

# The Response of Ornamental Plants to Saline Irrigation Water

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## 1. Introduction

Salinity affects about one third of irrigated land, causing a significant reduction in crop productivity (Flowers & Yeo, 1995; Ravindran et al., 2007). For this reason researchers have paid considerable attention to this important environmental problem over the last decades. Few studies, however, have dealt specifically with ornamental plants used in landscapes, despite the fact that salt stress causes serious damage in these species (Cassaniti et al., 2009a; Marosz, 2004). Salinity is of rising importance in landscaping because of the increase of green areas in the urban environment where the scarcity of water has led to the reuse of wastewaters for irrigation (McCammon et al., 2009; Navarro et al., 2008). Salinity is also a reality in coastal gardens and landscapes, where plants are damaged by aerosols originating from the sea (Ferrante et al., 2011) and in countries where large amounts of de-icing salts are applied to roadways during the winter months (Townsend & Kwolek, 1987).

Although water is used for purposes other than irrigation, “a landscape may serve as a visual indicator of water use to the general public due to its visual exposure” (Thayer, 1976). While in the past only good quality water (in some States of the USA, homeowners used approximately 60% of potable water to irrigate landscapes; Utah Division of Water Resources, 2003) was used for landscaping and/or floriculture (Tab. 1), nowadays the ecological sensitivity widely diffused in landscape management and planning (Botequilla Leitão & Ahern, 2002) determines the need to explore alternative water sources for irrigation. Landscape water conservation consequently requires making choices of plant species able to tolerate salt stress in order to allow the use of low quality water.

Alternative water sources might be recycled water, treated municipal effluent and brackish groundwater, all of which generally have higher levels of salts compared with potable waters (Niu et al., 2007b). Treated effluent may also contain nutrients essential for plant growth; if water quality is good (not too saline), treated effluent can improve plant growth and reduce fertilizer requirements (Gori et al., 2000; Quist et al., 1999); application of industrial and municipal wastewater to land can be an environmentally safe water management strategy (Rodriguez, 2005; Ruiz et al., 2006). The potential physical, chemical or biological problems that are associated with effluent water applied to edible crops (Kirkam, 1986) are of lesser concern for landscape plant production (Gori et al., 2000).

Characteristics	Desired Level
Soluble salts (EC)	less than 0.5 dS m <sup>-1</sup>
pH	5.0 to 7.0
Alkalinity (expressed as calcium carbonate)	between 40 and 100 ppm (0.80 and 2.00 me/L <sup>-1</sup> )
Nitrate (NO <sub>3</sub> )	less than 5 ppm
Ammonium (NH <sub>4</sub> )	less than 5 ppm
Phosphorous (P)	less than 5 ppm
Potassium (K)	less than 10 ppm
Calcium (Ca)	less than 120 ppm
Sulfates (SO <sub>4</sub> )	less than 240 ppm
Magnesium (Mg)	less than 24 ppm
Manganese (Mn)	less than 2 ppm
Iron (Fe)	less than 5 ppm
Boron (B)	less than 0.8 ppm
Copper (Cu)	less than 0.2 ppm
Zinc (Zn)	less than 5 ppm
Aluminum (Al)	less than 5 ppm
Molybdenum (Mo)	less than 0.02 ppm
Sodium (Na)	less than 50 ppm
SAR*	less than 4 ppm
Chloride (Cl)	less than 140 ppm
Fluoride (F)	less than 1 ppm

\*SAR (Sodium Absorption Ratio) relates sodium to calcium and magnesium levels.

Table 1. Desiderable characteristics of high-quality irrigation water (Source: Dole & Wilkins, 1999).

However, any negative effects of salts on plant growth have to be taken into consideration mainly for their influences on aesthetic value which is an important component of ornamental plants. Salt tolerance does, however, vary considerably among the different genotypes of ornamentals used in landscaping. Ornamental plants can be considered all the species and/or varieties that provide aesthetic pleasure, improve the environment and the quality of our lives (Savé, 2009). This definition is, however, rather imprecise because these plants are used around the world and consequently the concept of 'ornamental' is ambiguous because it includes very important cultural differences (Savé, 2009). Ornamental plants are also used to restore disturbed landscapes, control erosion and reduce energy and water consumption, to improve the aesthetic quality of urban and rural landscapes, recreational areas, interiorscapes and commercial sites. So the number of plant species is very large due to the great geographical range over which they are used and their different functions. In relation to this high number of species that can potentially be utilized in the

landscape, the possibility of finding genotypes able to cope with salt stress is high. Unlike in agriculture, performance of an amenity landscape is not measured with a quantifiable yield but how well it meets expectations of the user or the individual paying for installation and maintenance, who may or not be one and the same person. Expectations include aesthetic appearance and/or utility, such as shading, ground cover and recreation (Kjelgren et al., 2000). Sometimes in marginal conditions plant survival is often the only aim of cultivation. Furthermore, for landscape plants, maximum growth is not always essential and indeed excessive shoot vigor is often undesirable. To keep a compact growth habit, ornamentals often have to be pruned or treated with growth regulators (Cameron R.W.F. et al., 2004) so using an alternative water source may be prove advantageous where a more compact form arises as result of salt stress and where slower growth is desirable for easier landscape management (Niu et al., 2007b). Hence, the use of reclaimed water could conserve potable water and irrigation budgets (Fox et al., 2005). However, to expand the use of such waters while minimizing salt damage, the salt tolerance of ornamentals needs to be determined (Niu & Rodriguez, 2006b).

Apart from plant characteristics, soil composition and drainage characteristics also need to be taken into consideration as they can influence the severity of plant damage by saline irrigation water. For example, clay soils and soils with a high percentage of organic matter exhibit faster and greater build up in concentration of sodium than sandy soils (Dirr, 1976). High concentrations of sodium can displace calcium and magnesium ions, whereas bicarbonate ions can destroy soil structure. This is especially important when irrigation water with high soluble salts is applied on a long-term basis (Fox et al., 2005).

With this in mind the present chapter analyses this large environmental issue as it relates to the response of ornamental plants (herbaceous annuals and perennials, shrubs and woody trees) to salt. We look at the range of tolerance, the possible management practices that could be used to realize a sustainable landscape in which saline water is used and the means available to reduce the effect of salt stress: we also consider the choice of plant species and tailoring plant management to the saline conditions.

## 2. The response of ornamental plants to salt stress

Salt effects on plants are the combined result of the complex interaction among different morphological, physiological and biochemical processes (Fig. 1).

One of the first responses of plants to salinity is a decreased rate of leaf growth (Blum, 1986) primarily due to the osmotic effect of salt around the roots, which leads to a reduction in water supply to leaf cells. High external salt concentrations can also inhibit root growth (Wild, 1988), with a reduction in length and mass of roots (Shannon & Grieve, 1999) and of function. Reduction in cell elongation and division in leaves reduces their final size, resulting in a decrease in leaf area (Alarcón et al., 1993; Matsuda & Riazi, 1981; Munns & Tester, 2008). Leaf area reduction could be caused by a decrease in turgor in the leaves, as a consequence of changes in cell wall properties or a reduction in photosynthetic rate (Franco et al., 1997). Such consequences are seen in ornamental plants: Cassaniti et al. (2009b) showed that the decrease in shoot dry weight and leaf area were the first visible effects of salinity both in sensitive and tolerant species such as *Cotoneaster lacteus* and *Eugenia myrtifolia*, respectively (Fig. 2). Another common response to high salt level is leaf thickening, which occurred in ornamental plants such as *Coleus blumei* and *Salvia splendens* (Ibrahim et al., 1991).

