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Evaluation of the halophyte *Salsola soda* as an alternative crop for saline soils high in selenium and boron

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ABSTRACT

Urbanization, industrial development, and intensive agriculture have caused soil contamination and land degradation in many areas of the world. Salinization is one important factor contributing to land degradation and it affects agricultural production and environmental quality. When salinization is combined with soil pollution by trace elements, as it occurs in many arid and semi-arid regions around the world, strategies to phyto-manage pollutants and sustain crop production need to be implemented. In this study, we present the case of saline soils in the West side of Central California which contain naturally-occurring selenium (Se), boron (B), and other salts, such as NaCl, $CaCl_2$, Na_2SO_4, and Na_2SeO_4. To sustain crop production on Se- and B-laden arid saline soils, we investigated the potential of the halophyte "agretti" (*Salsola soda* L.) as an alternative crop. The aim of our greenhouse study was to examine adaptability, B tolerance, and Se accumulation by *S. soda* grown on soils collected from a typical saline-laden field site located on the West side of the San Joaquin Valley (SJV). Our results showed that *S. soda* tolerates the saline (EC ~ 10 dS m^{-1}) and B-laden soils (10 mg B L^{-1}) of the SJV even with the additional irrigation of saline and B rich water (EC ~ 3 dS m^{-1} and 4 mg B L^{-1}). Under these growing conditions, the plant can accumulate high concentrations of Na (80 g Na kg^{-1} DW), B (100 mg B kg^{-1} DW), and Se (3–4 mg Se kg^{-1} DW) without showing toxicity symptoms. Hence, *S. soda* showed promising potential as a plant species that can be grown in B-laden saline soils and accumulate and potentially manage excessive soluble Se and B in soil.

1. Introduction

Loss of productive land due to abiotic stresses (i.e. drought, increased salinity, and soil pollution) is posing major challenges to provision of nutritious and safe food, sustainability of agriculture, and conservation of agro-ecosystems and environmental quality. Salinization combined with recurrent droughts and higher uncertainty in climate stability represents a serious threat to agricultural production in many regions around the globe (e. g., United States, China, Australia, Bangladesh, India, etc.). Salinization combined with occurrence of trace elements, as in salt marshes and in arid-saline areas where the soil is naturally rich in trace elements, requires implementation of management strategies for sustainable crop production and protection of water quality.

For example, farming traditional and alternative crops in saline, arid and poor quality soils may be considered one of the potential strategies to sustain the current and future global food system. One possible strategy to manage high levels of soluble trace elements is to firstly identify drought and salt tolerant crops that can survive such poor growing conditions, and then use the plants to extract soluble trace elements (i.e. Se and B) from the soils (Bañuelos, 1996).

Many soils in the Western United States, e.g. West side of central California, are derived from Cretaceous shale rock and contain naturally-occurring selenium (Se), boron (B), and other salts, such as sodium chloride (NaCl), calcium chloride ($CaCl_2$), sodium sulfate (Na_2SO_4), and sodium selenate (Na_2SeO_4) (Schoups et al., 2005). In the West side of central California excessive accumulation of Se and B in the groundwater was caused by a combination of geology, salinity, intensive irrigation practices, and lack of tile drainage system (Presser and Schwarzbach, 2008). In the past, inefficient irrigation delivery systems contributed to solubilization and

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redistribution of those natural-occurring trace elements and other salts within the soil profile. Excessive concentrations of soluble trace elements, i.e., B, Se, have proven to be damaging to their surrounding eco-environment, including both plants and biological systems (Ohlendorf et al., 1986). Other similar areas within the Western USA, i.e., Colorado, Wyoming, Nevada, and Montana, were also concerned about similar ecological disasters occurring within their respective susceptible regions, due to high levels of soluble B, Se, and other trace elements present in their soils. In the west side of central California, indian mustard (*Brassica juncea*) and canola (*Brassica napus* L.) are two of the most common plants species utilized for phyto-managing B- and Se-laden saline soils (Bañuelos, 2001). Plant species used for the phyto-management of soluble ions in arid saline soils must tolerate high levels of salinity and B and accumulate naturally occurring Se from the soil. In regard to salt and B tolerance, salt-tolerant plants (halophytes) may satisfy this requirement and thus making halophytes optimal candidates for the phyto-management of soluble ions in trace element laden saline soils.

