The effect of reducing production water availability on the post-production quality of potted miniature roses

(\textit{Rosa \times hybrida})

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Abstract

Water deficit is a major problem during the post-production life of potted plants. This study evaluates the effect of reducing water availability on the quality of rose plants and if it is possible to acclimatise rose plants to subsequent water deficit conditions. Two cultivars of potted miniature roses (Charming and Bianca Parade*) were produced under four water availability treatments. Control plants were watered so that water availability equalled evaporational loss. The cyclic water deficit treatment consisted of three 10 day cycles, each cycle included 4–5 days without water followed by a recovery phase during which the plants were watered as for the controls. There were two long term steady state water deficit treatments at approximately 60 and 75% of the control water availability. At flowering the plants were transferred to an evaluation room, half were watered adequately and the remaining plants were wilted and then watered adequately. Plant performance was evaluated over a 25 day period. The response of plants to both production and post-production water availability was cultivar-dependent. Plants grown with cyclic water availability tolerated subsequent water stress better than plants produced with a constant supply of water, irrespective of whether the constant supply of water was adequate or not. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Reducing water availability affects many physiological processes (Oliver and Bewley, 1997). The ability of a plant to cope with reduced water may be modified by exposure to stressful conditions during production (Clemens and Jones 1978; Kramer 1983). Conditioning is recommended in the production of bedding plants (Armitage, 1981; Armitage and Kowalski, 1983; Eaks et al., 1991) and woody species (Rook, 1973; Edwards and Dixon, 1995a,b) to improve plant survival following transplanting. Potted miniature roses do not normally experience transplanting shock. However, they experience stress due to large differences in irradiance and water availability between
the production and post-production phases. Production conditions are frequently chosen to maximise growth in a minimum period of time (Armitage and Tsujita, 1979). During production plants are watered ‘optimally’, yet during post-production they often wilt due to limited water within the pot and the high water consumption by flowering plants (Williams et al., 1999). Potted miniature roses are produced with a 20 h day at a photosynthetic photon flux density (PPFD) of approximately 120 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) supplementary light. In contrast, plants experience darkness for a transport period of 4–7 days (Borch et al., 1995). Interior conditions, representative of those in the home of a consumer, are accepted as about 8 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) for approximately 12 h each day (Nell and Høyer, 1995). Currently there is no information available on acclimatising potted flowering plants to cope with these differences.

Potted miniature roses produced with restricted water supply have reduced water consumption, function at a lower water content and are more efficient in dry matter accumulation per volume of water consumed than control plants (Williams et al., 1999). Water availability during production also affects photosynthesis through stomatal regulation (Williams et al., 1999). It is unknown if the daily carbon gained through photosynthesis or mobilization of starch is the primary carbon source for development and quality of buds and flowers. It would be of value to determine if reduced water availability during production gives any long term effect on the potential for carbon gain and how the plant is able to photosynthesise under the low light in post-production conditions. Whilst there appear to be several significant benefits in reducing water availability during production gives any long term effect on the potential for carbon gain and how the plant is able to photosynthesise under the low light in post-production conditions. There are at least several significant benefits in reducing water availability during production gives any long term effect on the potential for carbon gain and how the plant is able to photosynthesise under the low light in post-production conditions.

In this study, two rose cultivars were chosen based on their economic importance and post-production performance: Bianca Parade® has a relatively poor quality compared to Charming Parade®. In this study we report on how reduced water availability during production influences plant quality. We also evaluate if it is possible to condition rose plants during production to improve post-production drought tolerance.

2. Materials and methods

2.1. Plant material

Potted miniature rose plants (\textit{Rosa x hybrida} cv. Poulhappy, Charming Parade® and cv. Poulbian, Bianca Parade®) were grown in peat:perlite with four cuttings per 10.5 cm pot. The plants were cut back twice during production and following the second cut, the plants were randomly placed into four blocks at a spacing of 30 plants per m². Williams et al. (1999) described the production conditions for light, temperature and humidity.

2.2. Water deficit treatments during production

The production treatments were carried out from 5 days after second cut to flowering (a 38 day period). There were 40 plant replicates for each of the four production water availability treatments and for each of the two cultivars. Of these 40 plants, ten were randomly chosen and weighed at 24 h intervals to determine mean gravimetric water consumption per treatment per cultivar and these plants were not subsequently used for other evaluations.

Control plants were top-watered daily with a volume of nutrient solution equal to 100% evapotranspiration. The nutrient solution contained (mM): N, 15.7; P, 1.1; K, 5.0; Ca, 3.7; Mg, 1.2 and SO₄, 1.4 at EC 1.5, pH 5.5. The two steady-state water deficit treatments were equal to 75 and 60% of the daily evapotranspiration of control plants. The cyclic water deficit treatment included three stress cycles beginning 10, 20 and 30 days after second cut. Each cycle consisted of a 4–5 day stress phase where the plants were unwatered and a recovery phase where the plants were watered and treated as control plants until the next cycle started. Evaluation of production treatments and plant response to water deficit conditions has been described previously (Williams et al., 1999).