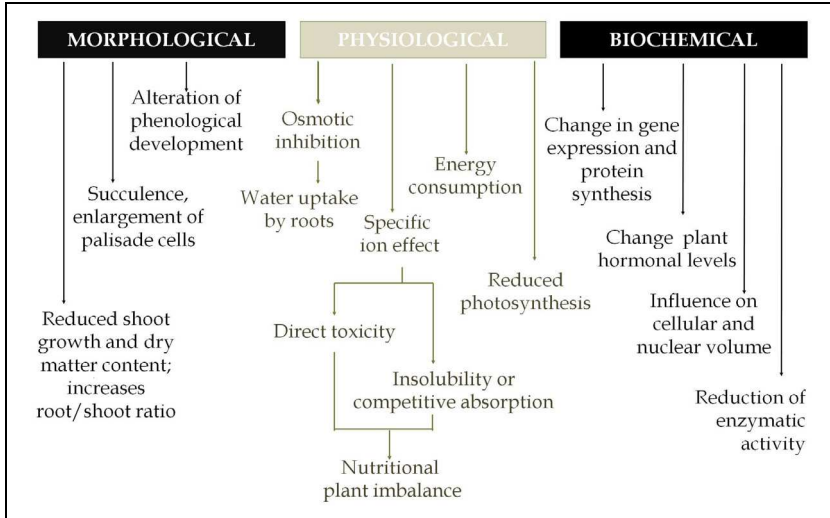


Fig. 1. Morphological, physiological, and biochemical effects of salt stress on plants (modified from Singh & Chatrath, 2001).

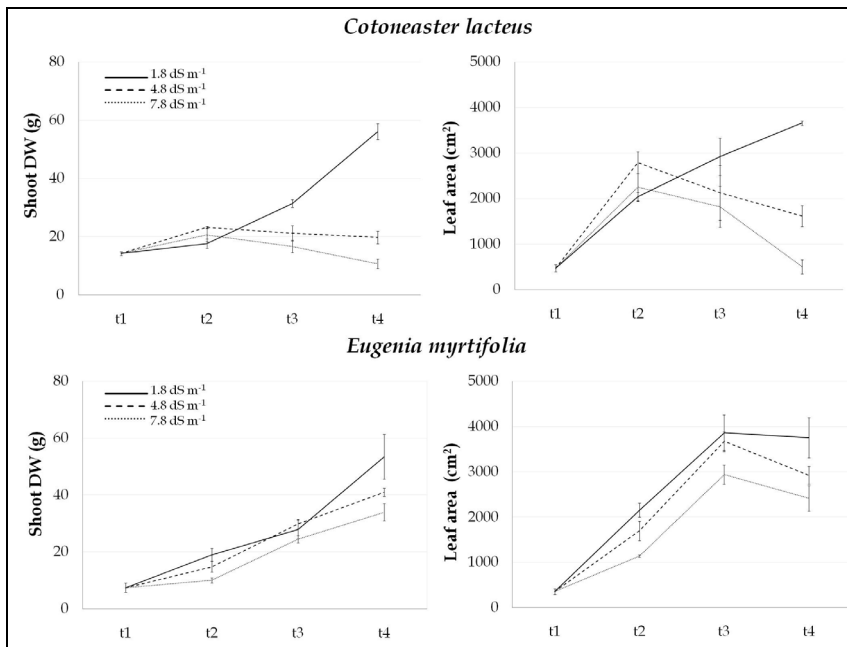


Fig. 2. Shoot dry weight (g) and leaf area (cm<sup>2</sup>) per plant for *Cotoneaster lacteus* (upper panels) and *Eugenia myrtifolia* (lower panels) at three salinities - 1.8, 4.8 and 7.8 dS m<sup>-1</sup> - at the beginning (t<sub>1</sub>) and 8 (t<sub>2</sub>), 16 (t<sub>3</sub>) and 24 (t<sub>4</sub>) weeks after the beginning of the salt treatment (Source: Cassaniti et al., 2009b).

Depending upon the composition of the saline solution, ion toxicities or nutritional deficiencies may also reduce growth because of competition between cations or anions (Shannon & Grieve, 1999). When toxic ions such as  $\text{Na}^+$  and  $\text{Cl}^-$  are present in the rhizosphere, they can disrupt the uptake of nutrients by interfering with transporters in the root plasma membrane, such as those for  $\text{K}^+$  and  $\text{NO}_3^-$  (Tester & Davenport, 2003). The influence of salt stress on plant growth alone is, however, not sufficient to evaluate the salt tolerance of ornamentals: tip and marginal leaf burn as consequence of ion toxicity have to be considered (Francois, 1982) due to their influence on decorative value (Fig. 3).

Chloride toxicity manifests as slight bronzing and leaf-tip yellowing followed by tip death and general necrosis, whereas  $\text{Na}^+$  toxicity starts as a marginal yellowing followed by a progressive necrosis (Ferguson & Grattan, 2005; Marschner, 1995). Thus the overall appearance as well as survival should be the ultimate criteria governing the choice of landscape species (Townsend, 1980). Many methodologies based on visual quality ratings have been developed by different authors to evaluate the appearance of ornamental plants in response to salt stress (Tab. 2).



Fig. 3. Necrotic areas due to the effect of salt stress on some ornamental species: a) *Cotoneaster lacteus*; b) *Grevillea juniperina* var. *sulphurea*; c) *Pyracantha* 'Harlequin'; d) *Teucrium fruticans* (Source: Cassaniti, 2008).

Source	Rating/Marks	Considered attributes
Cassaniti, 2008	1= no leaf necrotic area; 2= leaf necrotic area between 0 and 33%; 3= leaf necrotic area between 33 and 66%; 4= necrotic area between 66 and 100%	Incidence of leaf necrosis: percentage of necrotic areas, leaf bronzing
Fox et al., 2005	1= dead plant; 2= severe damage such as stunting, dead stems; 3= moderate damage such as visible salt residue on the foliage, < 50% defoliation, leaf deformity, necrosis; 4= slight damage, such chlorosis, tip and/or marginal leaf burn, spotting; 5=no damage, highest aesthetic quality	Stunting, discoloration, defoliation
Jordan et al., 2001	Each parameter was evaluated on a 1-9 scale, where a value of 1 equated to a rating of 10% and a value of 9 equated to a rating of 90% damage	Absence of crown dieback, overall canopy discoloration, presence of dead leaves, presence of deformed leaves, discoloured leaves and tip and marginal damage
Niu & Rodriguez, 2006a, 2006b	0= dead; 1= severely stunted growth with over 50% foliage salt damage (leaf necrosis, browning); 2= stunted growth with moderate (25-50%) foliage salt damage; 3= average quality with slight (<25%) foliage salt damage; 4= good quality with acceptable growth reduction and little foliage damage; 5= excellent with vigorous growth with no foliage damage	Leaf necrosis, browning
Niu et al., 2007a, 2007b	1= over 50% foliage damage or plant dead; 2= moderate foliage damage (25-50%); 3= slight foliage damage (<25%); 4= good quality with acceptable growth reduction and little foliage damage; 5= excellent with no foliage damage	Salt damage: burning and discoloration
Quist et al., 1999	Ranking scale of 1 to 10 with a score of 10 indicating plants with the highest quality	Necrosis, chlorosis, leaf color, leaf turgor, tip die back, misformed leaves, leaf size, leaf loss and disease.
Valdez-Aguilar et al., 2011	1= poor quality, leaf bronzing higher than 75% or dead plants; 5= best quality	Leaf bronzing, leaf scorching, overall appearance
Zollinger et al., 2007	Salt damage: 1= more than 50% of leaf area damaged ; 2= 25% to 50% of the leaf area damaged; 3= 5% to 24% of the leaf area damaged; 4= less than 5% of the leaf area damaged with burn or discoloration primarily restricted to leaf damage. Wilt: 1= more than 65% of the plant was wilted; 2= 35% to 65% of the plant was wilted; 3= 5% to 34% of the plant was wilted; 4= less than 5% of the plant was wilted	Salt damage: burning/ discoloration, wilting

Table 2. Some visual quality rating scales for evaluating salt damage on the foliage.

The tolerance to saline water can also be evaluated by growth analysis indices: for example, plant response to water deficit and saline treatment was investigated by Rodríguez et al. (2005) using *Asteriscus maritimus*, a native species of coastal areas. Salinity caused a

reduction of RGR (Relative Growth Rate) and NAR (Net Assimilation Rate) at 70 mM and 140 mM NaCl (about 7 and 14 dS m<sup>-1</sup>, respectively) while LAR (Leaf Area Ratio) was not affected. However, the LWR (Leaf Weight Ratio) increased in plants treated at 140 mM NaCl, due to the greater reduction of stem than leaf dry weight. LWR is an important parameter for ornamental plants, in which the aesthetic value is strictly correlated to the appearance of the leaves. RGR reduction clearly suggests a direct effect of the stress on stomatal closure and/or photosynthetic apparatus, indicating that photosynthesis could be the growth-limiting factor (Cramer et al., 1990; Sánchez-Blanco et al., 2002).

