HortScience 49(10):1284–1291. 2014.

# The Influence of Deficit Irrigation on Growth, Ornamental Quality, and Water Use Efficiency of Three Potted *Bougainvillea* Genotypes Grown in Two Shapes

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*Additional index words.* *Bougainvillea*, flower index, leaf water potential, mineral composition, water productivity, water stress

***Abstract*. *Bougainvillea* is widely used as flowering shrub in gardening and landscaping in the Mediterranean region characterized by limited water supply. The evaluation of deficit irrigation as a possible technique to improve water productivity and selection of genotypes that can better withstand soil water deficits are essential for sustainable production. A greenhouse experiment was conducted to determine the effects of deficit irrigation on three potted *Bougainvillea* genotypes [*B. glabra* var. Sanderiana, *B.* ×*buttiana* 'Rosenka', *B. 'Lindleyana'* (=*B. 'Aurantiaca'*)] grown in two shapes, globe and pyramid, on agronomical and physiological parameters. Irrigation treatments were based on the daily water use (100%, 50%, or 25%). The shoot, total dry biomass, leaf number, leaf area, and macronutrient [nitrogen (N), phosphorus (P), and potassium (K)] concentration decreased in response to an increase in water stress with the lowest values recorded in the severe deficit irrigation (SDI) treatment. At 160 days after transplanting (DAT), the percentage of total dry biomass reduction caused by irrigation level was lower in *B.* ×*buttiana* 'Rosenka' compared with *B. glabra* var. Sanderiana and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*). At 160 DAT, the flower index increased in response to an increase in water stress with the highest values recorded under both moderate deficit irrigation (MDI) and SDI for *B.* ×*buttiana* 'Rosenka'. The biomass water use efficiency (WUE) increased under water stress conditions with the highest values recorded in *B. glabra* var. Sanderiana and *B.* ×*buttiana* 'Rosenka' grown under MDI (average 1.43 and 1.25 $g·L^{-1}$, respectively) and especially with SDI (average 1.68 and 1.36 $g·L^{-1}$, respectively). A number of tolerance mechanisms such as increase in stomatal resistance, decrease in leaf water potential, and decrease in leaf osmotic potential have been observed, especially under SDI. The MDI treatment can be used successfully in *Bougainvillea* to reduce water consumption while improving the overall quality and WUE, whereas the genotypes *B. glabra* var. Sanderiana and *B.* ×*buttiana* 'Rosenka' could be considered suitable for pot plant production.**

Water is fast becoming a scarce resource in arid and semiarid regions such as the Mediterranean basin (Gregory, 1984). There is high pressure on the ornamental floriculture industry to reduce water regimes and to produce plants more efficiently in the face of government regulations on water use (Sánchez-Blanco et al., 2009; Sweatt and Davies, 1984). The irrigation scheduling, in particular the water amount and frequency in most ornamental nurseries, is based on arbitrary personal experience, which is rarely modified to match the crop water requirements (Álvarez and Sánchez-Blanco, 2013; Grant et al., 2012). Possible consequences of exposing plants to drought stress is the decrease in internode length, leaf size, flower number, and size with a possible negative effect on the their ornamental values (Álvarez et al., 2009, 2013; Cameron et al., 1999; Sánchez-Blanco et al., 2002). From a physiological point of view, it is well established that under severe water stress, plants reduce photosynthesis, mainly because of stomata closure (Chaves et al., 2003). With closing the stomata, plants reduce not only water loss by transpiration, but also carbon dioxide supply to the leaves (Cornic and Massacci, 1996). Consequently, plant biomass and growth are reduced, resulting in the loss of plant quality. However, the sensitivity to water stress may vary considerably between different species and/or cultivars (Clary et al., 2004; Sánchez-Blanco et al., 2002; Zollinger et al., 2006). For all these reasons, understanding agronomical and physiological responses of flowering plants to water management is critical for optimizing the production in pots of high-quality ornamentals.

Water-saving irrigation management strategies are among the options available to horticultural growers to reduce water consumption and improve WUE. Possible strategies include deficit irrigation (DI), regulated deficit irrigation, and partial root-zone drying. DI involves the application of water at a rate and volume lower than the evapotranspiration rate (ET) throughout the whole growth period and may be used in potted ornamental plants to improve plant quality by reducing excessive vigor and increasing WUE. However, the level and the duration of water stress imposed in each species and/or cultivars are also critical to reach this purpose (Álvarez et al., 2009; Álvarez and Sánchez-Blanco, 2013). In the last three decades, interest in DI has primarily centered on its potential to save water and/or to control excessive vegetative growth in fruit trees and vegetables (Costa et al., 2007, and references cited therein; Goldhamer and Beede, 2004; Mao et al., 2003; Rouphael et al., 2008a). Its application to ornamental crops has received limited interest so far, because flowering ornamental plants are generally grown in pots, which provide a small water storage capacity in the root zone compared with open-field conditions. This small water-holding capacity makes it technically more difficult to apply DI without causing stress damage to the plants (Cameron et al., 2006).

*Bougainvillea* is a genus of flowering plants that belongs to the family *Nyctaginaceae* native in South America originated from west Brazil to southern Argentina. Different authors accept between four and 18 species in the genus (Kent et al., 2007); it is widely used in the arid landscapes for horticulture, agriculture, and environmental industries as a result of its high adaptability in different agroclimatic regions around the world (Saifuddin et al., 2010; Suxia et al., 2009). Potted *Bougainvillea* plants are a significant part of the Italian ornamental plant industry as a result of the high demand for this product on national and international markets (ISMEA, 2013). Despite the importance of the *Bougainvillea* in floriculture production, no published data are available concerning the effects of different levels of deficit irrigation on agronomical and physiological parameters of three *Bougainvillea* genotypes grown in two different shapes. For these reasons, the evaluation of DI as a possible technique to improve water productivity and the selection of genotypes that can better withstand soil water deficits are essential for sustainable production.