2.3. Post-production water deficit

At flowering, as defined by 3–5 flowers per plant, 24 plants from each of the production
treatments were transferred to an evaluation room at 20 ± 0.2°C, 60% RH and 8 μmol m⁻² s⁻¹ for 12 h per day. The plants were placed in four blocks and within these blocks the plants were randomly allocated to one of two post-production treatments. Control plants were sub-irrigated as necessary with tap water. Plants allocated to the wilting treatment remained unwatered for a period of 3–6 days; the wilting treatment ended on an individual pot basis depending on the time to complete wilting. At wilting each plant was watered and thereafter all plants were watered as necessary.

2.4. Tissue analysis

The youngest fully developed 5-leaflet leaf was removed from four plants per treatment at wilting and, thereafter, at days 11, 14, 18 and 25. The leaves were frozen in liquid nitrogen and stored at −80°C for determination of proline. The frozen plant samples were ground with an Ultraturrax in a 1:10 ratio of tissue to 3% sulfosalicylic acid, extracts were centrifuged at 5000 rpm for 10 min and proline content was determined on the supernatants according to Bates et al. (1973).

At both wilting and at day 11, the first 5-leaflet leaf was removed from each plant. The leaves were weighed and dried at 70°C for 24 h to determine fresh weight to dry weight ratio (FW:DW). Data are presented as means (n = 12) with S.D.s. Pot weight and time to wilting were also recorded.

2.5. Post-production evaluation

Post-production performance was evaluated on an individual pot basis on 12 plants for each of the eight post-production treatments at days 0 (day of transfer to evaluation room), 4, 7, 11, 14, 18, 21 and 25. The total number of flowers (which included fresh, wilted and damaged flowers), number of damaged and wilted flowers (defined by ≥10% damaged petal tissue), number of buds larger than 5 mm and number of yellow and brown buds were recorded. All post-production data were analysed at the individual observation day using the SAS GENMOD procedure (SAS Institute, Cary, NC). Counted responses, such as total number of buds and flowers, were analysed by a Poisson regression model, whereas rates, such as percent damaged and wilted buds and flowers were analysed by a logistic regression model. With this model when the observations fall into one of two categories (responses close to 0 or 100%) then the model reaches its limitations and cannot carry out the statistical analysis. For estimation of both Poisson and logistic regressions a maximum likelihood method was considered. The output gives a predicted mean, and these are presented in the figures. For significance the responses are shown together with likelihood ratio-based 95% confidence intervals.

2.6. Photosynthesis measurements

Measurements were made on eight plants per cultivar from control, 60% water availability and cyclic-treated plants. Half of the plants were watered optimally and half were wilted during the first 3–6 days in the interior room. All plants were evaluated for a 1 week period beginning 1 week after rewatering. Measurements were made on single leaves using an LCA-3 (ADC, Hoddesdon, UK). Irradiance was maintained at 613 ± 15 μmol m⁻² s⁻¹, leaf temperature at 24.8 ± 0.4°C, vapour pressure deficit (VPD) at 0.75 ± 0.16 bar with an ambient CO₂ concentration of 318 ± 11 μl l⁻¹ in the cuvette. Net photosynthesis (Pₙ), transpiration (E), stomatal conductance (gₛ) and intracellular CO₂ concentration (Ci) were measured and the instantaneous transpiration efficiency (ITE) was calculated as ITE = Pₙ/E (von Caemmerer and Farquhar, 1981).

3. Results

The plants which received adequate water during the post-production phase had a FW:DW ratio of approximately 3.5–5 (Fig. 1). The plants which experienced wilting had a FW:DW ratio of approximately 3 at wilting and this increased to 4–5 following recovery. Charming plants produced with 60% water availability maintained a significantly lower FW:DW ratio than control
plants (LSD = 0.258) irrespective of post-production water availability or time of sampling (Fig. 1A). All Bianca plants produced with deficit water availability had a significantly lower FW:DW ratio early in the post-production phase (days 3–6), this difference being no longer significant by day 11 (LSD = 0.258, Fig. 1B).

The mean pot weight at wilting was significantly influenced both by the production water availability (LSD = 3.38) and the cultivar (LSD = 2.35). At wilting Charming plants had a mean pot weight of 123 g for control, 112 g for cyclic, 115 g for 75% and 107 g for 60% water availability. Bianca plants had significantly lower mean pot weights at wilting: 119 g for control, 104 g for cyclic, 111 g for 75% and 100 g for 60% water availability.