Herbaceous, annuals and perennials, show different responses to salinity than woody plants, although similar mechanisms can be involved. Because a typical landscape is a blend of species (annuals, grasses, climbing plants, shrubs, trees and palms; Graf, 1992) it is important to determine the salt tolerance of all commonly used plants in any specific landscape to minimize potential salt damage before converting to treated effluents or any other non-potable water source (Niu & Rodriguez, 2006a). Evaluating salt tolerance is made more complex by intra-specific variation: any given species can vary in its tolerance to salinity, depending on genotype.

## 2.1 Herbaceous plants

Herbaceous perennials are popular for landscaping because of their low maintenance and as their planting increases diversity in the landscape (Cameron A. et al., 2000; Johnson & Whitwell, 1997). Herbaceous plants do, however, show a very variable response to salt stress, from the tolerant halophytes to the sensitive glycophytes and their sensitivity to salty irrigation water can influence plant selection, irrigation method and frequency of watering.

The irrigation of landscapes with treated effluent has become a common practice in states like Florida and California (Cuthbert & Hajnosz, 1999; Parnell, 1988) where the municipal water consumption typically increases by 40-60% for landscape irrigation during summer months (Kjelgren et al., 2000) and could be important for Mediterranean countries. Studies on herbaceous perennials in semiarid parts of United States (Niu & Rodriguez, 2006a, 2006b) have involved herbaceous perennials and have emphasized the importance of visual quality for expressing relative salt tolerance and acceptability of species for landscape use (Fox et al., 2005; Niu & Rodriguez, 2006a, 2006b). Research programs conducted in Israel have revealed ornamental species suitable for saline environments or to be irrigated with salt waters (Forti, 1986). Perennial turf grasses have been selected at Arizona University to cope with a salt concentration more than 15 g L<sup>-1</sup>: *Distichlis spicata*, commonly known as *desert saltgrass*, is able to survive at concentration up to 400 mM of NaCl (Pessarakli et al., 2001).

Niu & Rodriguez (2006b) observed the response to salt stress on eight herbaceous perennials (*Penstemon eatonii*, *P. pseudospectabilis*, *P. strictus*, *Ceratostigma plumbaginoides*, *Delosperma cooperi*, *Lavandula angustifolia*, *Teucrium chamaedrys*, *Gazania rigens*); three salt treatments plus control were tested (3.2, 6.4, 12 and 0.8 dS m<sup>-1</sup>). The relative water content significantly declined as salinity increased in *C. plumbaginoides* and in *G. rigens* at the highest salt level; *D. cooperi* showed the highest water potential due to increased succulence of the leaves, a common mechanism of salt tolerance (Kozłowski, 1997). The higher Na<sup>+</sup> concentration in roots than shoots indicated in this plant Na<sup>+</sup> exclusion from aerial parts and a capability to

tolerate  $\text{Cl}^-$  in leaf tissues. Plants of *L. angustifolia* and most of the species of *Penstemon* showed symptoms of necrosis and eventually died with an EC more than  $3.2 \text{ dS m}^{-1}$ . Among the *Penstemon* species, the earliest leaf injury appeared on *P. strictus*, perhaps related to its rosette growth habit allowing some leaves to have been in direct contact with saline water during irrigation. *G. rigens* did not show any injury symptom even at the highest salt level, although growth was stunted, probably due to the high  $\text{Na}^+$  accumulation in the shoots. *T. chamaedrys* exhibited necrosis in some leaves at medium and high salt level, while *C. plumbaginoides* manifested slight leaf browning at  $3.2 \text{ dS m}^{-1}$ , severe symptoms at  $6.4 \text{ dS m}^{-1}$  and death of many plants at  $12 \text{ dS m}^{-1}$ .

As we have noted, visual quality is an important factor in the choice of herbaceous perennials for saline landscapes (Tab. 2). Because plants respond differently to salinity, visual quality may or may not be related to biomass production and photosynthetic response (Zollinger et al., 2007). Following this argument, Niu & Rodriguez (2006b) argued that *Gazania rigens* and *Delosperma cooperi* can be used in a landscape irrigated with saline waters as, in spite of their decrease in growth rate, they did not show any injury symptoms. The other species they tested could be considered salt sensitive, since most of them died at the highest salt treatments. *L. angustifolia* began to show leaf injury about 4 weeks after the start of saline irrigation, and died in the subsequent weeks at  $6.4$  and  $12 \text{ dS m}^{-1}$ . However, the importance of the nature of the salts present is illustrated by the results of Zollinger et al. (2005), who reported that *L. angustifolia* survived at  $8.3 \text{ dS m}^{-1}$  when  $\text{NaCl}$  and  $\text{CaCl}_2$  (2:1 molar ratio) were used for saline solution.

Earlier research indicated that the climatic conditions can also influence the extent of foliar damage (Jordan et al., 2001; Quist et al., 1999; Wu et al., 1999). Subsequently various trials have been reported comparing data obtained by conducting experiments in different seasons and in years when the climatic conditions varied considerably. For example, a trial was conducted for testing the salinity tolerance of five herbaceous perennials commonly used in the landscape, *Achillea millefolium*, *Agastache cana*, *Echinacea purpurea*, *Gaillardia aristata* and *Salvia coccinea* (Niu & Rodriguez, 2006a). In this case, the tolerance to salt stress was evaluated, in summer and fall, with many parameters - dry weight, plant height, osmotic potential and visual score - being used to estimate the damage to their ornamental value (Tab. 2). Plants were treated with three salinity levels:  $0.8$ ,  $2$  and  $4 \text{ dS m}^{-1}$ . In the summer experiment, all species showed a lower osmotic potential at  $2 \text{ dS m}^{-1}$  and  $4 \text{ dS m}^{-1}$  compared the control. Nevertheless, despite the reduction in dry weight that occurred in salt treatments, *A. millefolium*, *G. aristata* and *S. coccinea* showed a visual score acceptable for landscape performance. When the experiment was conducted in the fall, the lowering of the osmotic potential in these species was much less than occurred during the summer. As confirmed by other authors (Niu et al., 2007a; Zollinger et al., 2005), results highlighted how environmental conditions could influence the response to salt stress: the higher temperature and irradiance typical of summer meant that plants became more stressed than in the fall, when all the species, except *A. cana*, maintained an acceptable visual quality. Species like *S. coccinea*, *A. millefolium* and *G. aristata* were considered highly salt tolerant, because they could be irrigated with a saline solution up to  $4 \text{ dS m}^{-1}$  under both summer and fall conditions, with little or no growth reduction.

In experiments again conducted during different seasons (spring, summer or fall) at different salinities ( $0.3$ ,  $1.9$ ,  $5.0$  and  $8.1 \text{ dS m}^{-1}$ ) were tested on eight species (Zollinger et al.,



2007). Species were selected for being native of inter-mountain Western United States (*Penstemon palmeri*, *Mirabilis multiflora*, *Geranium viscosissimum*, *Eriogonum jamesii*) or available in the nursery industry (*Echinacea purpurea*, *Lavandula angustifolia*, *Leucanthemum ×superbum* 'Alaska' and *Penstemon ×mexicali* 'Red Rocks'). Light intensities and greenhouse temperatures varied among the seasons and had an impact on the response of certain species to salinity. Results suggested that irrigation with saline water would lower the visual quality of *G. viscosissimum*, *E. purpurea* and *P. palmeri*, more during the warmer, summer months than at cooler times of the year.

Based on visual score, Fox et al. (2005) evaluated the response to treated effluent as an irrigation source (from 0.75 dS m<sup>-1</sup> to 2.5 dS m<sup>-1</sup>) of seven annuals and seven perennials in a two-year experiment when conditions differed considerably. Damage symptoms were more severe in 2001 than 2000, which was characterized by having the hotter and drier summer, confirming the important influence of temperature on plant performance under saline conditions.