The aim of this study was to determine the effects of three irrigations treatments (full or

Received for publication 20 May 2014. Accepted for publication 23 July 2014.
This work was funded by the Italian Ministry of Agricultural, Food and Forestry Policies (MiPAAF). Project "Tecnologie di filiera per il controllo della tolleranza a stress idrico in Bougainvillea" (D.M. 11053/7643/09 of 7 May 2009).
We thank Professor Giancarlo Barbieri and Dr. Boris Basile for critically reading the manuscript and their constructive comments.
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Table 1. Analysis of variance for irrigation treatments, genotypes, and shapes on plant growth parameters and ornamental value of potted *Bougainvillea* plants.

| Source of variance | Leaf biomass (g/plant) | | Stem biomass (g/plant) | | Flower biomass (g/plant) | | Total biomass (g/plant) | |
|---|---|---|---|---|---|---|---|---|
| | 160 DAT[z] | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT |
| | Significance[y] | | | | | | | |
| Irrigation (I) | Q*** | L*** | L*** | Q*** | NS | Q** | L*** | L*** |
| | $R^2$ = 0.82[x] | $R^2$ = 0.73 | $R^2$ = 0.86 | $R^2$ = 0.76 | | $R^2$ = 0.45 | $R^2$ = 0.94 | $R^2$ = 0.87 |
| | $P \le 0.006$[w] | $P \le 0.003$ | $P \le 0.000$ | $P \le 0.014$ | | $P \le 0.163$ | $P \le 0.000$ | $P \le 0.000$ |
| Genotypes (G) | *** | *** | *** | *** | *** | *** | *** | *** |
| Shape (S) | *** | *** | *** | *** | *** | NS | *** | *** |
| I × G | NS | NS | *** | ** | * | *** | *** | NS |
| I × S | NS | NS | NS | NS | NS | NS | NS | NS |
| G × S | *** | *** | NS | * | *** | *** | *** | *** |
| I × G × S | NS | NS | NS | NS | NS | NS | NS | NS |

| Source of variance | Leaves (no./plant) | | Total leaf area (cm²/plant) | | Flower (no./plant) | | Flower index (no. dm⁻² LA) | |
|---|---|---|---|---|---|---|---|---|
| | 160 DAT[z] | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT |
| | Significance[y] | | | | | | | |
| Irrigation (I) | L*** | L*** | L*** | L*** | L*** | * | L*** | Q*** |
| | $R^2$ = 0.89 | $R^2$ = 0.59 | $R^2$ = 0.88 | $R^2$ = 0.76 | $R^2$ = 0.78 | $R^2$ = 0.55 | $R^2$ = 0.83 | $R^2$ = 0.79 |
| | $P \le 0.000$ | $P \le 0.016$ | $P \le 0.000$ | $P \le 0.002$ | $P \le 0.002$ | $P \le 0.090$ | $P \le 0.001$ | $P \le 0.010$ |
| Genotypes (G) | *** | *** | *** | *** | *** | *** | *** | *** |
| Shape (S) | *** | NS | *** | * | * | NS | *** | NS |
| I × G | *** | NS | * | ** | *** | NS | * | NS |
| I × S | NS | NS | NS | ** | NS | * | NS | NS |
| G × S | ** | NS | *** | *** | *** | *** | *** | NS |
| I × G × S | NS | NS | NS | NS | NS | NS | NS | NS |

[z]DAT = days after transplanting.
[y]L = linear; Q = quadratic.
[x]$R^2$ = coefficient of determination
[w]$P$ values indicate the level of significance.
LA = leaf area.
NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

deficit irrigation) on the agronomical and physiological responses of three potted *Bougainvillea* genotypes [*B. glabra* var. Sanderiana, *B. ×buttiana* 'Rosenka', *B. 'Lindleyana'* (=*B. 'Aurantiaca'*)] trained to two canopy shapes (globe and pyramid). For this, plant growth, ornamental quality, WUE, mineral composition, stomatal resistance, and water relations were measured during the growing cycle. These results can play an important role for the ornamental industry, which is very interested in selecting tolerant genotypes and suitable shapes under water stress conditions and to evaluate the DI as a useful technique to save water without affecting the economic value of the plant.

## Materials and Methods

*Plant material and growth conditions.* The experiment was conducted from Mar. to Oct. 2011 in a 265-m² glass zinc-coated steel greenhouse situated at the Experimental Station of the University of Naples Federico II, South Italy (lat. 43°31′ N, long. 14°58′ E; alt. 60 m above sea level). Plants were grown under a 50% black shading net. The greenhouse was maintained at daily temperature between 16 and 26 °C and day/night relative humidity of 50/88%.

Rooted cuttings of three flowering potted *Bougainvillea* genotypes [*B. glabra* var. Sanderiana, *B. ×buttiana* 'Rosenka', *B. 'Lindleyana'* (=*B. 'Aurantiaca'*)] were obtained from a commercial grower (Vivai Torsanlorenzo, Ardea, Rome, Italy) and transplanted on Mar. 1 into pots (depth 17 cm, height 15 cm) containing 3 L of peatmoss. The pots were placed on three 180 cm wide and 7-m-long troughs with a plant density of 6 plants/m². Bougainvillea plants were grown in two canopy shapes: globe and pyramid. The *Bougainvillea* globe shape was obtained by regular pruning based on the new shoot thinning and cut back, whereas the pyramid *Bougainvillea* plants were grown as a vine on a tutor and pruned by trimming exceeding shoots.

Treatments were arranged in a randomized complete block design with three replicates. The treatments were defined by a factorial combination of three irrigation levels based on the daily water use (100%, 50%, or 25%), three *Bougainvillea* genotypes [*B. glabra* var. Sanderiana, *B. ×buttiana* 'Rosenka', *B. 'Lindleyana'* (=*B. 'Aurantiaca'*)], and two canopy shapes (globe or pyramid). Each experimental unit consisted of 15 plants.

*Irrigation treatments.* The irrigation treatments consisted of a control; when substrate moisture was maintained close to container capacity, it was watered so that 20% of the applied water was leached; and two DI treatments obtained applying 50% (MDI) or 25% (SDI) of the amount of water supplied in the control treatment. The electrical conductivity of the water applied was 0.6 dS·m⁻¹. The three levels of water recovery (100%, 50%, and 25%) were obtained using four, two, and one emitter(s) per plant, respectively (flow rate of 2 L·h⁻¹).

Plants were fertigated with a nutrient solution containing the following macro- and micronutrients: 1.45 mM $N\text{-}NO_3$, 2.66 mM $N\text{-}NH_4$, 4.36 mM N-ureic, 1.41 mM P, 4.24 mM K, 5.34 µM iron, 3.45 µM manganese, 0.84 µM copper, 0.83 µM zinc, 37 µM boron, and 2.08 µM molybdenum.

A separate set of 54 potted plants was placed on an electronic weighing balance at the same plant density of the canopy; these plants were in the center of a bench containing guard plants to form a continuous canopy. The pots were covered with plastic film to minimize evaporation. The transpiration was measured by a gravimetric method, weighing the pots before and after the irrigation episode, and was determined by noting when the leaching fraction reached 15% to 20% (Rouphael et al., 2008b; Rouphael and Colla, 2005). The assumption was made that the weight loss measured by the electronic balance was equal to the plant transpiration.

