The effect of alternating irrigation with fresh and saline water on the aesthetic quality, ion accumulation and water relations of *Hibiscus* plants

S. Álvarez[1,2,a], P.A. Nortes[2], J.R. Acosta-Motos[2] and M.J. Sánchez-Blanco[2]

[1]Instituto Tecnológico Agrario de Castilla y León (ITACYL), Valladolid, Spain; [2]Centro de Edafología y Biología del Segura (CEBAS-CSIC), Murcia, Spain.

Abstract

Applying saline water resources for irrigation ornamental plants is becoming a widespread practice in urban areas in arid and semi-arid regions, but it can restrict plant growth and lead to environmental problems. A strategy to reduce the adverse effects of saline water irrigation is the alternate irrigation with fresh and saline water at different phases or different sides of the rooting zone, but this irrigation practice is still not well understood. In this experiment, 120 hibiscus plants (*Hibiscus rosa-sinensis*) were grown in a commercial substrate with the root system divided equally between two plastic pots (3 L). Plants were subjected to three irrigation treatments lasting 6 months: control (both sides irrigated with freshwater, 0.8 dS m^{-1}; F), a saline treatment (both sides irrigated with moderate saline water, 4.0 dS m^{-1}; S) and a fresh-saline treatment (half of the root system was irrigated with freshwater, 0.8 dS m^{-1} and the other half was irrigated with severe saline water, 8.0 dS m^{-1}; F-S). All the plants were irrigated daily to field capacity. Results showed that leaf fresh weight was affected more by moderate saline treatment (S) than by alternating fresh and severe saline water (F-S), while plant height was reduced similarly in both treatments. Plants of F-S treatment were those with greater number of flowers per plant throughout the experiment. Both saline irrigation treatments induced active osmotic adjustment, especially plants with both sides of the root system irrigated with saline water. Saline treatment affected leaf colour and relative chlorophyll content and induced an important decrease of its fresh weight due to the leaf tissue dehydration (decrease in leaf water potential) and a high Cl and Na accumulation in the plant tissues. When alternating fresh and saline water irrigation (F-S) was used, most of the adverse effects were mitigated.

Keywords: salinity, ornamental plants, irrigation, root system, osmotic adjustment, ion uptake, flowering

INTRODUCTION

Due to rising water demands and decreasing amount of available water for agriculture in the arid and semi- arid areas, such as Mediterranean countries, the application of water-saving irrigation strategies has increased in the last decades (Navarro et al., 2009). As a result of this, the exploitation of unconventional water resources has become a reliable option, that may play a role toward achieving a more sustainable use of water (Acosta-Motos et al., 2014; Vivaldi et al., 2021). In this context alleviating the freshwater shortage using saline water is an urgent need and an efficient irrigation management is therefore crucial for irrigated agriculture.

Hibiscus rosa-sinensis is a widely grown ornamental shrub of great interest for gardening and decorative use, mainly due to its presence of a large number of showy and colourful flowers. *Hibiscus* is a plant native to China, that nowadays is very popular and can be found in gardens almost everywhere in the world. Applying saline water resources for irrigation ornamental plants is becoming a widespread practice in urban areas in many regions, but it can restrict plant growth and lead to environmental problems (Acosta-Motos

[a]E-mail: alvmarsa@itacyl.es

et al., 2016). A strategy to reduce the adverse effects of saline water irrigation is the alternate irrigation with fresh and saline water at different phases or different sides of the rooting zone (Li et al., 2019), but this irrigation practice is still not well understood and no experiments have been conducted studying ornamental plant characteristics in such conditions.

The main goal of this wok was to investigate the effects on *Hibiscus rosa-sinensis* of alternating irrigation with fresh and saline water on the development, water relations, ion uptake and plant quality. Knowledge of the irrigation management in saline conditions may help to horticultural sector (nursery and gardeners) to select the most appropriate irrigation strategy to optimize water quality and to reduce the consumption of fresh water.

MATERIAL AND METHODS

Plant material and experimental conditions

In this experiment, 120 hibiscus plants (*Hibiscus rosa-sinensis* L. 'President'), which had been grown in 1.8 L plastic pots (diameter 14 cm; height 12 cm) by a specialized nursey, were transplanted in April with the root system divided equally between two plastic pots. For this, the plants were removed from their pots, and the root system of each plant was divided and repotted into two pots (volume 3 L each) containing the same commercial substrate, an 8:7:1 (v/v/v) mixture of coconut fibre, peat, and perlite. Therefore, the root system of each plant was split into two hydraulically separate compartments.