Another important aspect of salinity in the landscape is the foliar absorption of ions, whether from irrigation water or aerosols produced by wind blowing over seawater. Plant species typical of the coastal areas have adapted to survive direct contact of the salt on the leaves, although the exposure to sea aerosol and salt water infiltration of the ground water may well reduce plant growth and affect their reproduction (Cheplick & Demetri, 1999; Hesp, 1991). The presence of surfactant can, however, enhance the foliar absorption of sea salt through stomatal and cuticular penetration (Greene & Bukovac, 1974; Schönherr & Bauer, 1992). Sánchez-Blanco et al. (2003) conducted a trial to evaluate the response to sea aerosol of two wild native species from littoral areas, *Argyranthemum coronopifolium* and *Limonium pectinatum*. Plants were treated with one of three solutions: one containing an anionic surfactant, one simulating the composition of sea aerosol and a third with sea aerosol and anionic surfactant; the control involved spraying with deionized water alone. The most sensitive to sea aerosol was *A. coronopifolium*, in which salt sprays reduced its growth and dry mass, while any effect on *L. pectinatum* was not evident. Although it is a native plant of coastal areas, *A. coronopifolium* is not a salt-tolerant species (Morales et al., 1998). On the other hand, the halophyte *L. pectinatum* was more tolerant, directly excreting salts from its leaves (Alarcón et al., 1999). Foliar damage is directly linked to foliar absorption, with increased leaf ion penetration with increasing temperature (Darlington & Cirulis, 1963).

## 2.2 Shrubs and woody trees

Although there have been many studies on the effects of salt stress on landscape plants, few have investigated the effects of salinity on shrubs, despite their importance for landscaping (Bernstein et al., 1972; Bañon et al., 2005; Cassaniti et al., 2009a; Francois & Clark, 1978; Picchioni & Graham, 2001; Valdez-Aguilar et al., 2011) and production in Mediterranean countries (Marosz, 2004; Zurayk et al., 1993). Salinity may affect the growth of ornamental shrubs by reducing growth and leaf expansion resulting from osmotic effects or toxicity due to the high concentration of Na<sup>+</sup> and Cl<sup>-</sup> typical of saline water (USEPA, 1992). In a study conducted on 15 ornamental shrubs commonly used for landscaping (Cassaniti, 2008), many parameters (dry weight of different organs, leaf area, number of leaves, SPAD, growth indexes, aesthetic value) were considered to evaluate

plant response to salt stress. Plants were grown in a greenhouse and subjected for a six month period to three salt levels: 1.8, 4.8 and 7.8 dS m<sup>-1</sup>. The aesthetic value, calculated as percentage of leaves showing necrotic areas (Tab. 2), was affected by the increasing EC, confirmed by the increased percentage of leaf necrosis, most of all in *Cotoneaster lacteus* and *Grevillea juniperina* var. *sulphurea*. These symptoms were clearly associated with the large amount of Na<sup>+</sup> and Cl<sup>-</sup> in the leaves (Cassaniti et al., 2009a; Karakas et al., 2000). Shoot dry weight was reduced in many species and, in general terms, these reductions followed the same trend as the leaf area. Leaf number was affected by salinity, hence leaf abscission reduced the photosynthetic area (c.f. Munns & Termatt, 1986). Chlorophyll content (SPAD index) and root dry weight were less influenced than the other parameters by salt treatment at the end of the experimental period. Among the many parameters analysed, the relative growth rate and shoot dry weight best highlighted the differential response to salt stress (Fig. 4). Therefore, based on the shoot dry weight reduction, plants were grouped in four categories: (1) salt sensitive species, showing more than 75% reduction (*Cotoneaster lacteus*, *Pyracantha* 'Harlequin'); (2) moderately salt sensitive species, showing between 50 and 75% growth reduction (*Grevillea juniperina* var. *sulphurea*); (3) moderately salt tolerant species, showing a growth reduction between 25 and 50% (*Cestrum aurantiacum* and *Cestrum fasciculatum* 'Newellii' *Escallonia rubra*, *Viburnum lucidum*, *Teucrium fruticans*, *Eugenia myrtifolia*, *Ceanothus thyrisiflorus* var. *repens*, *Bougainvillea glabra*, *Ruttya fruticosa*, *Polygala myrtifolia*); (4) salt tolerant species, showing less than 25% growth reduction (*Leucophyllum frutescens*, *Leptospermum scoparium*).

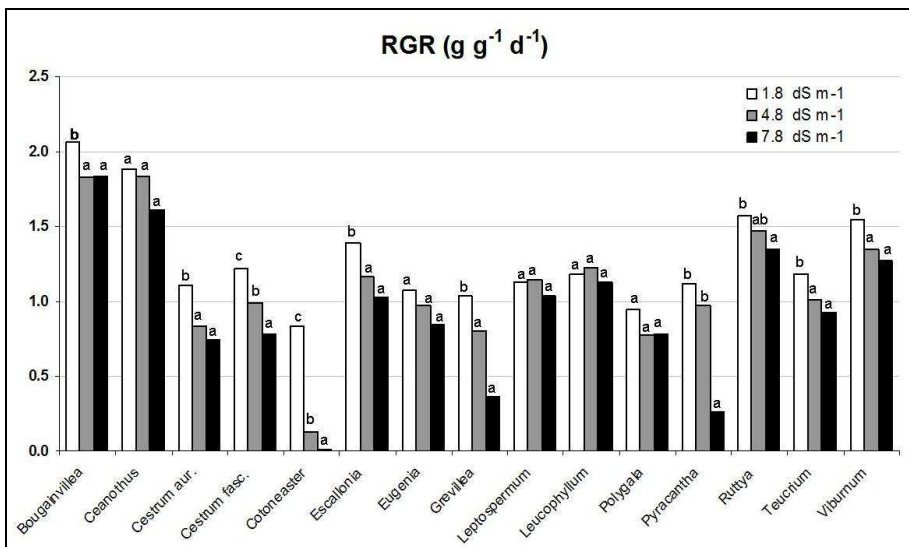


Fig. 4. RGR (Relative Growth Rate g g<sup>-1</sup> d<sup>-1</sup>) of ornamentals shrubs in relation to three salt levels (1.8, 4.8 and 7.8 dS m<sup>-1</sup>) calculated between the beginning and end of experimental period (180 days) (Source: Cassaniti, 2008).

As observed for herbaceous species, the growing season seems to affect the response of shrubs to salt (Valdez-Aguilar et al., 2011). Five species (*Buxus microphylla* var. *japonica*, *Escallonia ×exoniensis* 'Fradesii', *Raphiolepis indica* 'Montic', *Hibiscus rosa-sinensis* 'Brilliant' and *Juniperus chinensis* 'Torulosa') were investigated at different salinities (EC of irrigation water of 0.6, 2, 4, 6 and 8 dS m<sup>-1</sup>) for two growing seasons (starting from May and September, respectively, until plant harvest). Species were ranked for their salinity tolerance according to the slope of linear regressions of reduction in leaf DW as the EC increased; tolerances were, from higher to lower: *H. rosa-sinensis*, *J. chinensis*, *E. ×exoniensis*, *R. indica* and *B. microphylla*. Plant response differed with growing season. Roots of *R. indica*, *J. chinensis* and *E. ×exoniensis* accumulated more DW during the spring-summer while leaves accumulated more DW in the fall-winter. The highest root DW recorded, during the spring-summer cultivation, allowed the allocation of Ca<sup>2+</sup>, Na<sup>+</sup> and Cl<sup>-</sup> to the roots, preventing toxic concentrations accumulating in the leaves. This mechanism, Na<sup>+</sup> and Cl<sup>-</sup> retention by the roots, was especially efficient in *Juniperus*, which was rated as one of the most tolerant in terms of growth and visual quality. However, as we have mentioned previously, for ornamental plants responses other than DW need to be considered, because plants with good DW accumulation can still show a high percentage of leaf bronzing, while other species respond with high reductions in shoot dry weight but no visual damage. *B. microphylla* exhibited acceptable tolerance in terms of growth but the visual quality of the final product was impaired. Growth of *Hibiscus* was the most severely reduced when grown in spring-summer but the lack of injury in leaves suggests salt compartmentalization (Rodríguez et al., 2005; Sánchez-Blanco et al., 2004).

