L}{H + L} \tag{1}$$

where Q is the volume (cm^3), A is the cross-sectional area of the soil core (cm^3), t is the time interval (h), L is the length of the sample (cm), and H is the hydraulic head (cm).

For the soil moisture characteristics, a pressure plate extractor was used and soil moisture contents were determined for the potentials of 0, −0.03, −0.1, −0.2, −0.3, −0.5, −1.0, and −1.5 MPa on the cores used for K_s tests (Klute, 1986).

For soil chemical analysis, saturated soil paste extracts were prepared. Soil pH and EC were determined using portable meters, and the concentrations of Mg^{2+}, Na^{+}, and Ca^{2+} ions (meq/L) were determined using an ICP ($mmol_c$/L; PerkinElmer Optima 4300 DV ICP-OES) (US Environmental Protection Agency Staff, 1982; Gavlak et al., 1994). The sodium adsorption ratio (SAR) was calculated according to Eq. (2) (Robbins, 1983):

$$SAR = \frac{[Na^+]}{\sqrt{\frac{([Ca^{2+}][Mg^{2+}])}{2}}} \tag{2}$$

At the conclusion of the experiments, soil samples were collected from each pot, separately, and similar procedures were followed to obtain pH, EC, ion concentrations, and SAR.

2.2. Experimental site and set up

This experiment was carried out in the Fabian Garcia Science Center greenhouse in Las Cruces, New Mexico (32.2805°N latitude and 106.770°W longitude at an elevation of 1186 m above sea level). The experiment was conducted in the greenhouse because according to New Mexico Department of Agriculture guidelines, irrigation water above 4 dS/m salinity cannot be land applied. The first experiment (season one) started on October 5, 2015 and was concluded on January 3, 2016. During the season two, experiments were conducted between February 15, 2016 and May 14, 2016.

The experimental set up consisted of 32 cylindrical pots (4 replicates × 4 treatments × 2 species) for each of the two sea-