Treatments

Plants were subjected to three irrigation treatments lasting 6 months: control (both sides irrigated with freshwater, 0.8 dS m^{-1}; F), a saline treatment using tap water with salt added up to 44 mM NaCl (both sides irrigated with moderate saline water, 4.0 dS m^{-1}; S) and a fresh-saline treatment (F-S). In F-S, during each irrigation time, half of the root system was irrigated with freshwater (0.8 dS m^{-1}), while the remainder of the root system was irrigated with saline water using tap water with salt added up to 88 mM NaCl (8.0 dS m^{-1}). Plants were placed inside a plastic greenhouse equipped with a cooling system, located at Santomera (Murcia, Spain). One drip nozzle delivering 2 L h^{-1} pot^{-1} (two $plant^{-1}$) was connected to two spaghetti tubes (one each side of every pot) and the duration of each irrigation episode was used to vary the amount of water applied, which depended on the season and on climatic conditions. The volume of water varied between 200 and 700 mL $plant^{-1}$ and irrigation episode. All the plants were irrigated daily to field capacity and the irrigation amount was the same in the three irrigation treatments, applying 50% of the total amount on each side of the plant.

Plant quality, ions content, and water status measurements

At the end of the experiment, the substrate was gently washed from the roots of ten plants $treatment^{-1}$ were divided into shoots (leaves, herbaceous stem, woody stem, and flowers) and roots to measure the respective fresh weight (FW). These were then oven-dried at 80°C and stored at room temperature for inorganic solute analyses. The concentration of Cl^- was analyses in the aqueous extracts by a chloride analyser (Chloride analyser mod 926, Sherwood Scientific Ltd.). The concentrations of Na^+ were determined in a digestion extract by an ICP-OES IRIS INTREPID II XDL analyser. Plant height was determined at the end of the experiment in 30 plants $treatment^{-1}$. Throughout the experiment, number of flowers was measured periodically in 30 plants $treatment^{-1}$. Leaf colour was measured at the end of the experiment with a Minolta CR-10 colourimeter, which provides the colour coordinated lightness (L*), chroma (C*), and hue angle (h°), using 12 plants $treatment^{-1}$. The relative chlorophyll content (RCC) was measured using a Minolta SPAD-502.

Leaf water potential (Ψ_l) at midday was measured in seven plants per treatment at the end of the experiment. Ψ_l was estimated according to the method described by Scholander et al. (1965), using a pressure chamber (Soil Moisture Equipment Co., Santa Barbara, CA, USA). Leaf osmotic potential at full turgor (Ψ_{100s}) was estimated at the same time according to Gucci et al. (1991), using excised leaves with the petioles placed in distilled water overnight to reach full saturation. Leaves from the Ψ_{100s} measurements were frozen in liquid nitrogen and stored at -30°C. After thawing, the osmotic potential was measured in the extracted sap using a WESCOR 5520 vapour pressure osmometer (Wescor Inc., Logan, UT, USA).

Statistical analyses of data

The data were analysed by one-way ANOVA using Statgraphics Plus for Window 5.1 software. Treatments means were separated with Bonferroni's multiple range test ($P<0.05$).

RESULTS AND DISCUSSION

At the end of the experimental period, both salinity treatments (S and F-S) significantly reduced leaf fresh weight (FW) compared with the control, the effect being more pronounced in S plants, while stem and aerial FW was only reduced in S plants (Table 1). As regards flower and root FW no differences among treatments were observed, suggesting that these parameters were not modified by the salinity levels applied, meaning that leaf production was affected earlier than root system (Sánchez-Blanco et al., 2014). Control plants reached the greatest height at the end of the experiment, while plant height was similarly reduced in both S and F-S treatments. The results showed that combining fresh and saline water irrigation (F-S) led to a smaller decrease in fresh weight compared to irrigating with saline water in both sides (S).

Table 1. Growth parameters at the end of the experiment in *Hibiscus* plants subjected to different irrigation treatments.

Parameters	F	S	F-S	P
Leaf FW[a] (g pl^{-1})	163.0±20.5c	58.0±6.7a	108.4±24.6b	**
Stem FW (g pl^{-1})	270.6±23.2b	192.4±6.6a	219.7±23.6ab	*
Flower FW (g pl^{-1})	13.3±4.6	5.4±1.3	11.3±4.1	ns
Aerial FW (g pl^{-1})	446.9±44.1b	255.7±11.6a	339.5±47.5ab	**
Root FW (g pl^{-1})	263.7±23.2	269.8±24.8	256.1±20.8	ns
Plant height (cm)	89.6±2.7b	65.3±1.7a	70.7±2.8a	***

[a]FW: fresh weight.
Means within a row without a common letter are significantly different by Bonferroni $_{0.05}$ test.