Apart from reductions in DW, other reported effects of salinity on woody species that affect their visual appearance include crown dieback, lesions on the stem or trunk and leaf scorch (Percival, 2005). Buds may fail to open or grow and branches may die. The morphological adaptations allowing trees to cope with salinity can include penetration-resistant resinous buds and waxy leaves and stems. Mechanisms of salt exclusion can be smooth twigs, sunken buds and low surface-to-volume ratios (e.g., pine needles) (Appleton et al., 1999). On conifers, damage appears as brown needle tips (Azza Mazher et al., 2007). With time, symptoms may accumulate causing tip burn of the older needles in conifers with their consequent necrosis, die back of limbs and death (Dobson, 1991). Salt damage on evergreen trees usually first appears in late winter to early spring and becomes more extensive during the growing season (Azza Mazher et al., 2007). A general crown thinning may also occur as salt build-up in the soil causes soil structure to deteriorate and roots to be damaged. Trees may become misshapen due to greater damage on the side facing the wind or where trees stand taller than partially protective buildings (Appleton et al., 1999). NaCl applied to the canopy of *Thuja occidentalis* and *Picea glauca* induced fragmented cuticles, disrupted stomata, collapsed cell walls, coarsely granulated cytoplasm, disintegrated chloroplasts and nuclei and disorganized phloem (Kozłowski, 1997). A reduction in branch diameter may also occur (Stroganov, 1964).

As for herbaceous plants, the ionic composition of the irrigation water can affect the response of shrubs and trees to saline stress. Chloride salts seem to be more damaging than SO<sub>4</sub><sup>2-</sup> salts, and Mg<sup>2+</sup> associated with Cl<sup>-</sup> is more damaging than Na<sup>+</sup> with Cl<sup>-</sup> (Devitt et al., 2005a). However, trees like *Eucalyptus occidentalis* and *E. sargentii* can tolerate salinity of about 30 dS m<sup>-1</sup> (Choukr-Allah, 1997). Some results on salt response of ornamental shrubs are listed in the table below (Tab. 3).

Species	Rating	Salt response	Salinity threshold	References
<i>Bougainvillea spectabilis</i> , <i>Lantana camara</i> var. <i>aculeata</i>	Tolerant	Maintains a high visual quality	1.94 dS m <sup>-1</sup>	Devitt et al., 2005b
<i>Poinciana pulcherrima</i>	Questionable	Little foliar damage	1.94 dS m <sup>-1</sup>	Devitt et al., 2005b
<i>Euonymus japonica</i> , <i>Fraxinus pennsylvanica</i> var. <i>lanceolata</i> , <i>Taxus cuspidata</i> , <i>Tilia europaea</i>	Sensitive	Low rank score in visual quality	2.1 dS m <sup>-1</sup>	Quist et al., 1999
<i>Gleditsia tricanthos</i> var. <i>inermis</i> , <i>Prunus cerasifera</i> var. <i>atropurpurea</i> , <i>Berberis thunbergii</i> var. <i>atropurpurea</i> , <i>Pinus nigra</i> , <i>Pyrus calleryana</i> , <i>Picea pungens</i> , <i>Juniperus chinensis</i> var. <i>pfitzeriana</i>	Tolerant	High rank score in visual quality	2.1 dS m <sup>-1</sup>	Quist et al., 1999
<i>Crataegus opaca</i>	Sensitive	Reduction in relative growth rate (RGR)	3.15 dS m <sup>-1</sup>	Picchioni & Graham, 2001
<i>Olea europaea</i> 'Swan Hill', <i>Prosopis chilensis</i> , <i>Pinus halepensis</i> , <i>Pinus eldarica</i> , <i>Rhus lancea</i> , <i>Pinus pinea</i> , <i>Fraxinus oxycarpa</i> 'Raywood'	Tolerant	Good visual quality	1.87 dS m <sup>-1</sup>	Jordan et al., 2001
<i>Robinia ×ambigua</i> 'Idahoensis', <i>Vitex agnus-castus</i> , <i>Quercus virginiana</i> 'Heritage', <i>Albizia julibrissin</i>	Questionable	Medium visual quality	1.87 dS m <sup>-1</sup>	Jordan et al., 2001
<i>Salix matsudana</i> 'Navajo', <i>Prunus cerasifera</i> 'Atropurpurea', <i>Cercidium floridum</i> , <i>Ligustrum japonicum</i> , <i>Chitalpa tashkentensis</i> 'Pink Dawn', <i>Ulmus parvifolia</i> 'Drake', <i>Chilopsis linearis</i> , <i>Pistacia chinensis</i> , <i>Fraxinus velutina</i> var. <i>glabra</i> 'Modesto'	Sensitive	Low visual quality	1.87 dS m <sup>-1</sup>	Jordan et al., 2001
<i>Lantana ×hybrida</i> 'New Gold', <i>Lonicera japonica</i> 'Halliana', <i>Rosmarinus officinalis</i> 'Huntington Carpet'	Tolerant	Little reduction in growth, good aesthetic appearance	5.4 dS m <sup>-1</sup>	Niu et al., 2007a
<i>Lantana montevidensis</i>	Sensitive	Reduction in growth index, low aesthetic appearance	5.4 dS m <sup>-1</sup>	Niu et al., 2007a
<i>Potentilla fruticosa</i> 'Longacre', <i>Cotoneaster horizontalis</i>	Tolerant	No growth reduction and visible effects	12 dS m <sup>-1</sup>	Marosz, 2004
<i>Cotoneaster</i> 'Ursynów', <i>Spiraea</i> 'Grefsheim'	Sensitive	Leaf injuries	12 dS m <sup>-1</sup>	Marosz, 2004
<i>Arbutus unedo</i>	Sensitive	Reduction of total dry biomass	5.45 dS m <sup>-1</sup>	Navarro et al., 2007

Table 3. Results of studies of ornamental shrubs in order to evaluate salt response.

### 3. Salt tolerance in ornamentals

#### 3.1 Assessment of tolerance

Plant salt tolerance is the ability to withstand the effects of high salt concentrations in the root zone without a significant adverse effect (Shannon & Grieve, 1999). Maas and Grattan (1999) grouped crop species into five or six salt tolerance divisions based on growth, but for plants used in landscaping this is not necessarily the best approach; a separation based on the visual quality of the plants is often the most useful. A further complication to the assessment of tolerance is the fact that plants are generally more severely injured by saline water applied by sprinkler than by drip systems (Maas & Francois, 1982). Saline water applied by sprinklers can coat plant foliage burning and desiccating the leaves of sensitive species (Fox et al., 2005), although sometimes a waxy cuticle on the leaves can make them less sensitive to aerial salt than to soil salt (e.g. on plants native to strand lines and of some woody species; Van Arsdell, 1996). Furthermore, where grafted trees are used in landscaping – generally fruit trees – the genetic differences between rootstock and scion can confound evaluation of relative tolerance to sprinklers and drippers (Musacchi et al., 2006).

Despite these complexities, field trials have been conducted to compare sprinkler and drip irrigation systems able to differentiate salt resistance among landscape species based on their aesthetic quality (Miyamoto et al., 2004; Wu et al., 2001a, 2001b). For example, a study conducted in California (Wu et al., 2001b) on ten ornamentals used in the landscape (*Pistacia chinensis*, *Nerium oleander*, *Pinus cembroides*, *Buxus microphylla*, *Liquidambar styraciflua*, *Bignonia violacea*, *Ceanothus thyrsiflorus*, *Nandina domestica*, *Rosa* sp., *Jasminum polyanthum*) confirmed that the species showed a higher sensitivity when irrigated with sprinkler than drip irrigation. In studies conducted on native species of coastal areas other authors observed a large variation in foliage damage (with no symptoms to severe injury) in species that showed similar salinity tolerance in the roots (Cartica & Quinn, 1980; Sykes & Wilson, 1988), confirming that plants can evolve resistance to saline aerosols.

In a further trial, Wu et al. (2001b) evaluated 38 trees and ten herbaceous perennial subjected to two salt levels: 500 mg L<sup>-1</sup> NaCl (200 mg L<sup>-1</sup> Na<sup>+</sup>, 300 mg L<sup>-1</sup> Cl<sup>-</sup>) and 1500 mg L<sup>-1</sup> NaCl (600 mg L<sup>-1</sup> Na<sup>+</sup>, 900 mg L<sup>-1</sup> Cl<sup>-</sup>) to evaluate those that could be irrigated with brackish water (Tab. 4).