*Recording, sampling, and analysis.* During the whole growing cycle, the amount of water used by the plants was monitored daily in all treatments. At 171 DAT, the stomatal resistance to water vapor (s·cm⁻¹) was measured between 1100 and 1300 HR on the youngest fully expanded leaf (nine plants per treatment, three per each replication) with a diffusion porometer (AP-4; Delta-T Devices, Cambridge, U.K.). The water potential components of leaves were measured psychrometrically on the same date of the stomatal resistance measurements using a dew-point psychrometer (WP4; Decagon Devices, Pullman, WA). Leaf water potential ($\Psi_w$) was measured at midday. The osmotic potential ($\Psi_\pi$) was measured on frozen/thawed leaf

Table 2. Effects of irrigation treatments, genotypes, and shapes on dry biomass production and partitioning of potted *Bougainvillea* plants.

| Treatments | | Leaf biomass (g/plant) | | Stem biomass (g/plant) | | Flower biomass (g/plant) | | Total biomass (g/plant) | |
|---|---|---|---|---|---|---|---|---|---|
| | | 160 DAT[z] | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT |
| Irrigation (I) | | | | | | | | | |
| 100% (C) | | 11.3 a | 10.6 a | 43.8 a | 44.3 a | 15.9 | 10.5 a | 70.9 a | 65.3 a |
| 50% (MDI) | | 8.7 b | 8.3 b | 38.6 b | 37.7 b | 14.8 | 10.6 a | 62.1 b | 56.5 b |
| 25% (SDI) | | 7.8 b | 7.3 b | 33.3 c | 34.9 b | 16.2 | 8.7 b | 57.4 c | 51.0 c |
| Genotypes (G) | | | | | | | | | |
| *B. glabra* var. Sanderiana (BgS) | | 16.6 a | 16.7 a | 41.1 a | 44.0 a | 18.8 a | 11.6 a | 76.5 a | 72.4 a |
| *B. ×buttiana* 'Rosenka' (BxbR) | | 6.1 b | 4.7 b | 40.3 a | 43.2 a | 17.4 a | 12.3 a | 63.8 b | 60.2 b |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Ba) | | 5.1 b | 4.8 b | 34.2 b | 29.6 b | 10.7 b | 5.9 b | 50.1 c | 40.3 c |
| Shapes (S) | | | | | | | | | |
| Pyramid | | 11.6 a | 10.7 a | 51.4 a | 50.8 a | 18.6 a | 10.1 | 81.6 a | 71.6 a |
| Globe | | 6.9 b | 6.8 b | 25.7 b | 27.1 b | 12.7 b | 9.8 | 45.3 b | 43.7 b |
| I × G | | | | | | | | | |
| 100 | BgS | 19.0 | 19.5 | 47.4 a | 47.8 a | 21.1 a | 12.0 ab | 87.6 a | 79.4 |
| | BxbR | 7.4 | 5.2 | 40.5 ab | 44.8 ab | 17.6 bc | 14.8 a | 65.4 bc | 64.8 |
| | Ba | 7.5 | 7.1 | 43.4 ab | 40.2 ab | 9.0 d | 4.6 e | 59.8 bc | 51.9 |
| 50 | BgS | 16.0 | 16.2 | 39.4 ab | 41.2 ab | 16.7 bc | 13.8 ab | 72.0 b | 71.3 |
| | BxbR | 6.1 | 4.7 | 41.3 ab | 44.3 ab | 16.8 bc | 11.5 ab | 64.3 bc | 60.5 |
| | Ba | 4.0 | 4.0 | 35.3 ab | 27.4 bc | 10.9 c | 6.4 d | 50.1 c | 37.8 |
| 25 | BgS | 14.7 | 14.5 | 36.7 ab | 43.0 ab | 18.6 b | 9.0 cd | 70.0 b | 66.5 |
| | BxbR | 4.8 | 4.3 | 39.2 ab | 40.4 ab | 17.9 bc | 10.5 bc | 61.8 bc | 55.2 |
| | Ba | 3.9 | 3.3 | 24.1 b | 21.2 c | 12.3 c | 6.7 d | 40.3 d | 31.2 |
| I × S | | | | | | | | | |
| 100 | Pyramid | 13.8 | 13.5 | 58.0 | 57.6 | 19.1 | 10.9 | 90.9 | 82.0 |
| | Globe | 8.8 | 7.7 | 29.5 | 30.9 | 12.7 | 10.0 | 51.0 | 48.7 |
| 50 | Pyramid | 11.2 | 9.6 | 51.4 | 50.0 | 17.5 | 10.5 | 80.0 | 70.0 |
| | Globe | 6.2 | 7.0 | 25.9 | 25.3 | 12.1 | 10.7 | 44.3 | 43.0 |
| 25 | Pyramid | 9.9 | 9.1 | 44.9 | 44.7 | 19.1 | 8.8 | 73.9 | 62.6 |
| | Globe | 5.6 | 5.6 | 21.8 | 25.1 | 13.4 | 8.7 | 40.8 | 39.3 |
| G × S | | | | | | | | | |
| *B. glabra* var. Sanderiana | Pyramid | 23.9 a | 23.6 a | 54.5 | 57.3 a | 26.5 a | 13.4 ab | 104.9 a | 94.2 a |
| | Globe | 9.2 b | 9.9 b | 27.8 | 30.8 c | 11.1 d | 9.8 c | 48.1 d | 50.5 c |
| *B. ×buttiana* 'Rosenka' | Pyramid | 7.3 c | 5.1 cd | 52.1 | 56.6 a | 19.4 b | 13.6 a | 78.8 b | 75.3 b |
| | Globe | 4.8 d | 4.3 cd | 28.6 | 29.8 c | 15.4 c | 10.9 bc | 48.8 d | 45.0 c |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) | Pyramid | 3.6 d | 3.4 d | 47.8 | 38.4 b | 9.7 d | 3.2 d | 61.1 c | 45.1 c |
| | Globe | 6.6 c | 6.1 c | 20.8 | 20.8 d | 11.7 d | 8.6 c | 39.1 e | 35.5 d |

[z]DAT = days after transplanting.
Different letters indicate significant differences according to Duncan test ($P < 0.05$).
C = control; MDI = moderate deficit irrigation; SDI = severe deficit irrigation.

samples and the pressure potential ($\Psi_p$) was estimated as the difference between $\Psi_w$ and $\Psi_\pi$ assuming a matric potential equal to 0.

At 160 and 225 DAT, four plants per plot were sampled and separated into leaves, stems, and flowers, and their tissues were dried to constant weight in a forced-air oven at 80 °C for 72 h for biomass determination. Shoot biomass was equal to the sum of aerial vegetative plant parts (leaves + stems). Leaf area was measured with an electronic area meter (LI-COR 3000, Lincoln, NE). The number of leaves was measured and the number of flowers per plant was also recorded. Flower index was calculated as the ratio of the number of flowers to the total leaf area. Biomass WUE was also calculated as the shoot dry biomass measured at the end of the trial (225 DAT) divided by the evapotranspiration losses.

The dried leaf tissue were ground separately in a Wiley mill to pass through a 20-mesh screen; then 0.5 g of the dried plant tissues was analyzed for the following macronutrients: N, P, and K. Nitrogen concentration in the leaf tissue was determined after mineralization with sulfuric acid by the "Kjeldahl method" (Bremner, 1965). P and K concentrations were extracted by nitropercloric digestion and were analyzed by atomic absorption spectrophotometry according to the method described by Walinga et al. (1995).