Although the average salt level was the same in the two salinity irrigation treatments (around 4 dS m^{-1}), the lowest values for leaf growth were found when saline water was applied in both sides of the irrigation system (S). This indicates that plant growth does not only depend on the quality of water applied but also on the way how the water was applied (Khaleghi et al., 2020), and that irrigating the whole root with saline water is the most sensitive irrigation management to induce salt stress in the plant.

Both salinity treatments caused a significant modification in leaf colour parameters, but this effect was more pronounced in S plants (Table 2). The higher L* and C* values and lower h° and RCC values recorded in the leaves of these plants confirmed the brighter and less dark green colour of the foliage compared with control plants, suggesting that colour is modified by saline treatments.

Table 2. Colour and relative chlorophyll content in *Hibiscus* plants subjected to different irrigation treatments at the end of the experiment.

Parameters	F	S	F-S	P
L*	41.4±0.4a	52.7±0.5c	44.7±0.7b	***
C*	14.6±0.5a	31.2±0.6c	19.9±0.8b	***
h°	109.20±0.9b	103.8±0.6a	108.9±1.0b	**
RCC	43.0±2.0b	27.5±2.1a	33.2±2.8a	***

L*: Lightness; C*: chroma; h°: hue angle; RCC: relative chlorophyll content.
Means within a row without a common letter are significantly different by Bonferroni $_{0.05}$ test.

Hibiscus plants had flowers during the most of the experiment, although the greatest intensity of flowering happened during the summer (Figure 1). No pronounced differences in the number of flowers were observed during the experiment between control and S treatment. The highest values of this parameter were found in the F-S treatment (when alternating fresh and saline water), which shows this parameter depended on the quality of water and the way to deliver fresh and saline water.

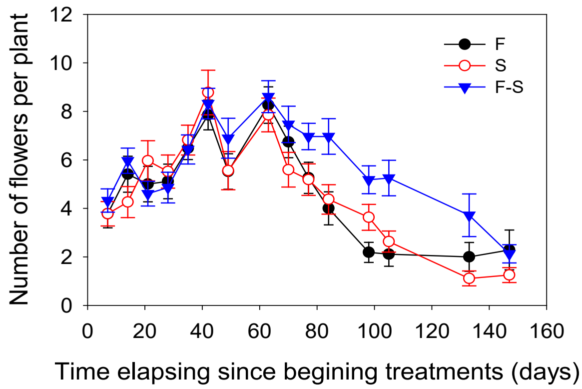

Figure 1. Evolution of plant height in *Hibiscus* plants subjected to different irrigation treatments.

In decorative plants, these effects can strongly reduce the market value of these plants, since the ornamental and aesthetic characteristics are essential for their quality (Sánchez-Blanco et al., 2019). Although F-S received about 50% less of the irrigation fresh water as compared to F, flowering was increased compared to control plants. S did not increase the number of flowers in *Hibiscus* plants but plant quality was affected due to lower RCC and leaf colour.

As regards leaf water potential (Ψ_l), control plants had the highest values, while S and F-S plants showed a significant reduction, reaching values of -1.13 MPa (Figure 2A). Leaf osmotic potential at full turgor (Ψ_{100s}) decreased in both saline treatments, although it only was significant in S, which indicative that the osmotic adjustment was due to irrigate both sides of the root with saline water (Figure 2B). This behaviour and the values of osmotic adjustment observed in this work are within those reported for other studies on Mediterranean ornamental plants submitted to saline stress (Álvarez et al., 2018).