Results showed that 21 (55%) of the 38 woody plant species and 7 (70%) of the 10 native grass species were salt tolerant when irrigated with 500 mg L<sup>-1</sup> salt and twelve (31%) woody species and 5 (50%) grass species were salt tolerant when they were irrigated with 1500 mg L<sup>-1</sup> salt. Wu & Dodge (2005) summarized the results of previous trials, listing the salt tolerance of 268 species (72 trees, 15 palms, 66 shrubs, 39 ground covers, 18 vines, 58 grasses) used in landscaping, based on plant response to salt applied with sprinklers or through soil. Tolerances to salt spray were defined by the degree of visual damage on the leaves (relative to plants irrigated with potable water) and the salt concentrations in the applied irrigation water, while tolerances to soil salinity were defined as the limit of soil salinity that did not induce significant salt stress symptoms. Species were grouped in four categories: highly tolerant, tolerant, moderately tolerant, and sensitive (Tab. 5). Generally the species that tolerate salt spray tolerate soil salinity. Approximately 50% of landscape ornamentals are either tolerant or moderately tolerant to salt.

Scientific name	Tolerance to NaCl		Scientific name	Tolerance to NaCl	
	500 mg L <sup>-1</sup>	1500 mg L <sup>-1</sup>		500 mg L <sup>-1</sup>	1500 mg L <sup>-1</sup>
Woody landscape plants			<i>Nerium oleander</i>	High	High
<i>Abelia</i> × <i>grandiflora</i> ‘Edward Goucher’	Low	Low	<i>Olea europaea</i> ‘Montra’	High	High
<i>Acacia redolens</i>	High	High	<i>Pinus cembroides</i>	High	High
<i>Albizia julibrissin</i>	Moderate	Low	<i>Pistacia chinensis</i>	Low	Low
<i>Arbutus unedo</i>	High	Moderate	<i>Pittosporum tobira</i>	High	High
<i>Buddleja davidii</i>	Low	Low	<i>Plumbago auriculata</i>	High	High
<i>Buxus japonica</i>	High	High	<i>Prunus caroliniana</i>	High	Low
<i>Ceanothus thyrsiflorus</i>	High	Moderate	<i>Quercus agrifolia</i>	High	Moderate
<i>Cedrus deodara</i>	High	High	<i>Rhaphiolepis indica</i>	High	High
<i>Celtis sinensis</i>	Low	Low	<i>Rosa</i> sp.	Low	Low
<i>Clytostoma callistegioides</i>	Low	Low	<i>Sambucus nigra</i>	Moderate	Low
<i>Cornus mas</i>	Low	Low	<i>Sapium sebiferum</i>	High	High
<i>Cotoneaster microphyllus</i> ‘Rockspray’	Moderate	Low	<i>Washingtonia filifera</i>	High	High
<i>Escallonia rubra</i>	High	Moderate			
<i>Euryops pectinatus</i>	Low	Low	Herbaceous landscape plants		
<i>Forsythia</i> × <i>intermedia</i>	High	Moderate	<i>Bromus carinatus</i>	High	Moderate
<i>Fraxinus angustifolia</i>	Moderate	Low	<i>Deschampsia cespitosa</i>	Moderate	Low
<i>Ginkgo biloba</i>	Low	Low	<i>Deschampsia elongata</i>	High	Moderate
<i>Jasminum polyanthum</i>	High	Moderate	<i>Elymus glaucus</i>	High	High
<i>Juniperus virginiana</i> ‘Skyrocket’	High	High	<i>Festuca californica</i>	High	High
<i>Koeleruteria paniculata</i>	Moderate	Low	<i>Melica californica</i>	Low	Low
<i>Lantana camara</i>	High	Moderate	<i>Muhlenbergia rigens</i>	High	High
<i>Liquidambar styraciflua</i>	Low	Low	<i>Poa scabrella</i>	Moderate	Low
<i>Mahonia pinnata</i>	Moderate	Low	<i>Sporobolus airoides</i>	High	High
<i>Myrtus communis</i>	High	Moderate	<i>Stipa pulchra</i>	High	High
<i>Nandina domestica</i>	Moderate	Low			

Table 4. List of salt tolerance of 38 landscape woody plant species and ten California native grass species grown under sprinkler irrigation with two NaCl concentrations (Source: Wu et al., 2001b).

Degree of tolerance	Salinity	
	Spray	Soil
Highly tolerant (H)	No apparent salt stress symptoms were observed when the plants were irrigated with water having 600 mg L <sup>-1</sup> sodium and 900 mg L <sup>-1</sup> chloride (salt concentrations rarely reach these levels in recycled water)	Acceptable soil electrical conductivity (EC) greater than 6 dS m <sup>-1</sup> and plants may not develop any salt stress symptoms even if the soil salinity exceeds this permissible level
Tolerant (T)	No apparent salt stress symptoms were observed when the plants were irrigated with water having 200 mg L <sup>-1</sup> sodium and 400 mg L <sup>-1</sup> chloride	Acceptable EC greater than 4 and less than 6 dS m <sup>-1</sup> and the plants in this category are adaptable to most reclaimed water irrigation without extra management input if restricted to soil application
Moderately tolerant (M)	Salt stress symptoms were observed in 10% or less of leaves when the plants were irrigated with water having 200 mg L <sup>-1</sup> sodium and 400 mg L <sup>-1</sup> chloride under dry and warm weather conditions	Acceptable EC greater than 2 and less than 4 dS m <sup>-1</sup> , plants in this category require extra irrigation and soil management input
Sensitive (S)	Salt stress symptoms were seen in 20% or more of leaves when the plants were irrigated with water having 200 mg L <sup>-1</sup> sodium and 400 mg L <sup>-1</sup> chloride.	Acceptable EC less than 2 dS m <sup>-1</sup> and plants in this category are very sensitive to soil salinity

Table 5. Definitions of salt tolerance categories for the plant species subjected to salt spray and soil salinity (Source: Wu & Dodge, 2005).

### 3.2 Mechanisms of tolerance

To cope with salinity, plants trigger divergent mechanisms that allow their adaptation and survival in saline environments; differences in the mechanisms determine their performance under saline conditions (Paranychianakis & Chartzoulakis, 2005).

Among the many mechanisms of salinity tolerance (Munns & Tester, 2008), the ability to restrict the entry of saline ions through the roots and limit the transport of Na<sup>+</sup> and/or Cl<sup>-</sup> to aerial parts, retaining these ions in the root and lower stem, has to be one of the most important of all the traits associated with tolerance (Colmer et al., 2005; Maathuis & Amtmann, 1999; Murillo-Amador et al., 2006). A related trait, the retention of toxic ion in roots, has been proposed to be important to salt tolerance in plants (Boursier & Läuchli, 1990; Pérez-Alfocea et al., 2000). Species that keep acceptable growth rates and possess mechanisms to exclude Na<sup>+</sup> and Cl<sup>-</sup> from roots or leaves and still have good appearance are ideal for landscaping.

As for all species, ornamentals differ in this trait. For example, *Rudbeckia hirta* 'Becky Orange' and *Phlox paniculata* 'John Fanick' accumulated large quantities of Cl<sup>-</sup> in the leaves which led to dry weight reduction of about 25%, while *Lantana ×hybrida* 'New Gold' and *Cuphea hyssopifolia* 'Allyson' tolerated salinity extremely well showing the low Cl<sup>-</sup> accumulation (Cabrera et al., 2006). The low reduction and absence of salt injury symptoms in *Eugenia myrtifolia* has been associated not only with the root storage of Na<sup>+</sup> and Cl<sup>-</sup> but also with their restricted uptake as the salinity increased (Cassaniti et al., 2009a).

An important aspect of salt tolerance is related to the ability of a plant to compartmentalize toxic ions, such as Na<sup>+</sup> and Cl<sup>-</sup> (Boursier & Läuchli, 1989). In this sense, species such as

*Bougainvillea glabra*, *Ceanothus thyrsiflorus* and *Leucophyllum frutescens* (Cassaniti et al., 2009a) and *Cistus monspeliensis* (Sánchez-Blanco et al., 2004) accumulated high concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  in the leaves but without showing any symptoms of necrosis. For woody perennials  $\text{Cl}^-$  is more problematic than  $\text{Na}^+$  which usually tends to be sequestered in roots and woody tissue (Ferguson & Grattan, 2005; Storey & Walker, 1999), while  $\text{Na}^+$  seems the primary cause of ion specific damage in grasses (Tester & Davenport, 2003).