*Statistical analysis.* All data were statistically analyzed by three-way analysis of variance (ANOVA) using the SPSS software package (SPSS 13.0 for Windows; SPSS Inc., Chicago, IL). Whenever the two-way interaction was significant, a one-way ANOVA was performed. Duncan's multiple-range test was performed at $P < 0.05$ on each of the significant variables measured. Linear regression analysis was conducted to identify relationships between stomatal resistance and leaf water potential using the GraphPad Prism Package (GraphPad Prism Software Inc., 1999). Differences between the slopes of linear regressions were examined by testing the homogeneity of regression coefficients (Gomez and Gomez, 1983).

## Results

*Plant growth and ornamental value.* Stem, flower, and total dry biomass were significantly affected by irrigation level (I) × genotype (G) interaction at 160 DAT, whereas only stem and flower biomass were significantly influenced at 225 DAT (Table 1). At both sampling dates, the leaf, flower, and total dry biomass were significantly influenced by G × shape (S) interaction (Table 1). The total dry biomass at the end of the growing cycle (225 DAT) decreased linearly in response to an increase in water stress with the lowest values recorded in the SDI treatment, having 25% of the control irrigation water (Tables 1 and 2). Irrespective of the shape treatment (I × G interaction), the percentage of total dry biomass reduction at 160 DAT caused by irrigation level was lower in *B. ×buttiana* 'Rosenka' (by 1.7% and 5.5% for MDI and SDI, respectively) compared with those recorded in *B. glabra* var. Sanderiana (by 18% and 20% for MDI and SDI, respectively) and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (by 16% and 33% for MDI and SDI, respectively) (Table 2). Moreover, the flower biomass at 160 DAT decreased significantly under MDI and SDI in *B. glabra* var. Sanderiana (by 21% and 12%, respectively), whereas the flower biomass in *B. ×buttiana* 'Rosenka' and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) remained unchanged or significantly increased (by 21% and 37% under MDI and SDI treatments, respectively) (Table 2). When averaged overall irrigation treatments (G × S interaction), the total dry biomass recorded in the three genotypes at 160 and 225 DAT was significantly lower in the globe when compared with the pyramid

Table 3. Effects of irrigation treatments, genotypes, and shapes on number of leaves, total leaf area, number of flowers, and flower density of potted *Bougainvillea* plants.

| | | Leaves (no./plant) | | Total leaf area (cm²/plant) | | Flower (no./plant) | | Flower index (no. dm⁻² LA) | |
|---|---|---|---|---|---|---|---|---|---|
| Treatments | | 160 DAT[z] | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT | 160 DAT | 225 DAT |
| Irrigation (I) | | | | | | | | | |
| 100% (C) | | 157.9 a | 144.1 a | 772.9 a | 660.5 a | 78.0 c | 67.6 b | 11.3 c | 11.4 b |
| 50% (MDI) | | 123.9 b | 111.7 b | 558.0 b | 501.9 b | 96.2 b | 77.9 a | 18.5 b | 16.2 a |
| 25% (SDI) | | 107.4 c | 105.3 c | 475.4 c | 437.9 c | 99.1 a | 80.4 a | 22.0 a | 19.0 a |
| Genotypes (G) | | | | | | | | | |
| *B. glabra* var. Sanderiana (BgS) | | 236.8 a | 239.4 a | 865.4 a | 854.5 a | 108.1 b | 104.6 a | 14.3 b | 13.5 b |
| *B.* ×*buttiana* 'Rosenka' (BxbR) | | 92.2 b | 73.9 b | 508.2 b | 428.5 b | 123.4 a | 92.9 b | 26.6 a | 22.5 a |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Ba) | | 60.3 c | 47.8 c | 432.8 c | 317.2 c | 41.7 c | 28.4 c | 10.9 c | 10.6 b |
| Shapes (S) | | | | | | | | | |
| Pyramid | | 139.7 a | 121.7 | 685.5 a | 571.1 a | 95.0 a | 77.7 | 15.3 b | 15.0 |
| Globe | | 119.8 b | 119.0 | 518.8 b | 495.7 b | 87.2 b | 72.0 | 19.3 a | 16.1 |
| I × G | | | | | | | | | |
| 100 | BgS | 292.5 a | 284.7 | 1132.1 a | 1086.0 a | 89.7 d | 90.0 | 8.4 e | 9.4 |
| | BxbR | 101.0 d | 79.5 | 594.7 bcd | 467.0 c | 100.5 cd | 89.0 | 17.9 bc | 19.4 |
| | Ba | 80.3 d | 68.2 | 592.0 bcd | 428.5 c | 43.8 e | 23.7 | 7.7 e | 5.4 |
| 50 | BgS | 222.7 b | 224.2 | 798.8 b | 794.3 b | 108.8 bc | 113.2 | 14.2 cd | 14.9 |
| | BxbR | 94.2 d | 68.8 | 498.2 cde | 404.0 cd | 135.2 a | 89.7 | 29.2 a | 22.8 |
| | Ba | 55.0 e | 42.2 | 377.1 de | 307.5 cd | 44.7 e | 31.0 | 12.2 cd | 10.9 |
| 25 | BgS | 195.3 c | 209.3 | 665.3 bc | 683.3 b | 125.8 ab | 110.7 | 20.4 b | 16.3 |
| | BxbR | 81.5 d | 73.5 | 431.7 cde | 414.6 cd | 134.7 a | 100.0 | 32.7 a | 25.3 |
| | Ba | 45.5 e | 33.0 | 329.3 e | 215.7 d | 36.7 e | 30.7 | 12.8 cd | 15.6 |
| I × S | | | | | | | | | |
| 100 | Pyramid | 169.4 | 157.7 | 880.7 | 772.8 a | 79.3 | 64.3 b | 9.6 | 9.1 |
| | Globe | 146.4 | 130.6 | 665.1 | 548.2 ab | 76.7 | 70.8 ab | 13.0 | 13.7 |
| 50 | Pyramid | 135.2 | 107.8 | 639.0 | 502.9 ab | 99.1 | 79.2 ab | 15.7 | 15.7 |
| | Globe | 112.7 | 115.7 | 477.0 | 500.9 ab | 93.3 | 76.7 ab | 21.3 | 16.7 |
| 25 | Pyramid | 114.6 | 99.7 | 536.7 | 437.7 b | 106.6 | 89.4 a | 20.5 | 20.1 |
| | Globe | 100.3 | 110.9 | 414.2 | 438.1 b | 91.6 | 71.4 ab | 23.4 | 17.9 |
| G × S | | | | | | | | | |
| *B. glabra* var. Sanderiana | Pyramid | 239.6 a | 237.8 | 1098.3 a | 994.8 a | 121.3 a | 120.4 a | 12.0 cd | 14.0 |
| | Globe | 234.1 a | 241.0 | 632.5 b | 714.3 b | 94.9 b | 88.8 b | 16.7 bc | 12.9 |
| *B.* ×*buttiana* 'Rosenka' | Pyramid | 112.4 b | 79.1 | 618.7 b | 473.2 c | 126.3 a | 91.6 b | 21.5 b | 19.8 |
| | Globe | 72.0 c | 68.8 | 397.6 cd | 383.9 cd | 120.6 a | 94.2 b | 31.7 a | 25.2 |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) | Pyramid | 67.2 c | 48.2 | 339.4 d | 245.4 d | 37.3 c | 21.0 d | 12.4 cd | 11.1 |
| | Globe | 53.3 c | 47.3 | 526.2 bc | 389.0 cd | 46.1 c | 35.9 c | 9.4 d | 10.1 |

[z]DAT = days after transplanting.

