Scientia Horticulturae 201 (2016) 84–91

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Tolerance mechanisms of three potted ornamental plants grown under moderate salinity

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ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form 14 January 2016
Accepted 20 January 2016
Available online 4 February 2016

Keywords:
Biomass
Electrical conductivity
Mineral composition
Proline
Salt tolerance
Sugars

ABSTRACT

The scarcity of water in the Mediterranean area has frequently led to the use of saline water in order to irrigate ornamental plants in many nurseries. However, before the large-scale use of such waters, the ways in which the plants deal with the salinity need to be evaluated. Plants of *Aloe vera* L. Burm, *Kalanchoe blossfeldiana* Poelln and *Gazania splendens* Lem sp. were grown in pots with a mixture of sphagnum peat-moss and Perlite. In order to evaluate the effects of different levels of salinity, three treatments using different NaCl concentrations (Electrical conductivity = 2.0 (control), 4.5 and 7.5 dS m^{-1}) were applied over a period of 60 days. At the end of the experiment, the growth, physiological parameters and mineral content of the roots and leaves were assessed for each salinity treatment. After 60 days of exposure to salinity, the total biomass of all species decreased similarly. The mineral composition of roots and leaves was clearly affected. Osmolytes, such as proline, played an important role in the osmotic adjustment in all species increasing in the roots and leaves at the higher EC_i. Different mechanisms of the salt tolerance were triggered in each species. *A vera* plants showed Na^+ accumulation at the root level and a decrease in succulence index of leaves. *K. blossfeldiana* plants shed leaves to release Na^+ and *G. splendens* plants accumulated Cl^- and Na^+ at the root level, secreted salt from leaves, lost salt by shedding of old leaves and increased the succulence index of remaining leaves. We concluded that the use of saline waters is feasible for growing these ornamental plants, and *G. splendens* seems to be particularly well adapted to salinity, a consideration that is particularly relevant in arid saline areas.

1. Introduction

The worldwide production value of ornamental potted plants and cut flowers is about 50 billion €, corresponding to an estimated global consumption of between 100 and 150 billion € (Lütken et al., 2012). However, nowadays there is a decrease in production around the world partly due to soil and water salinization (Cassaniti et al., 2013) as happens in the south-eastern coastal region of Spain with high salinity levels in the water due to the overexploitation of groundwater and seawater intrusion in some aquifers (Consejería de Medio Ambiente y Ordenación del Territorio (CMAOT), 2012).

There are three major constraints for plant growth under saline conditions: (1) the water stress, arising from lower water potential of the growing medium, (2) ion toxicity associated with the excessive uptake mainly of Cl and Na, and (3) a nutrient imbalance caused by depression in the uptake of other nutrient ions (Marschner, 1995). To cope with the effects of salt stress, plants have evolved many biochemical and molecular mechanisms to reduce detrimental effects of ions from those parts of the plants where they may be harmful; these mechanisms include accumulation at the root level, the shedding of dry leaves, salt secretion and succulence (Aslam et al., 2011). The cell osmotic adjustment necessary for growth in saline environments may be accomplished by the accumulation of inorganic and organic solutes. The inorganic ions are believed to

Abbreviations: ANOVA, analysis of variance; DW, dry weight; EC_i, electrical conductivity of the irrigation water; FW, fresh weight; H_2O_2, hydrogen peroxide; HPLC, high performance liquid cromatography; LWR, leaf weight ratio; LSD, least significant difference; L, leaves; PAR, photosynthetically active radiation; RH, relative humidity; RWR, relative root weight ratio; Yr, relative yield; R, roots; SI, succulence index; H_2SO_4, sulphuric acid; TDW, total dry weight; TSS, total soluble sugars; UL, unwashed leaves; WL, washed leaves; WC_l, water content in leaves; WC_r, water content in roots; Y, yield.

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http://dx.doi.org/10.1016/j.scienta.2016.01.031
0304-4238/

be sequestered in the vacuoles, while the organic solutes such as sugars and proline may be compartmentalized in the cytoplasm to balance the low osmotic potential in the vacuole (Munns and Tester, 2008).

Due to the great economic importance of the production of potted plants in south-eastern coast of Spain in the recent years, and the challenges to the continued supply of non-saline water mentioned above, further investigation is necessary on the effects of different irrigation water salinity (electrical conductivity, EC_i) in horticultural species. The adjustment of the nutrient solution in terms of electrical conductivity (EC) is crucial for the optimization of the water and nutrient availability (Kang and Iersel, 2004).

We investigated three species. *Aloe vera* L. Burm, a member of the *Asphodelaceae* family, is a succulent plant with green leaves, widely cultivated and valued due to its short growth period and the high economic value (Moghbeli et al., 2012). *Kalanchoe blossfeldiana* Poelln, originating from Madagascar, is a member of *Crassulaceae* (Abdel-Raouf, 2012) and it is one of the most financially important flowering, potted plant species in Europe, with a production of more than 150 million plants per year (Mibus et al., 2014). *Gazania splendens* Lem a sp., within Compositae, tribe *Arctotideae*, subtribe *Gorteriinae* (Karis, 2007), is an ornamental shrub widely cultivated in gardens across the world, being endemic from southern Africa (Magee et al., 2011). Nevertheless, very few studies on the effects of different EC of the irrigation water on the nutrition and physiology have been reported for *K. blossfeldiana* (Taybi et al., 1995; Mariaux et al., 1997) and *G. splendens*. In the case of *A. vera*, there are many investigations on the effects of high NaCl concentration such as 100 and 200 mM NaCl (Xu et al., 2006; Zheng et al., 2009) or 100% seawater (Liu et al., 2007), but very little is known regarding the effects under low NaCl stress. Therefore, in this trial, a pot experiment with *A. vera*, *K. blossfeldiana* and *G. splendens* plants was established in order to determine the effects of different salinity levels of the irrigation water on the plants' dry mass and allocation, mineral nutrient content, mechanisms of salt tolerance and their physiological changes. Such information can be used for optimizing the crop management with saline waters and also for evaluating which of these species might be suitable for the use of saline waters.