Among the factors used to characterize salt tolerance in crop plants, the maintenance of a high  $\text{K}^+/\text{Na}^+$  ratio in their tissues is an important diagnostic character (Maathuis & Amtmann, 1999; Munns & James, 2003), due to competitive effect of  $\text{Na}^+$  concentration in the rhizosphere on  $\text{K}^+$  uptake (Aktas et al., 2006; Carvajal et al., 1999). However, amongst ornamentals this parameter has rarely, as far as we are aware, been recorded, although a reduction of  $\text{K}^+$  concentration was detected in leaves of *Arbutus unedo* with an increase of salinity (Navarro et al., 2008).

The adaptability to salt stress can be also different between and within species belonging to the same genus. For example, Sánchez-Blanco et al. (2004) showed that *Cistus monspeliensis* seemed to be more tolerant to aerosol treatment than *C. albidus*, showing a minor reduction in growth and foliar damage. Results were confirmed by Torrecillas et al. (2003) in which the two species, irrigated with saline water, showed different tolerance mechanisms involving  $\text{Na}^+$  and  $\text{Cl}^-$  inclusion, leaf area reduction and osmotic adjustment. *C. monspeliensis* had a higher water use efficiency than *C. albidus*. Although, some investigations have been carried out in order to assess the difference between species in the same genera of ornamental plants such as *Cestrum* spp. (Cassaniti, 2008), *Cotoneaster* spp. (Marosz, 2004) and *Lantana* spp. (Niu et al., 2007a), no information within cultivars is available.

#### 4. Sustainable landscape

A “sustainable landscape” commonly refers to one that supports environmental quality and conservation of natural resources (Rodie & Streich, 2009). As reported in the Brundtland Report (1987), the concept of sustainability, or the needs of the present without compromising the ability of future generations to utilise the land, is of increasing interest. Other terms such as xeriscape, native landscape, xerogarden, wild garden and environmental friendly landscape have often been used to describe such landscapes (Franco et al., 2006; Rodie & Streich, 2009). A well-designed sustainable landscape reflects a high level of self-sufficiency, even though this can be difficult to achieve due to the environmental stresses and artificial conditions of urban areas. Sustainable landscapes try to: 1) enhance landscape microclimate; 2) increase biodiversity; 3) reduce resource inputs and waste and 4) maximize re-use of resources. The benefits achievable in sustainable landscapes include enhanced beauty, low environmental decline and water consumption, reduction of use of pesticides and of other chemical resources, the generation of valuable wildlife habitats, and cost savings from reduced maintenance, labour and resource use. At the current time, the use of saline water could also be included as a benefit in accordance with the new trend of planning landscape with agronomical, political, social, cultural and ecological needs (Hitchmough, 2004). To realize a sustainable landscape as far as the use of saline water is concerned, two aspects have to be considered: the choice of plant species and tailoring the plant management to reduce the effects of salt stress.



#### 4.1 Choice of species resistant to salt stress

The response to saline water varies greatly among the plants that are used or potentially used in landscape design (see above; Niu et al., 2007b), often an intricate blend of woody and herbaceous ornamentals with a vast array of manufactured elements (generally referred to as 'hardscape'; Iles, 2003). The plant choice can be based on a very large number of species from a wide geographical range and with different functions in the landscape (Savé, 2009) and whose adaptability changes within genera or species (Sánchez-Blanco et al., 2002; Torrecillas et al., 2003). Where salinity is an issue, although many ornamentals are adversely affected, the choice can include plants that grow naturally on coastal and inland saline areas such as salt marshes and salt deserts (halophytes), and survive at salt concentration equal to or greater than that of seawater (Flowers & Colmer, 2008; Ravindran et al., 2007). As well as halophytes, a wide number of ornamental plants are able to tolerate salt stress (see above) so that making the appropriate choices is important to simplify the work (Fig. 5).

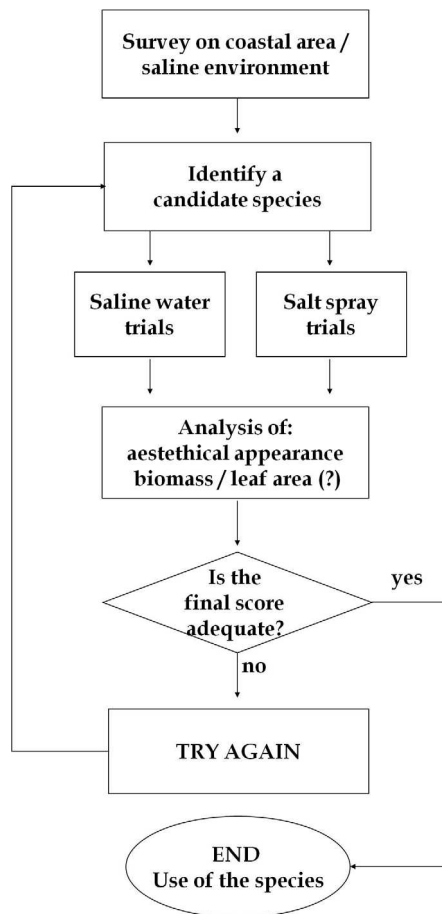


Fig. 5. A schematic summary of the steps included in the selection of a suite of landscape species.

The first step is an exploration of plants growing within seaside and other saline environments; subsequently species have to be tested experimentally to verify at which salt level they are able to cope with salinity without compromising their appearance. In relation to the large number of genotypes potentially available and the difficulty of making choices appropriate to the particular environmental conditions, unsuitable genotypes have to be excluded. Cassaniti & Romano (2011) carried out a survey to identify halophytes, which naturally grow in the Mediterranean area and which could be utilized for ornamental purpose. The investigation, based on the literature, showed about 172 suitable species in 30 families and 86 botanical genera were available. Most suitable species (34) came from the Chenopodiaceae and within the genera, the most represented were *Limonium* (Plumbaginaceae; 17 species) and *Atriplex* (Chenopodiaceae; 14 species).

Native plants can assume an important role for their adaptability to both biotic and abiotic stress (Iles, 2003; Kotzen, 2004; Savè, 2009). Although interest in them has recently risen for restoring disturbed landscapes, controlling erosion and improving the aesthetic quality of environments (Martínez-Sánchez et al., 2003; Savè, 2009), they have been largely ignored in landscaping (Romano, 2004). Many of them could represent an alternative to the species traditional used, particularly because of their enhanced water use efficiency (Clary et al., 2004; Franco et al., 2002; Morales et al., 2000). The key question here is can only native species be used sustainably? Undoubtedly there are many alien species that are salt tolerant, but there is a critical necessity to preserve and enhance the ecological and landscape integrity of particular environments, like the Mediterranean or desert areas (Kotzen, 2004). Thus a new landscape paradigm that includes the wide use of native plants has been developed, which appears appropriate for arid and coastal ecosystems where salinity is frequent (Kotzen, 2004; Sánchez-Blanco et al., 2003). However, the introduction of alien species has its dangers because a) many of the introduced species will not survive without large inputs of water and maintenance and b) those that are xerophytes or halophytes and can adapt to the drought/salt condition can turn out to be pernicious weeds (Kotzen, 2004). Hence the threat from using exotic plants needs to be considered along with the advantages in the context of specific countries or regions, as a species that is aggressive in one climatic region may be much less so in another (Hitchmough, 2004). It is possible to choose non-invasive exotics (Dunnet, 2010) that could be used for their resistance to salt stress.

#### 4.2 Plant management

The consociation of halophytes with other less salt-tolerant species might enhance the tolerance of the latter if the halophytes, which are salt accumulators, reduce the local salinity through salt bioaccumulation. In an attempt to evaluate this approach, five species (*Suaeda maritima*, *Sesuvium portulacastrum*, *Clerodendrum inerme*, *Ipomoea pes-caprae*, *Heliotropium curassavicum*) and one tree species (*Excoecaria agallocha*) were used in a trial (Ravindran et al., 2007). Of the six species studied *S. maritima* and *S. portulacastrum* exhibited greater accumulation of salts in their tissues and reduced salts in the soil medium.