Different letters indicate significant differences according to Duncan test ($P < 0.05$).

LA = leaf area; C = control; MDI = moderate deficit irrigation; SDI = severe deficit irrigation.

shape (Table 2). A similar pattern was also observed for the flower biomass, where higher values were recorded in the pyramid form for both *B. glabra* var. Sanderiana (by 138% at 160 DAT and by 36% at 225 DAT) and *B.* ×*buttiana* 'Rosenka' (by 26% at 160 DAT and by 25% at 225 DAT), whereas an opposite trend was observed for *B. 'Lindleyana'* (=*B. 'Aurantiaca'*), where the globe form exhibited higher flower biomass at 225 DAT (by 168%) in comparison with the pyramid shape (Table 2).

The number of leaves, flowers, flower index at 160 DAT, and the total leaf area at 160 and 225 DAT were significantly affected by I × G interaction, whereas the total leaf area and number of flower at 225 DAT were significantly influenced by I × S interaction (Table 1). The number of leaves and flower index at 160 DAT, the total leaf area, and flower number at both sampling dates were highly influenced by G × S interaction (Table 1). The number of leaves per plant and the total leaf area decreased linearly in response to an increase in water stress with the lowest valued recorded in the SDI, whereas an opposite trend was recorded for both number of flowers per plant and the flower index (Tables 1 and 3). At 160 DAT, irrespective of the shape treatment (I × G interaction), the percentage of number of leaves reduction caused by irrigation level was lower in *B.* ×*buttiana* 'Rosenka' (–6.7% and –19.3%) compared with those recorded in *B. glabra* var. Sanderiana (–24% and –33%) and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (–31% and –43%) for MDI and SDI treatments (Table 3). On the contrary, when averaged overall shape treatments, the flower index increased in a response to an increase in water stress with the highest values recorded in *B.* ×*buttiana* 'Rosenka' under both MDI and SDI treatments (Table 3). Irrespective of genotype treatment (I × S interaction), the total leaf area, at 225 DAT, was significantly reduced by 43% in pyramid under SDI conditions, whereas no significant decrease was observed in the globe shape (Table 3). When averaged over irrigation treatment (G × S interaction), the highest total leaf area was recorded at both sampling dates in the pyramid shape of *B. glabra* var. Sanderiana, whereas the lowest values were observed in the pyramid shape of *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Table 3). Finally, at 160 DAT, the flower index recorded in *B.* ×*buttiana* 'Rosenka' was significantly higher by 48% in globe when compared with pyramid shape (Table 3).

*Water requirement and water use efficiency.* Irrespective of genotype and shapes, the seasonal water requirement decreased with increasing water deficit. When averaged overall treatments, the reduction in water use in plants at MDI and SDI treatments was 40% (average 38.9 L/plant) and 48% (average 33.7 L/plant), respectively, compared with the control (average 65.0 L/plant). Moreover, the biomass WUE was significantly affected by the I × G and G × S interactions (data not shown). The biomass WUE expressed on a dry weight basis increased with increasing water stress with the highest values recorded in both genotypes *B. glabra* var. Sanderiana and *B.* ×*buttiana* 'Rosenka' grown under MDI (average 1.43 and 1.25 $g \cdot L^{-1}$, respectively, data not shown) and especially with SDI (average 1.68 and 1.36 $g \cdot L^{-1}$, respectively, data not shown), whereas no significant differences among irrigation levels were observed in *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (average 0.75 $g \cdot L^{-1}$; Fig. 1). When averaged over irrigation rate (G × S interaction), the highest WUE was recorded in pyramid *B. glabra* var. Sanderiana (average 1.83 $g \cdot L^{-1}$) followed by pyramid *B.* ×*buttiana* 'Rosenka' (average 1.42 $g \cdot L^{-1}$), whereas the lowest values were recorded in globe *B. 'Lindleyana'*

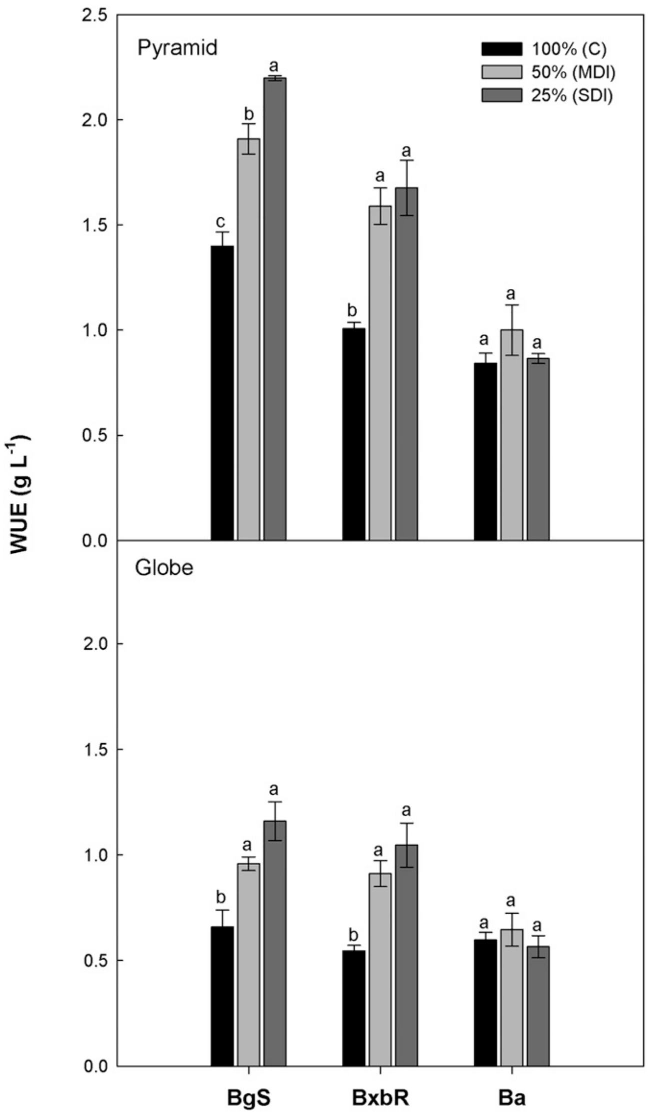


Fig. 1. Effect of deficit irrigation based on different levels of water recovery: 100% [control (C)], 50% (MDI), and 25% (SDI) on the dry biomass water use efficiency (WUE) of three potted *Bougainvillea* genotypes [*B. glabra* var. Sanderiana-BgS, *B.* ×*buttiana* 'Rosenka'-BxbR, *B. 'Lindleyana'* (=*B. 'Aurantiaca'*)-Ba] grown in two shapes, pyramid and globe. Different letters indicate significant differences according to Duncan test ($P < 0.05$).