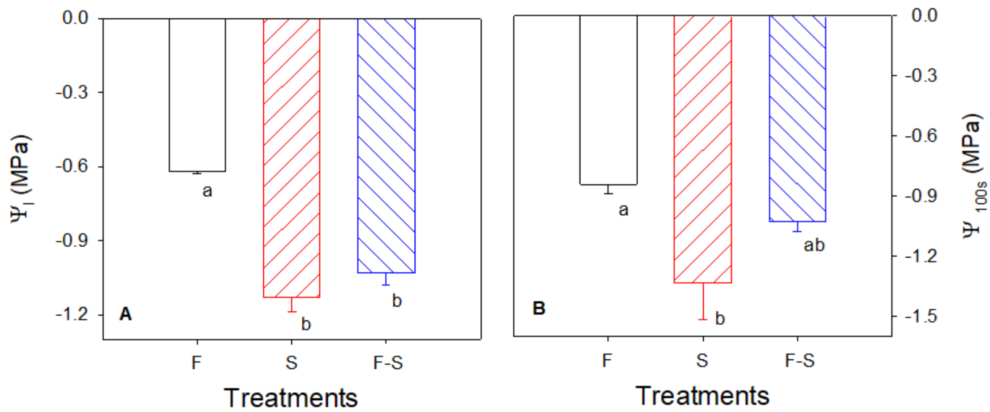

Figure 2. Leaf water potential (Ψ_l; A) and leaf osmotic potential at full turgor (Ψ_{100s}; B) at the end of the experiment in *Hibiscus* plants subjected to different irrigation treatments. Means without a common letter are significant different by Bonferroni $_{0.05}$ test.

The concentrations of Na^+ and Cl^- increased with salinity in different parts of the plants (leaves, herbaceous, and woody stem and root). At the end of the experiment, Na and Cl ion concentrations in leaves were higher in F-S plants than in control plants, while the highest Na and Cl concentrations in all parts of the plant were found using S, when both sides of the roots were irrigated with saline water (Figure 3). Concerning the distributions of both ions in the different parts of the plants, control plants had similar Na and Cl ion concentrations in all parts (leaves, stem, and root), while in S and F-S plants the highest concentration of both ions were found in the leaves compared to the rest of tissues.

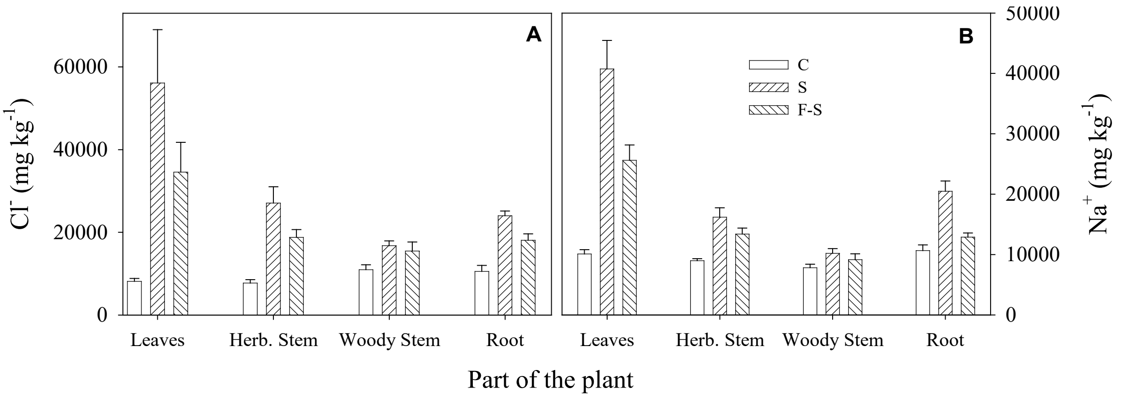

Figure 3. Concentrations of Na^+ and Cl^- at the end of the experiment in *Hibiscus* plants subjected to different irrigation treatments.

Plants of the S treatment increased their leaf ion concentrations sharply, reaching a value seven-fold higher than in control plants for Cl^- and four-fold higher for Na^+. Such increase was lower in the case of F-S plants, 4-fold higher for Cl and 2.5-fold higher for Cl^- compared to control plants. Under salinity, controlling the salt concentration of the leaves, (retaining these ions in the root and woody stem) is an important mechanism that allows plants growth under salt stress (Colmer et al., 2005; Álvarez and Sánchez-Blanco, 2014). However, in our study such mechanisms did not prevent the over-accumulation of these ions in leaves of plants subjected to S treatment, which probably contributed to a greater decrease in growth observed in these plants.

CONCLUSIONS

In conclusion, our results indicate that irrigating both sides of the root system with moderate saline water (around 4.0 dS m^{-1}) affected leaf colour and relative chlorophyll content and induced an important decrease of leaf growth due to the leaf tissue dehydration and a high Cl^- and Na^+ accumulation in the plant tissues, which resulted in a decrease in the overall quality of the plants. However, when alternating fresh and severe saline water irrigation (0.8 and 8.0 dS m^{-1}) was used, most of the adverse effects were mitigated. Also, the different irrigation modalities applied in our experiment induced different flowering responses in *Hibiscus*, meaning that the quality of water and irrigation strategy applied must be considered an important aspect when is used as a technique for saving freshwater without reducing quality in ornamental species. Therefore, these findings indicate that in areas where fresh water is scarce, priority should be given to the application of fresh water on one side of the root instead of mixing fresh with saline water in order to reduce EC of the irrigation water.

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