Arbuscular mycorrhizal (AM) symbiosis can increase host resistance to drought stress, although the effect is unpredictable. Since water and salt stress are often linked in drying soils, the AM influence on plant drought response can be partially the result of AM influence on salinity stress. With this idea in the mind, Cho et al. (2006) tested the hypothesis that AM-induced effects on drought responses would be more pronounced when plants of comparable size were exposed to drought in salinized soils than when only

drought was applied. In two greenhouse experiments, several water relations characteristics were measured in sorghum plants colonized by *Glomus intraradices*, *Gigaspora margarita* or a mixture of AM species, during a sustained drought following exposure to salinity treatments (NaCl stress, osmotic stress via concentrated macronutrients, or soil leaching). The findings confirmed that AM fungi can alter host response to drought but did not lend much support to the idea that AM-induced salt resistance might help explain why AM plants can be more resilient to drought stress than their non-AM counterparts. As far as we are aware, the value of AM to combating salinity in landscaping has yet to be evaluated.

Shade conditions can also influence the effects of salinity on plants. Devitt et al. (2005b) quantified the foliar damage and flower production of 19 flowering landscape plants, sprinkle irrigated with reuse water and reuse water plus a period of shade (24% reduction in solar radiation). Results indicated that about half of the treated species had an acceptable levels of foliar damage at 1.94 dS m<sup>-1</sup> in both of the reuse treatments (*Asteriscus maritimus* 'Gold Coin', *Centaurea cineraria*, *Lantana camara* var. *aculeate*, *Bougainvillea spectabilis*, *Gazania* spp., *Hemerocallis fulva*, *Gaillardia aristata*, *Mesembryanthemum crystallinum*). However while the partial shade minimized the negative effect of salt spray application, none of the species tested performed well enough to be used in the landscaping.

The use of enhanced potassium plant nutrition is an efficient method of preventing sodium-induced stress in many crops (Evans & Sorger, 1966) and additional nitrate fertilization can alleviate chloride-induced stress (Bar et al., 1997) so the application of potassium nitrate fertilizer has been shown as a very efficient method of enhancing crop performances under saline conditions (Achilea, 2003). It has to be determined if this procedure is applicable in the landscape, where the maintenance level is low.

## 5. Irrigation modalities to reduce salt stress

As in agriculture, amenity landscapes that provide ornamental or utility value are irrigated when rain is insufficient to support expected growth. Irrigation to compensate for inadequate rainfall can be permanent in arid areas or temporary when short-term drought threatens. Landscapes have additional irrigation requirements uncommon in agriculture. Most landscape plants need short-term irrigation following planting until they establish new roots in the surrounding soil. Also, plants can be placed in landscape situations of very limited soil-water availability, such as aboveground planters, that require permanent irrigation regardless of the climate (Kjelgren et al., 2000). Sometimes plants that are damaged or dead have to be replaced but this operation is very expensive (e.g. amounting to hundreds of thousands of dollars in a golf course in Southern Nevada, Devitt et al., 2004). Unlike the monoculture of agricultural crops, most landscape plantings include a variety of species with different abilities to tolerate drought and salt in irrigation water (Wu et al., 2001b) and hence different needs for water. Additionally, the method of irrigation used such as drip, ground surface application or sprinkler irrigation can, as we have seen (Section 3.1), affect the severity of plant damage from salty irrigation water (Miyamoto, 2004; Wu & Dodge, 2005). It has been well documented that applying irrigation water containing soluble salts via drip, bubbler or even flood irrigation has a less damaging effect on plants than applying the same water via overhead irrigation (Benes et al., 1996; Bernstein & Francois, 1975; Gornat et al., 1973; Jordan et al., 2001). Drip irrigation is often preferred, as it also minimizes fluctuations in soil water content (Shalhavet, 1984), maintaining the soil moisture continuously high at the root zone and a low salt concentration. The development of saline

bulbs within the root zone can be managed with a sufficient leaching and monitoring of soil  $EC_e$  (Boland, 2008). However, even though the majority of plants are more sensitive to sprinkler than drip irrigation, the use of sprinklers is often preferred as it requires less maintenance and is less vulnerable to damage than drip irrigation (Wu & Dodge, 2005). Common problems associated with drip irrigation are the need to remove the accumulated salts from the wetting front and avoidance of drippers clogging. Where flood irrigation is used, the leaching of salts is largely determined by the soil type, as the low hydraulic conductivity of clay soils (especially in the presence of sodicity) often minimizes any opportunity for management or 'strategic leaching' (i.e. leaching at specific times) - although there may be some opportunity for the installation of surface or subsurface drains to assist drainage (Boland, 2008).

Techniques for controlling salinity that require relatively minor changes to schedules are more frequent irrigations, additional leaching, pre-plant irrigation, bed forming and seed placement. Salt concentrations are lowest following an irrigation and highest just before the next irrigation. Increasing irrigation frequency maintains more constant moisture content in the soil so that more of the salts are then kept in solution which aids the leaching process (Fipps, 2003). Applying sufficient volumes of water to allow an adequate salt leaching can alleviate salt accumulation and sustain the prolonged use of alternative water sources for irrigation of landscapes (Niu & Cabrera, 2010). The growth stage can also affect the sensitivity of the plants to salt stress. Woody species demonstrate greater sensitivity to salinity during the early developmental phases, so in this case giving water of better quality is preferred.

The term 'irrigation scheduling' includes both the estimation of the irrigation requirements of the given crop and the appropriate irrigation intervals, which is often complicated to establish in landscapes due to lack of information on the water-use of salt-stressed plants (Paranychianakis & Chartzoulakis, 2005). Precise irrigation scheduling relies on the right amount of water at the right time (Feres et al., 2003) and a proper choice can have a significant impact on salinity effects through either over or under irrigation. The adoption of irrigation scheduling tools such as monitoring evapotranspiration and soil moisture, the monitoring of salinity (EC in the soil, leaf-sap in the plant), determining adequate leaching or drainage for water-logging-sensitive crops and balancing the accumulation of the salts with leaching irrigations under conditions of limited water supply (Boland, 2008) can assist scheduling decisions.

## 6. Conclusions

The salt tolerance of landscape plants varies widely with species, environmental conditions and soil or substrate. Landscape plants, most of which are non-halophytes, have similar mechanisms of salt tolerance to agricultural crops, but assessment of salt tolerance for landscape plants should be based primarily on aesthetic value rather than effects on biomass. In relation to the wide number of plant species potentially available, it should be possible choose ornamental genotypes suitable for saline environments. Problems that occur are linked to: 1) the necessity to carry out trials on a wide range of plant species to find those most suitable for specific sites; 2) choosing parameters that are easy to measure to characterize tolerance to salt stress and 3) tailoring irrigation modalities or plant management strategies to enable chosen species to cope with salt stress. The use of saline water can be adopted only where the soil characteristics (e.g. sandy soil) and the nature of

the salts present in any irrigation or ground water allow the salt water use without damage to the soil structure. However, there are many places where the use of low quality water should be possible and so improve the quality of landscapes and urban life.

## 7. References

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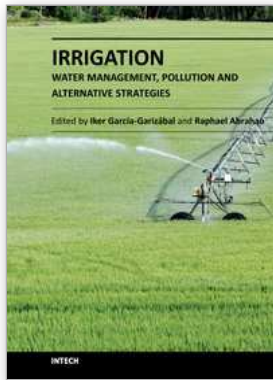


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## **Irrigation - Water Management, Pollution and Alternative Strategies**

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Irrigated agriculture is the most significant user of fresh water in the world and, due to the large area occupied, is one of the major pollution sources for the water resources. This book comprises 12 chapters that cover different issues and problematics of irrigated agriculture: from water use in different irrigated systems to pollution generated by irrigated agriculture. Moreover, the book also includes chapters that deal with new possibilities of improving irrigation techniques through the reuse of drainage water and wastewater, helping to reduce freshwater extractions. A wide range of issues is herein presented, related to the evaluation of irrigated agriculture impacts and management practices to reduce these impacts on the environment.

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