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# Effects of salinity on fine root distribution and whole plant biomass of *Tamarix ramosissima* cuttings

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ABSTRACT

To increase understanding of the influence of soil salinity on fine-root development and whole-plant growth of halophytic species, *Tamarix ramosissima* cuttings were exposed to various salinity conditions at a constant water table depth. Rooted cuttings of *T. ramosissima* were individually grown in pots in a greenhouse for 416 days in the following five treatments: 0 (field water only), 50, 100, 200, and 400 mM NaCl. Irrigation water was applied from the bottom of the pots and the water table was kept constant during the experiment. Fine roots were scarce at the surface layer probably because of low moisture and/or high salinity concentrations. Fine-root biomass and length increased in layers with higher soil moisture availability in the control, 50, and 100 mM NaCl treatments. In contrast, the distribution of fine roots appeared to be influenced by salinity in the 200 and 400 mM NaCl treatments. Total biomass and total fine-root length were highest in the 100 mM NaCl treatment, and total biomass was positively correlated with total fine-root length under all conditions, suggesting that variation in fine-root length may have an important effect on the whole-plant biomass of the cuttings across a salinity gradient.


## 1. Introduction

Soil salinity is a major factor limiting the growth and development of most plants (Bernstein and Kafkafi, 2002). In arid regions, salinity can potentially contribute to shifts in vegetation communities and may cause increases in the establishment and proliferation of salt-tolerant invasive species (Bui, 2013). Salinization is a process in which salts accumulate near the soil surface and is often caused by capillary rise from shallow water tables because of higher potential evapotranspiration relative to precipitation in arid regions (Salama et al., 1999; Rengasamy, 2006). Salinization is facilitated by human activities such as water management and vegetation change (Breckle, 2004). Increased salt concentration at the soil surface decreases water availability for plants because salinity decreases water potential in the soil medium. In such areas, some perennial plant species that have longer roots rely on groundwater as a reliable water source (Batanouny, 2001), although groundwater contains some salts in solution (Rengasamy, 2006).

Many salt-sensitive plant species are adversely affected by even lower levels of salinity, resulting in growth reduction. Such plants may often die when salt levels increase. In contrast, halophytes grow and survive in environments where salt concentrations are high (>200 mM NaCl) (Flowers and Colmer, 2008; Bui, 2013). The mechanisms of salt tolerance in halophytes are generally recognized to be related to controlled uptake and compartmentalization of salts, synthesis of compatible solutes, and excretion of excess salts (Breckle, 2004; Flowers and Colmer, 2008). However, despite the essential role of soil resource uptake for plant growth and survival, the acquisition of soil resources for halophytes in saline soils is inadequately understood.

Roots, particularly fine roots, are essential for the uptake of soil water and nutrients in terrestrial ecosystems (e.g., Eissenstat et al., 2000). Roots directly interact with the soil solution, and therefore are the first to encounter the saline medium and potentially the first site of damage or line of defense under salt stress (Bernstein and Kafkafi, 2002). Root growth and development are inhibited by high concentrations of NaCl in the medium. The inhibition of root growth and development reduces the soil volume for exploitation for acquiring soil resources, and therefore influences soil resource uptake by roots and growth at a whole-plant level

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(Bernstein and Kafkafi, 2002). However, fine-root responses to soil salinity in halophytes and their relation with whole-plant growth have been inadequately understood. For better understanding of plant growth and plant tolerance to salinity, the response of fine roots to saline water with a shallow water table should be investigated.

*Tamarix* spp. (*Tamarix ramosissima*, *Tamarix chinensis*, or their hybrids) are invasive trees/shrubs in arid riparian areas of the western United States (Di Tomaso, 1998; Shafroth and Briggs, 2008; Stromberg et al., 2009) and now occupy more than 400,000 ha across the region (Shafroth and Briggs, 2008). It has been reported that the growth and distribution of *Tamarix* have been largely associated with changes in water regimes resulting from water management programs, such as reservoir and dam construction, river diversions, and irrigation, which lead to altered flood frequency and stream flow, increased groundwater depth, and elevated soil salinity (Di Tomaso, 1998; Glenn and Nagler, 2005; Stromberg et al., 2007). On the other hand, these altered conditions reduce the establishment, growth, and survivorship of native tree species, such as *Populus* and *Salix* (Glenn and Nagler, 2005; Stromberg et al., 2007). *Tamarix* is a facultative halophyte known to tolerate such harsh conditions via salinity and water tolerance mechanisms, such as selective exclusion of salts from roots, compartmentalization and secretion in salt glands, and facultative phreatophytic ability (Ohrtman and Lair, 2013). *Tamarix* often develops its root system under conditions in which water tables are relatively high and where salts accumulate in the soil profile (Nippert et al., 2010; Glenn et al., 2012; Imada et al., 2013) and produce adventitous roots from stems under flooding (Everitt, 1980; Jaoudé et al., 2012). However, little is known about how the species distributes fine roots under higher salinity conditions and captures resources from the soil. This information is critical for understanding a potential mechanism for success in the establishment and growth of *Tamarix*.