(=*B. 'Aurantiaca'*) (average 0.60 $g{\cdot}L^{-1}$, data not shown).

*Leaf mineral composition.* The macroelements concentration in *Bougainvillea* leaves as a function of irrigation level, genotype, and shape is displayed in Table 4. When averaged over genotypes and shapes, the concentration of N and P decreased quadratically, whereas the concentration of K decreased linearly in response to an increase in water stress (Table 5). The results also indicate that the concentration of N and P in leaves was significantly higher, by 4% and 11%, respectively, in globe than in pyramid plants (Table 4). Irrespective of the shape treatment (I × G interaction), the lowest P content was recorded under SDI in *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Table 4).

*Stomatal resistance and water relations.* The stomatal resistance increased linearly as the water stress increased (Table 5). The highest values of stomatal resistance were recorded in pyramid *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Table 6). $\Psi_w$ and $\Psi_\pi$ decreased linearly in response to an increase in water stress with the lowest values recorded at SDI treatment (Tables 5 and 6). When averaged over irrigation treatment (G × S interaction), the lowest values of $\Psi_w$ and $\Psi_\pi$ were recorded on *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) grown in a globe shape. Irrespective of *Bougainvillea* genotypes, the highest $\Psi_P$ values were recorded in the pyramid shape at 100% of water use (Table 6). A linear regression analysis showed a significant difference in stomatal resistance (y) as a function of leaf water potential (x) between globe and pyramid shapes for *B. glabra* var. Sanderiana and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*), whereas a similar relationship was recorded between the two shapes for *B.* ×*buttiana* 'Rosenka' (Table 7).

## Discussion

It is well established that crop growth decreases with water limitation, although the exact effect may vary depending on the intensity of the water stress imposed (Cameron et al., 1999, 2006). Deficit irrigation reduced the morphological parameters such as shoot, flower, total biomass, leaf number, and total leaf area (Tables 2 and 3), which may be an adaptive role, restricting the evaporative surface area (Sharp, 1996). Our results are in agreement with many ornamentals studies on *Cistus albidus* and *Cistus monspeliensis* (Sánchez-Blanco et al., 2002), *Nerium oleander,* and *Lotus creticus* (Bãnón et al., 2004, 2006); *Dianthus* (Álvarez et al., 2009); *Callistemon citrinus* (Álvarez and Sánchez-Blanco, 2013; Mugnai et al., 2009); and *Pelargonium ×hortorum* (Álvarez et al., 2013). The different water stress levels (MDI and SDI) applied in our experiment induced different growth responses in *Bougainvillea* genotypes with a reduction of the total biomass (at 225 DAT) by 13.4% and 21.9% under MDI and SDI, respectively, in comparison with the control, meaning that the severity of the water stress should be considered an important factor, when used as an irrigation strategy for saving water. These results are consistent with the findings of Álvarez et al. (2009) who observed a reduction in the shoot dry weight of potted carnation plants by 19.3% and 33.4% under MDI (receiving 70% of the control) and SDI (receiving 35% of the control), respectively. Similarly, Álvarez et al. (2013) and Sánchez-Blanco et al. (2009) reported a decrease in growth and biomass traits in potted geranium when exposed to different water regimes during different phenological stages.

The application of MDI and SDI reduces growth in *Bougainvillea*. However, ornamental plants subjected to water limitation may delay flowering and reduce the flowering intensity (Álvarez et al., 2012, 2013; Bernal et al., 2011; Cuevas et al., 2009). In the current study, the number of flower per plant and the flower index were significantly higher under both deficit irrigation treatments compared with fully irrigated plants (Table 3). Our results are consistent with the findings of Cameron et al. (1999), who observed that the highest number of flowers per plant in *Rhododendron* occurred after a moderate drought. In contrast, Álvarez et al. (2009), Álvarez and Sánchez-Blanco (2013), and Sánchez-Blanco et al. (2009) have reported that MDI did not reduce the number of flower in *Dianthus*, *Callistemon citrinus,* and potted geranium, whereas the plant quality was negatively affected (e.g., lower number of flowers) by the SDI treatment. Explanations for this disagreement could be related to the period of exposure, the intensity of water stress, and the variations between species in their sensitivity to drought. Therefore, the use of DI in *Bougainvillea* could be a potential strategy to cope with water shortage without losing the ornamental value.

Significant differences emerged in the plant growth parameters (leaf number, total leaf area, and dry biomass) of the tested genotypes and shapes (Tables 2 and 3). Leaf number, total leaf area, and dry weight were all reduced by drought in all genotypes but the reduction was much more pronounced in *B. 'Lindleyana'* (=*B. 'Aurantiaca')* when compared with *B. glabra* var. Sanderiana and especially *B.* ×*buttiana* 'Rosenka'. Similarly, the highest ornamental quality parameters (number of flowers and flower index) at 160 DAT were recorded in *B.* ×*buttiana* 'Rosenka' followed by *B. glabra* var. Sanderiana, whereas flower index increased, especially with the globe shape. The marked differences found between *B. glabra* var. Sanderiana or *B.* ×*buttiana* 'Rosenka' and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) suggest the possibility of exploiting this kind of variability in breeding programs with the aim of selecting genotypes that can better withstand water stress. The higher flower index recorded in the globe than in the pyramid shape could be related to the frequent pruning, which was responsible for the increase in flowers per unit of leaf area.

In general, ornamental species respond to water stress by reducing the daily ET (Jaleel et al., 2008; Lenzi et al., 2009) and the ET decreases as the water stress severity increases (e.g., SDI treatment), even if the intensity of this response depends on the species/variety (Lenzi et al., 2009). The reduction in water use in plants at MDI and SDI treatments was 40% and 48%, respectively, compared with the control treatment. The reduction in water use under deficit irrigation treatments has been attributed to the reduction in total leaf area (Table 3; Atkinson and Crisp, 1983) and to a higher stomatal resistance (Table 6; Bolla et al., 2010). In this study, we found that the relationship between water use and dry biomass (WUE) was modified by water supply, genotypes, and shapes. When averaged among treatments, the highest WUE was recorded in pyramid (average 1.6 $g \cdot L^{-1}$) when compared with globe (average 1.0 $g \cdot L^{-1}$) shape as a result of the frequent shoot trimming applied during the growing cycle. Moreover, WUE increased under MDI and SDI in both *B. glabra* var. Sanderiana and *B.* ×*buttiana* 'Rosenka', whereas the WUE remained unchanged in *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Fig. 1). Increased WUE values under water stress conditions were also found in several ornamental plants (Álvarez et al., 2009; Álvarez and Sánchez-Blanco, 2013; Cameron et al., 2006; Jaleel et al., 2008). Cameron et al. (2006) reported that the WUE increased between 5% and 33% in the woody ornamental tested species (*Choisya*, *Cornus*, *Forsythis*, *Lavandula*, and *Lonicera*). However, according to other authors, the WUE was not modified under water stress conditions (Andersson, 2001) or even decreases (Anyia and Herzog, 2004; Eiasu et al., 2012), depending on the species, genotype, water stress level, and duration (Cameron et al., 2006, and references cited therein).

