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Review

The effects of salt stress on ornamental plants and integrative cultivation practices

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ABSTRACT

Ornamental horticultural production is closely associated with a high water consumption and yet the availability of freshwater is reducing. The irrigation of ornamental plants with saline water may be an alternative, but an improvement in knowledge of the effects on salinity on species used as ornamentals is essential. In this review, considering the references from the last decade, we summarized the main effects of salt stress on growth, nutrient, photosynthetic and physiological parameters in ornamental plants. At high salinities, plants exhibit a reduction of growth parameters such as biomass or leaf area related to osmotic and ionic effects of salinity. Growth under saline conditions leads to uptake of Na^+ and Cl^- by plants, which can result in a nutritional imbalance due to the antagonism between nutrients and saline ions with possible effects on the foliage. Salinity can affect water relations in plants and photosynthetic capacity by stomatal limitations. These negative effects can be counteracted by the plants through the accumulation of compatible solutes or osmolytes and the activation of antioxidant machinery. Nevertheless, the performance of these mechanisms is sometimes not enough to avoid damage to the appearance of the plant and in consequence the saleability of an ornamental species. In this review recommendations for the establishment of integrative cultivation practices for nursery growers are made; these include exogenous application of nutrients and osmolytes and enrichment with CO_2, in order to mitigate the damage caused by salt stress to ornamental plants.

1. Introduction

Ornamental plants have an important place within the horticultural industry as they are used in gardening, landscaping, and as cut flowers. The total turnover for all aspects of floriculture is estimated to be more than 300 billion USD and cut flowers make up about one-third of the global value of the ornamental plants market (Azadi et al., 2016). Currently, the main constraint to ornamental plant production is water consumption: it has been estimated that 100–350 kg of water are needed to produce 1 kg of plant dry matter, although this can vary with species and variety, cultivation system and plant growing season (Fornes et al., 2007). Growers have, over decades, used high quality water to irrigate ornamental plants because of their high economic value. Nowadays the increase in population and agricultural production together with the diminishing sources of fresh water continue to intensify competition for good water (Carter and Grieve, 2010).

Ornamental plants can be grown under field conditions and sold on as bare-rooted plants or potted in containers filled with substrates such as peat moss, coconut fibre or different kinds of mixtures with other materials (Reid and Jiang, 2012). The selection of how plants are grown, whether under field conditions or in containers, will be influenced by the salinity in the soil and the irrigation water available. There are different causes of salinity in the soil and water. In the case of the soil, the main causes are long-term natural accumulation of salts, deposition of sea-salt carried by wind and rain and anthropogenic activities that disrupt the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration) (Singh, 2015). For the salinization of water, the main causes are overexploitation of ground-waters, percolation of salts into the aquifers and seawater intrusion in aquifers (Payen et al., 2016).

Soils are considered saline when they have an EC of 4 $dS\,m^{-1}$ or higher, which can be particularly problematic if the increased EC is the result of NaCl (Ghassemi et al., 1995). Cassaniti et al. (2013) (modified from Paranychianakis and Chartzoulakis, 2005) classified water salinity by EC as freshwater with lower values of 0.6 $dS\,m^{-1}$, slightly brackish with an EC which ranges from 0.6 to 1.5 $dS\,m^{-1}$, brackish with an EC from 1.5 to 3.0 $dS\,m^{-1}$, moderately saline from 3 to 8 $dS\,m^{-1}$, saline from 8 to 15 $dS\,m^{-1}$ and highly saline from 15 to 45 $dS\,m^{-1}$.

Abbreviations: DW, dryweight; EC, electrical conductivity; FW, fresh weight; LED, light emitting diode; PT, pour through

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Plant growth response under saline conditions presents two phases. In the first phase (osmotic stress), there is a growth reduction which starts immediately after exposure of the roots to salt. This effect is associated with an osmotic impediment to water uptake and consequent changes in water relations at a cellular level. The second phase (ionic toxicity) results when leaves, becoming senescent, are anymore able to compartmentalize sufficient Na^+ and Cl^- to prevent effects on photosynthesis and consequently old leaves die (Munns and Tester, 2008). However, plants differ considerably in the concentration of salt that brings about these changes and species have been divided into halophytes and glycophytes. Some halophytes benefit from growing under saline conditions, whereas among glycophytes some species are more tolerant than others (see Munns and Tester, 2008). The main difference between the two groups of plants is the mechanism adopted to face the salinity stress (see Flowers and Colmer, 2015).

The effect of saline irrigation on ornamental plants has been investigated to a much lesser extent than other crops because ornamentals are normally irrigated with high quality water. Nevertheless, there are many papers on the effects of the saline stress in ornamental plants, describing the effects on one or more species (e.g. Valdés et al., 2015a; García-Caparrós et al., 2016) as well as comprehensive reviews (Niu and Cabrera, 2010; Cassaniti et al., 2013; Acosta-Motos et al., 2017a). In this review we update information on the effects of salinity on ornamental plants with material covering the last ten years, tabulating effects on growth, nutritional status, water relations, photosynthetic parameters, osmolytes accumulation and antioxidant activity, with the aim of allowing the grower to make rational choices of plants and culture methods.

2. The effects of salt stress on ornamental plants

2.1. Growth (biomass, leaf area and number of flowers)

Plant growth is affected by salinity as a result of the disruption of physiological processes such as: 1) disturbed photosynthesis, 2) disturbed osmoregulation, 3) down-regulation of aerial growth following a long distance signal, and 4) disturbance in mineral supply to the aerial part (Negrão et al., 2017).