Salsola soda L., more commonly known as 'agretti' (Fig. 1), is a halophyte native to the Mediterranean basin. It is a relatively small plant that grows to about 0.7 m on average in coastal regions and can be irrigated with salt water. Throughout history, the plant was a very important source of soda ash, as people would extract the ashes from *S. soda*. The plant is no longer grown for the use of its soda ash but rather it is farmed as a vegetable. In folk medicine, *Salsola* species are traditionally used for the treatment of hypertension, constipation and inflammation (Tundis et al., 2009). In this regard, alkaloid extracts from *Salsola* species have been evaluated for the treatment of Alzheimer's disease (Tundis et al., 2009).

S. soda has been studied by Colla et al. (2006) and Graifenberg et al. (2003) as a "biodesalinating companion plant" to tomatoes and peppers in saline soils in central Italy. The authors showed that pepper and tomatoes respectively grown together with *S. soda* had a higher yield than if grown alone as monocrop. They attributed the higher yields to the ability of the halophyte 'agretti' to accumulate Na and reduce sodium's impact on pepper and tomatoes.

S. soda is a halophyte that is cultivated in Italy where it is consumed as a vegetable and it is offered in gourmet restaurants in Europe and America. The plant was recently documented as one of the endemic species in alkali grasslands typical of Central and Eastern Europe such as those in the Carpathian-basin (Török et al., 2012). Recent studies have shown the potential use of *S. soda* for the phytostabilization of polluted areas, as it can accumulate moderate levels of trace metals (Milić et al., 2012; Lorestani et al., 2011).

This study evaluates the potential of growing *S. soda* in B- and Se-laden soils of the west side of central California as both an alternative food crop and as potential species for phyto-management of Se and B in saline soils.

The aim of our study was to evaluate adaptability, salt and B tolerance, and Se accumulation by *S. soda* grown on typical unproductive saline soils collected from the west side of central California (Five Points, CA). We hypothesized the following: a) *S. soda* will be able to tolerate B and the salts present in the soil and safely accumulate potentially plant toxic ions, i.e., Na, Cl, and B, and b) *S. soda* will accumulate Se in the above ground biomass.

2. Materials and methods

2.1. Greenhouse pot experiment

Seeds of *S. soda* were purchased from the commercial retailer 'Seeds from Italy' (Lawrence, KS). The seeds were pre-germinated on potting soil and in plastic flats for 18 days. The germination potential of the seeds was about 65%. Seeds were watered daily twice a day with low saline water (electrical conductivity (EC) < 0.5 dS m^{-1}). The experiment was carried out under greenhouse conditions at SJV Agricultural Research Center in Parlier, CA. Greenhouse conditions were as follows: day/night temperatures 28/20 °C, 16 h photoperiod, 40–50% relative humidity of ambient air, and an average daily 200 μmol photons m^{-2} s^{-1} minimum light intensity. After 18 days, seedlings were transplanted into 2 kg pots filled with two types of typical west (saline) and east side (non-saline) soils of Central California. The saline soils consisted of an Oxalis silty clay loam (fine montmorillonitic, thermic Pachic Haploxeral with a well-developed salinity profile) collected at Red Rock Ranch (Five Points, CA), while the non-saline soil (designated as control) consisted of a Hanford sandy loam (coarse-loamy, mixed superactive, nonacid, thermic Typic Xerothents) soil collected at the SJV Agricultural Research Center in Parlier, CA. Chemical characteristics of the two soils (saline and control) are described in Table 1 and in Bañuelos (2002) and in Bañuelos and Lin (2010), respectively.

Treatments on saline and control soils were as follows: treatment 1 (T1): saline soil from Red Rock Ranch with EC of 10 dS m^{-1} and water soluble B of 10 mg L^{-1}; treatment 2 (T2): saline soil from Red Rock Ranch with EC 10 dS m^{-1} and water soluble B of 10 mg L^{-1} + irrigation with saline solution (described below and in Table 1); treatment 3 (T3): non-saline control soil from SJV Agricultural Research Center with EC of 2.3 dS m^{-1} and water soluble B of 0.12 mg L^{-1}; and treatment 4 (T4): non-saline control soil from SJV Agricultural Research Center with EC of 2.3 dS m^{-1} and water soluble B of 0.12 mg L^{-1} + irrigation with saline solution (described below and in Table 1). Five replications per treatment were used and the pots were placed in the greenhouse in a complete randomized block design. For each treatment, three pots without plants were also added and treated similarly as the planted pots within each treatment. Soil EC and pH were measured in both

Fig. 1. Wild *S. soda* growing on the coast near the sea water (left) and cultivated *S. soda* known as 'agretti' vegetable (right).