The low macronutrient concentration (N, P, and K) recorded in the current study under SDI could be attributed to a decrease in soil moisture content in the root zone (Table 4). Our results are in agreement with those of

Table 4. Effects of irrigation treatments, genotypes, and shapes on leaf mineral composition of potted *Bougainvillea* plants.

| Treatments | | N ($g \cdot kg^{-1}$ DW) | P ($g \cdot kg^{-1}$ DW) | K ($g \cdot kg^{-1}$ DW) |
|---|---|---|---|---|
| Irrigation (I) | | | | |
| 100% (C) | | 24.25 a | 11.95 a | 31.82 a |
| 50% (MDI) | | 23.31 a | 11.42 a | 28.80 b |
| 25% (SDI) | | 21.21 b | 9.32 b | 22.04 c |
| Genotypes (G) | | | | |
| *B. glabra* var. Sanderiana (BgS) | | 22.38 b | 11.43 | 28.50 |
| *B.* ×*buttiana* 'Rosenka' (BxbR) | | 23.76 a | 10.32 | 27.37 |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Ba) | | 22.63 b | 10.93 | 26.97 |
| Shapes (S) | | | | |
| Pyramid | | 22.47 b | 10.11 b | 27.61 |
| Globe | | 23.37 a | 11.27 a | 27.49 |
| I × G | | | | |
| 100 | BgS | 23.7 | 12.1 ab | 33.9 |
| | BxbR | 25.0 | 11.1 ab | 32.0 |
| | Ba | 24.0 | 12.6 a | 30.4 |
| 50 | BgS | 22.7 | 11.5 ab | 32.5 |
| | BxbR | 23.9 | 10.0 b | 24.7 |
| | Ba | 23.3 | 12.8 a | 25.1 |
| 25 | BgS | 20.7 | 10.6 ab | 19.2 |
| | BxbR | 22.3 | 10.1 b | 24.0 |
| | Ba | 20.5 | 7.3 c | 23.1 |
| I × S | | | | |
| 100 | Pyramid | 24.2 | 11.0 | 33.3 |
| | Globe | 24.3 | 12.9 | 31.3 |
| 50 | Pyramid | 23.3 | 11.2 | 26.8 |
| | Globe | 23.3 | 11.7 | 28.7 |
| 25 | Pyramid | 19.9 | 9.6 | 22.4 |
| | Globe | 22.5 | 10.2 | 21.5 |
| G × S | | | | |
| *B. glabra* var. Sanderiana | Pyramid | 21.4 | 10.4 | 28.2 |
| | Globe | 23.4 | 12.6 | 28.9 |
| *B.* ×*buttiana* 'Rosenka' | Pyramid | 23.7 | 10.1 | 23.2 |
| | Globe | 23.8 | 10.7 | 30.1 |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) | Pyramid | 22.3 | 10.4 | 31.3 |
| | Globe | 23.0 | 11.9 | 22.7 |

[z]DAT = days after transplanting.
Different letters indicate significant differences according to Duncan test ($P < 0.05$).
N = nitrogen; DW = dry weight; P = phosphorus; K = potassium; C = control; MDI = moderate deficit irrigation; SDI = severe deficit irrigation.

Table 5. Analysis of variance for irrigation treatments, genotypes, and shapes on leaf mineral composition, stomatal resistance ($r_s$), leaf water potential ($\Psi_w$), leaf osmotic potential ($\Psi_\pi$), and leaf turgor potential ($\Psi_P$), of potted *Bougainvillea* plants.

| Source of variance | N ($g \cdot kg^{-1}$ DW) | P ($g \cdot kg^{-1}$ DW) | K ($g \cdot kg^{-1}$ DW) | $r_s$ ($s \cdot cm^{-1}$) | $\Psi_w$ (MPa) | $\Psi_\pi$ (MPa) | $\Psi_p$ (MPa) |
|---|---|---|---|---|---|---|---|
| | | | | Significance[y] | | | |
| Irrigation (I) | Q***[z] $R^2 = 0.98$[y] $P \leq 0.000$[x] | Q*** $R^2 = 0.73$ $P \leq 0.020$ | L*** $R^2 = 0.76$ $P \leq 0.002$ | L*** $R^2 = 0.91$ $P \leq 0.000$ | L*** $R^2 = 0.98$ $P \leq 0.000$ | L*** $R^2 = 0.98$ $P \leq 0.000$ | NS |
| Genotypes (G) | * | NS | NS | ** | *** | *** | NS |
| Shape (S) | * | ** | NS | ** | *** | *** | NS |
| I × G | NS | *** | NS | NS | NS | NS | NS |
| I × S | NS | NS | NS | NS | NS | NS | * |
| G × S | NS | NS | NS | *** | *** | *** | NS |
| I × G × S | NS | NS | NS | NS | NS | NS | NS |

[z]L = linear; Q = quadratic.
[y]$R^2$ = coefficient of determination
[x]*P* values indicate the level of significance.
N = nitrogen; DW = dry weight; P = phosphorus; K = potassium.
NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 6. Effects of irrigation treatments, genotypes, and shapes on stomatal resistance ($r_s$), leaf water potential ($\Psi_w$), leaf osmotic potential ($\Psi_\pi$), and leaf turgor potential ($\Psi_P$), of potted *Bougainvillea* plants.