A greenhouse experiment was conducted to determine the effects of various salinity concentrations on fine-root distribution and whole-plant biomass on rooted cuttings of *T. ramosissima*. Irrigations were applied from the bottom of the pots to a constant water depth for more than one year. It was hypothesized that water and salinity profiles would affect the vertical distribution of fine roots so that soil layers with low soil moisture or high salinity concentrations would have smaller fine-root biomass and length because of low soil water potential. It was also hypothesized that high salinity concentrations would decrease whole-plant biomass. Our previous study showed that parallel relationships exist between the total fine-root length and whole-plant biomass for rooted cuttings of a tree species grown under different soil moisture conditions (Imada et al., 2008). If different salt concentrations influenced total fine-root lengths, the changes would affect whole-plant biomass.

## 2. Materials and methods

### 2.1. Plant material and growth conditions

Branch tips were collected from a few individual *T. ramosissima* plants in a monotypic stand on the Virgin River, Nevada, United States (36°41′N; 114°15′E) in early March 2009. The cuttings were planted in a planter in mid-March and grown in a nursery in a greenhouse at the Arid Land Research Center, Tottori University, Japan (35°32′N; 134°13′E). In early June, when cuttings were well rooted, they were transplanted to 42 plastic pots (60 L, 50-cm diameter, 55-cm tall, 45-cm soil depth) with washed sandy soil with the following properties (Inoue and Nomura, 1983): field capacity 0.040 g $g^{-1}$, air-dry water content 0.008 g $g^{-1}$, and average dry soil bulk density 1.50 g $cm^{-3}$. There was one rooted cutting per pot. The plants were irrigated daily with freshwater to a level above field capacity for approximately three weeks to acclimate to the pot environment. In mid-June during the acclimation period, slow-release fertilizer powder (Hyponex, 17-10-16 NPK, Hyponex Japan, Osaka, Japan) was added at 55.55 g $m^{-2}$ (10 g $m^{-2}$ of nitrogen) on the surface.

### 2.2. Salinity treatments

Subirrigation with saline water was initiated at the end of June 2009. The rooted cuttings were divided into five treatments with seven plants in each. The treatments were 0 (field water only), 50, 100, 200, and 400 mM NaCl. The average height of the cuttings was 30.0 ± 1.2 cm (mean ± SE) and the average diameter was 7.69 ± 0.29 mm at the beginning of the treatments. The treatment water was applied from the bottom of the pots and kept at a constant water table depth of 40 cm using an underground irrigation system (Imada et al., 2008, 2010). This depth of the water table was chosen because it was able to create soil moisture and salinity gradients in the experimental setting. The pots in each treatment were connected by PVC pipes. One end of a line of pipes was connected to a water tank and the other end was capped by a PVC plug. A float valve was used to maintain the level of the water table by controlling water flow from the water tank. Saline water was gradually replaced during growing seasons by supplying newly prepared water into the water tank. The treatments were continued until mid-August 2010 for 416 days. Volumetric water content was measured using ECH2O-TE soil moisture probes (Decagon Devices Inc, Pullman, Washington, USA) at the depth of 10 cm in one pot of each treatment during the experiment to monitor if the water table depths were effectively controlled. In the spring of the second year, liquid fertilizer (Hyponex, 6-10-5 NPK, Hyponex Japan) was combined with the treatment water at 1000-fold dilution and applied via the watering system for a period of one month from end of May to end of June 2010. Mortality of the cuttings was observed in the 100, 200, and 400 mM NaCl treatments from early July 2010. One or two cuttings were dead in these treatments by the end of the experiment.

### 2.3. Soil conditions

Vertical profiles of soil moisture, pH, electrical conductivity (EC), and soluble $Na^+$ concentration were determined by sampling with a 20-mm diameter pipe in pots at the end of the treatments. Soil samples in each pot were collected at 5 cm intervals from 0 to 40 cm depth. The soil samples were oven-dried at 80 °C for at least 48 h and weighed. The soil water content (SWC) was calculated as follows: soil water content = (fresh weight − dry weight)/dry weight. Soil samples were pooled for each 10-cm depth and the pooled samples were used for analyzing soil pH, EC, and $Na^+$ concentration. Deionized water (50 mL) was added to 10 g of dry soil and the solution was shaken for 1 h. The pH and EC of the soil were measured using a 1:5-w/w suspension of soil and water ($EC_{1:5}$) (twin pH meter B-212 and conductivity meter B-173, Horiba, Kyoto, Japan). The soluble $Na^+$ concentration was determined using atomic absorption spectrometry (AA-6700S, Shimadzu, Kyoto, Japan) with the same water extract. Soil water salinity ($EC_{SW}$) was calculated by the equation of Sakaguchi et al. (2004): $EC_{SW} = 4.155 \times EC_{1:5}{}^{1.004} \times SWC^{-0.896}$.

### 2.4. Root morphology

Root samples were collected with soil using a liner sampler (55-mm diameter; DIK-110C, Daiki Rika Kogyo, Saitama, Japan) in each