2. Material and methods

2.1. Plant material and experimental conditions

The present study was carried out at the University of Almeria (36°49′N, 2°24′W). Rooted cuttings (plants) of *A. vera* L. Burm, *K. blossfeldiana* Poelln and *G. splendens* Lem were obtained from a local nursery and transplanted into 1.5 L polyethylene pots containing a mixture of sphagnum peat-moss and Perlite 80:20 (v/v). During the trial (60 days), the pots were placed in a greenhouse of 150 m^2. The microclimatic conditions inside the greenhouse for the experimental period, monitored continuously with HOBO SHUTTLE sensors (model H 08-004-02) showed a daily average temperature of 25.4 ± 2.5 °C, relative humidity (RH) of 65.6 ± 2.1% and photosynthetically active radiation (PAR) of 225 ± 9.4 $\mu mol\ m^{-2}\ s^{-1}$.

2.2. Experimental design and treatments

This experiment had been performed previously with a wider range of salinities. The experiment consisted of three treatments using different salinities in a standard solution with the following composition (in $mmol\ L^{-1}$): 0.70 $H_2PO_4^-$, 6.00 NO_3^-, 2.00 SO_4^{2-}, 3.00 K^+, 2.00 Ca^{2+} and 1.40 Mg^{2+} amended with different concentrations of NaCl (sole salinizing agent) to achieve EC levels of the irrigation water (EC_i) of either 2.0 (T_1 or control, 3 $mmol\ L^{-1}$ NaCl), 4.5 (T_2, 30 $mmol\ L^{-1}$ NaCl) or 7.5 (T_3, 60 $mmol\ L^{-1}$ NaCl) $dS\ m^{-1}$. The plants were irrigated manually every day. The EC_i and pH were measured daily using a conductivity meter and pH meters (models Milwaukee C66 and pH52), respectively. The treatments (EC levels) were chosen in accordance with previous research reported by Wu and Dodge (2005) regarding the salinity tolerance with a range from 2 to over 6 $dS\ m^{-1}$ to avoid salt stress symptoms, considering the irrigation with the nutrient solution of 2.0 $dS\ m^{-1}$ as a control in the experiment. The volume of saline water added to each pot during the experimental growing period was 4.2 L for each saline treatment and the same for all species. The experimental design consisted of three salinity treatments, four blocks, and four plants (one plant per pot) per block giving a total of 12 plants per species plus border plants.

2.3. Plant parameters

At the end of the saline period, the plants were harvested and the substrate gently washed from the roots of four plants per treatment for all the studied species. The plants were divided into roots (R) and leaves (L) and the respective fresh weights (FW) measured; roots and leaves were then oven-dried at 60 °C until they reached a constant weight to measure the respective dry weights (DW). These dry weights were used to calculate several plant parameters as indicated by Ryser and Lambers (1995) and Correia et al. (2010): the leaf weight ratio (LWR; leaf DW per unit plant DW) and the relative root weight ratio (RWR; root DW per unit plant DW). The total dry weight (TDW) was calculated as the sum of leaves and roots DW. The fresh and dry weight of roots and leaves were used to calculate the water content (WC) (−) as indicated by Ben Amor et al. (2005):

$$WC = \frac{(FW - DW)}{FW} \quad (1)$$

2.4. Yield response salinity models

To model the yield response to the different EC_i values in the three species, regression analyses were tested and the best fitted models were selected based on the determination coefficient (R^2) in accordance with Steppuhn et al. (2005) and Correia et al. (2010). In this experiment, the total plant DW (roots and leaves) was used as yield (Y), being assessed 60 days from salinization. The absolute yield (Y) was converted into relative yield (Yr) by employing a scaling divisor (Ym) based on the maximum value of total plant biomass (DW) obtained in control plants (Maas and Hoffman, 1977). The Yr value for each salt treatment was determined at the end of the experiment according to the following equation:

$$Yr = \frac{Y}{Ym} \quad (2)$$

2.5. Physiological measurements

Four plants per treatment were randomly selected at the end of the experiment in each species to determine the Na and Cl accumulation by roots, calculated as the ratio between the quantity of Cl and Na in the root (R) relative to total quantity in the plant (Cl^- and Na^+ extraction per plant in mmol/root DW in gram); (ii) the Cl^- and Na^+ secretion by leaves (L) was assessed by the difference between the content of this elements in washed leaves (WL) and in unwashed leaves (UL) ($mmol\ g^{-1}$ DW); (iii) the loss of Na and Cl was evaluated by collecting and quantifying the contents of these elements ($mmol\ g^{-1}$ DW) in shed old leaves, and (iv) the succulence index (SI) of leaves was determined as the ratio between leaf FW and leaf DW (−) as proposed by Hoolbrook and Putz (1996).