Roots are the most vulnerable part of the plant because they are directly exposed to salt, as a result, water absorption capacity, water use efficiency and other parameters and processes may be affected (Sánchez-Blanco et al., 2014). In general, root growth is inhibited by exposure to high salinity as a result of osmotic and toxic effects (Bañón et al., 2012), although this response depends on the species and salinity level. For instance, *Phlomis purpurea* plants irrigated with water of $4\ dS\ m^{-1}$ reduced root DW, although *Callistemon citrinus*, *Evonimus* and *Pistacia lentiscus* plants irrigated with the same salt level did not show a reduction in root DW (Castillo, 2011; Álvarez et al., 2012b; Gómez-Bellot et al., 2013).

Ornamental plants subjected to salt stress exhibit a decrease in fresh weight (FW) and dry weight (DW), especially in the aerial part, a reduction in total leaf area and plant height and a reduction of the number and quality of flowers, which has been recorded in previous reviews (Quist et al., 1999; Kucukahmetler, 2002) and can be seen in the updated references in Table 1. The decrease in FW or DW is mainly due to a reduction in the number of leaves or the formation of smaller and fewer leaves and reduced plant height (see also below) as reported by Acosta-Motos et al. (2017a). This reduction of FW and DW under saline conditions can be used for the classification of the degree of salt tolerance of ornamental species, essential information for the nursery grower in order to choose which species is the most suitable for the soil and water available. Species that are very sensitive to salinity include *Impatiens walleriana*, *Zinnia angustifolia* and *Viola tricolor* with a high biomass decrease (90%), while *Chamaerops humilis* and *Washingtonia robusta* can be grown with electrical conductivity of irrigation water from 2 to $8\ dS\ m^{-1}$ (see Table 1). In order to ameliorate the negative effects produced by saline irrigation, some researchers have proposed that arbuscular mycorrhizal fungi have positive effects on the growth of crops under saline conditions being a sustainable option that should be considered (Porcel et al., 2012; Estrada et al., 2013).

For ornamental plants, exposure to saline conditions can involve not only a decrease in plant weight, but also a consequent reduction of plant height (Zhang and Shi, 2013). Nevertheless, this reduction in size could be an advantage from the grower's point of view since consumers often require more compact plants with high quality and ornamental value, but taking into account that the consumer might have to continue with the irrigation with salt water in order to maintain the reduction in size. Furthermore, smaller plants require less space in expensive production facilities, are easier to handle, have reduced transportation costs and advantages for retailers (Lutken et al., 2012). Nevertheless, the use of salt has not yet been adopted as a technique to manage plant size.

A typical response to salt stress described in literature is a reduction in total leaf area. The reduction in leaf area, a consequence of changes in cell wall properties, cell water relations and a reduction in photosynthetic rate (Munns and Tester, 2008), has been recorded (see Table 1) for *Paulownia* sp. (Ivanova et al., 2014), *Callistemon laevis* (Álvarez and Sánchez-Blanco, 2015) and *Euonymus japonicus* (Gómez-Bellot et al., 2013). A reduction of leaf area due to the salt stress could, again, be beneficial for nursery growers, especially when they want to produce compact plants avoiding the use of plant growth regulators (Rademacher, 2015). Also, reduced leaf area is an avoidance mechanism in order to minimise water loss via transpiration under saline conditions (Acosta-Motos et al., 2017a).

In floricultural crops, under salt stress there can be a reduction of the number and quality of flowers as was reported in previous literature (Wahome et al., 2000; Shillo et al., 2002). Thus, plants subjected to saline stress may reduce flowering intensity, bring forward or delay flowering and shortened the period of flowering (Fornes et al., 2007; Álvarez et al., 2012a). This effect can be related to an alteration of the concentration of hormones directly involved in flowering such as abscisic and jasmonic acids (Rogers, 2013). The reduction of number and quality of flowers can result in a decrease of sales for floricultural crops which is not acceptable to growers. Therefore, one possible solution to mitigate these effects could be the foliar application of hormones, following the recommendations given in a comprehensive review on postharvest biology and technology in potted plants by Reid and Jiang (2012). For instance, Ashour and Sakr (2016) reported the application of ABA or salycilic acid on *Hamelia patens* plants to alleviate the effects of saline irrigations. On the same hand, Gad et al. (2016) noted an enhancement of growth and flowering in *Ixora coccinea* plants sprayed with salicylic acid.

2.2. Nutritional balance

Salt stress can affect the nutritional status of a plant through a complex net of interactions, including a decrease of nutrient uptake and/or transport from root to shoot (Munns and Tester, 2008). As can be seen in Table 2, ornamental plants grown under saline conditions exhibited a decrease of N, P, K and Ca concentration in leaves related to antagonisms with Cl and Na and an increase in Na and Cl concentration in leaves.

Under salt stress conditions, nitrogen uptake is often disrupted mainly due to the antagonism between Cl^- and NO_3^- (Munns and Gilliham, 2015). Salinity stress also reduces P availability because of the antagonism between Cl^- and $H_2PO_4^-$ as reported by Parihar et al. (2015). Reduced uptake of P under salt stress can also be a consequence of the strong influence of sorption processes that control the concentration of P in the soil and low solubility of Ca-P minerals (Marschner, 2011). The inhibition of K^+ uptake in plant occurs primarily due to the physical and chemical similarities between K^+ and Na^+ and the tendency of the latter to compete with K^+ for major