| Treatments | | $r_s$ (s·cm$^{-1}$) | $\Psi_w$ (MPa) | $\Psi_\pi$ (MPa) | $\Psi_p$ (MPa) |
|---|---|---|---|---|---|
| Irrigation (I) | | | | | |
| 100% (C) | | 0.861 c | –1.121 c | –1.416 c | 0.296 |
| 50% (MDI) | | 1.695 b | –1.498 b | –1.787 b | 0.290 |
| 25% (SDI) | | 2.129 a | –1.807 a | –2.084 a | 0.268 |
| Genotypes (G) | | | | | |
| *B. glabra* var. Sanderiana (BgS) | | 1.426 b | –1.242 b | –1.532 c | 0.290 |
| *B. ×buttiana* 'Rosenka' (BxbR) | | 1.489 b | –1.527 a | –1.809 b | 0.282 |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) (Ba) | | 1.771 a | –1.657 a | –1.946 a | 0.292 |
| Shapes (S) | | | | | |
| Pyramid | | 1.680 a | –1.339 b | –1.636 b | 0.299 |
| Globe | | 1.443 b | –1.612 a | –1.889 a | 0.277 |
| I × G | | | | | |
| 100 | BgS | 0.795 | –1.037 | –1.332 | 0.295 |
| | BxbR | 0.873 | –1.138 | –1.438 | 0.300 |
| | Ba | 0.913 | –1.188 | –1.478 | 0.292 |
| 50 | BgS | 1.618 | –1.217 | –1.517 | 0.300 |
| | BxbR | 1.642 | –1.562 | –1.835 | 0.273 |
| | Ba | 1.825 | –1.717 | –2.010 | 0.297 |
| 25 | BgS | 1.863 | –1.473 | –1.748 | 0.275 |
| | BxbR | 1.952 | –1.882 | –2.153 | 0.272 |
| | Ba | 2.573 | –2.065 | –2.350 | 0.288 |
| I × S | | | | | |
| 100 | Pyramid | 0.909 | –0.972 | –1.296 | 0.324 a |
| | Globe | 0.812 | –1.270 | –1.537 | 0.267 bc |
| 50 | Pyramid | 1.928 | –1.414 | –1.727 | 0.314 ab |
| | Globe | 1.462 | –1.582 | –1.848 | 0.266 bc |
| 25 | Pyramid | 2.204 | –1.630 | –1.886 | 0.258 c |
| | Globe | 2.054 | –1.983 | –2.282 | 0.299 ab |
| G × S | | | | | |
| *B. glabra* var. Sanderiana | Pyramid | 1.424 b | –0.906 c | –1.230 c | 0.324 |
| | Globe | 1.427 b | –1.579 b | –1.834 b | 0.256 |
| *B. ×buttiana* 'Rosenka' | Pyramid | 1.494 b | –1.527 b | –1.797 b | 0.270 |
| | Globe | 1.483 b | –1.528 b | –1.821 b | 0.293 |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) | Pyramid | 2.122 a | –1.584 b | –1.881 b | 0.302 |
| | Globe | 1.419 b | –1.729 a | –2.011 a | 0.282 |

[z]DAT = days after transplanting.
Different letters indicate significant differences according to Duncan test ($P < 0.05$).
C = control; MDI = moderate deficit irrigation; SDI = severe deficit irrigation.

Table 7. Fitted constant (a) and coefficient (b) of the linear regression (y = a + bx) between the stomatal resistance ($r_s$) and leaf water potential ($\Psi_w$) of the three *Bougainvillea* genotypes grown in two shapes and subjected to control and deficit irrigation treatments.

| Genotypes | Shapes | Fitted constant (a) and coefficient (b) | | |
|---|---|---|---|---|
| | | a (± SE)[z] | b (± SE) | $R^{2y}$ |
| *B. glabra* var. Sanderiana | | | | |
| | Pyramid | –1.976 (0.745) | –3.703 (0.815) | 0.838** |
| | Globe | –0.289 (0.562) | –1.018 (0.378) | 0.644* |
| *B. ×buttiana* 'Rosenka' | | | | |
| | Pyramid | 0.042 (0.241) | –0.931 (0.167) | 0.886** |
| | Globe | 0.222 (0.483) | –0.914 (0.378) NS | 0.594* |
| *B. 'Lindleyana'* (=*B. 'Aurantiaca'*) | | | | |
| | Pyramid | 0.125 (0.259) | –1.334 (0.207) | 0.889** |
| | Globe | 0.375 (0.482) | –0.700 (0.353) * | 0.496 NS |

[z]SEs in parentheses.
[y]$R^2$ = coefficient of determination.
NS, *, **Nonsignificant or significant at $P < 0.05$, and 0.01, respectively.

Rouphael et al. (2012) who reported for several vegetable crops that drought has a wider role in reducing leaf macronutrient concentrations. The reduction in plant growth parameters recorded in SDI could be attributed to the lower nutritional status. This reduction in macronutrient uptake may be the result of their less solubility that results in altered physiological processes including low absorption and translocation of nutrients in plants under water limitation (Garg, 2003). Moreover, the lowest nutrient uptake recorded in SDI could be attributed to a decrease in transpiration rate and reduced active transport (Baligar et al., 2001; Gunes et al., 2006). However, in a number of reports, it has been observed that under water deficit conditions, plant species and genotypes within a species differ in absorbing nutrients from soil/substrate and transporting them to roots and then from roots to shoot (Ali et al., 2008, and references cited therein). This was the case in the current study, because the lowest reduction in nutrient uptake was observed in *B. ×buttiana* 'Rosenka'. Moreover, the globe *Bougainvillea* showed a high capacity for N and P assimilation with respect to the pyramid ones (Table 4), suggesting that frequent pruning might be responsible for increasing N and P concentration in leaf tissue.

SDI significantly reduced plant growth parameters of the three *Bougainvillea* genotypes. These reductions were associated with changes in various parameters of leaf water status and stomatal resistance (Table 6). In the present study, a number of tolerance and avoidance mechanisms such as increase in stomatal resistance, decrease in leaf water potential, and decrease in leaf $\psi_S$ have been observed, especially under SDI. The decrease of soil water moisture in the root zone can lead to an osmotic adjustment (lowering of leaf $\psi_\pi$) that is generally considered as an adaptation mechanism to water stress. The decrease of $\psi_\pi$ would compensate for the drought-induced lowering of $\psi_w$, helping to maintain turgor pressure under water stress conditions (Table 6). Finally, the slopes of the linear regression lines relating stomatal resistance to leaf water potential could be used as indices of sensitivity to water stress for the two *Bougainvillea* shapes (pyramid vs. globe). In fact, our results suggest that the mechanism of stomatal closure to a decreasing leaf water potential appeared to occur more markedly (higher slope) in pyramid than in globe shape for both *B. glabra* var. Sanderiana and *B. 'Lindleyana'* (=*B. 'Aurantiaca'*), indicating that a higher increase in stomatal resistance will occur even if the leaf water potential will decrease slightly (Table 7).

## Conclusions

It can be concluded that irrespective of genotypes and shapes, the water deficit decreased the plant growth parameters, adversely affected leaf mineral composition and water status, but improved number of flowers and flower index. Reductions of 75% of the water applied (SDI) significantly reduced growth of potted *Bougainvillea* but increased the WUE, whereas MDI (reductions of 50%) decreased slightly the agronomical traits but improved the ornamental quality and the WUE, indicating that *Bougainvillea* could be considered a tolerant ornamental species. The MDI treatment can be used successfully in *Bougainvillea* to reduce water consumption while improving the overall quality. The results also indicated that the agronomical traits and WUE of *Bougainvillea* appear to be strongly influenced by genetic factors and shape, suggesting that specific cultivars (e.g., *B. glabra* var. Sanderiana and *B. ×buttiana* 'Rosenka') and shapes (pyramid: higher WUE) could be selected as interesting genotypes and training system for ornamental and landscaping purposes under moderate and severe water deficit conditions.

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