Proline increased in response to wilting. Control plants had 0.564 and wilted plants 8.817 μmol proline per g leaf (LSD = 2.98). At wilting there was no significant influence of production water availability or cultivar on proline content. By day 11 there was no difference in proline content between control and wilted plants; the proline content remained less than 1.0 μmol proline per g leaf tissue from days 11–25.

At day 0 control plants had approximately 27 buds per plant, whereas plants produced with reduced water availability had between 13 and 21 buds per plant (Fig. 2A). At each of the evaluation days the production water availability significantly influenced the number of buds per plant (P < 0.001). At day 0 there was no significant effect of production water availability on the number of flowers due to the fact that plants were selected with 3–5 flowers (Fig. 2B). During the 25-day post-production evaluation the control plants opened a maximum number of 15 flowers and deficit-irrigated plants opened between 10 and 13 flowers per plant (Fig. 2B). Control and 60% water availability plants opened significantly more flowers (P < 0.001) than the 75% and cyclic grown plants. If we account for the 3–5 flowers which were open at day 0, we can estimate that 37% of buds on control plants and 40–54% of buds on deficit-irrigated plant will subsequently open.

During post-production the percentage of damaged flowers per plant was significantly influenced by the main factors: cultivar, production and post-production (P < 0.001), with the exception of those days where 0 or 100% damaged flowers were observed. At days 21 and 25 the percentage of damaged flowers per plant was significantly influenced by the three-way interaction between cultivar, production water availability and post-production water availability (P < 0.001). Charming plants which were watered optimally during
Fig. 3. Percentage of damaged and wilted flowers per plant as affected by production and post-production water availability. ▲ Represents control-watered plants, □ 60% water availability, ◊ 75% water availability and ● cyclic treatment. Charming (A) and Bianca Parade® (B) plants that received adequate water during the post-production period. Charming (C) and Bianca Parade® (D) plants that were wilted at flowering and then watered adequately during the post-production period. The data were analysed at the individual observation day using a logistic regression of the SAS GENMOD procedure. A maximum likelihood method was considered and the output gave a predicted mean (n = 12). The significant effects are shown together with likelihood ratio-based 95% confidence intervals.

The post-production phase developed very few damaged and wilted flowers (Fig. 3A). In these plants there was no significant influence of the production water availability on the number of damaged flowers. In Bianca plants the percentage of damaged and wilted flowers per plant increased from day 11 for control plants and from day 14 for deficit-irrigated plants (Fig. 3B). At day 18 the 75% and cyclic-grown Bianca plants had ≤ 30% damaged and wilted flowers, whilst the 60% and control plants had > 40% damaged and wilted flowers. The production water availability significantly influenced the percentage of damaged and wilted flowers (P < 0.001) from days 18–25.

Charming plants that experienced post-production wilting (Fig. 3C) had a higher percentage of damaged flowers than the optimally watered plants (Fig. 3A). Damaged flowers were observed in all plants at day 14. At days 21 and 25, the cyclic-grown Charming plants had a significantly lower percentage of damaged flowers per plant (P < 0.001) compared to plants produced under the other treatments. Bianca plants that experienced wilting (Fig. 3D) had damaged flowers earlier in the post-production period than plants which were watered optimally (Fig. 3B). Bianca plants produced with 75% water availability had damaged flowers from day 4 whereas, damaged flowers were not seen until day 11 in plants produced with cyclic water availability (Fig. 3D). By day 14 all the plants except those produced with the cyclic treatment had approximately 30% damaged and wilted flowers. From days 14 to 21 the cyclic-treated plants maintained the lowest percentage of damaged flowers.

The percentage of damaged buds per plant was significantly influenced by the main factors of cultivar, production and post-production water availability (P < 0.001), with the exception of those days where 0 or 100% damaged buds were observed. If the plants were watered optimally during the post-production period the percentage of damaged buds per plant was not influenced by production water (Fig. 4A and B). Charming plants watered optimally produced less than 30% damaged and wilted flowers (Fig. 3A). In these plants there was no significant influence of the production water availability on the number of damaged flowers.
damaged buds (Fig. 4A). In contrast, Bianca plants had approximately 30% damaged buds by day 18 and this increased to approximately 80% damaged buds by day 25 (Fig. 4B).

The percentage of damaged buds increased following wilting (Fig. 4C and D). At day 18 Charm ing plants produced with 75% water availability had the highest percentage damaged buds and the cyclic-grown plants had the lowest percentage of damaged buds (Fig. 4C). In wilted Bianca plants the percentage damaged buds rapidly increased from day 7, 1 week earlier than in plants which received adequate water (Fig. 4D versus B). By day 11 all Bianca plants, except those produced under the cyclic treatment had more than 60% damaged buds. From days 14–25 Bianca plants produced with cyclic water availability had significantly less damaged buds than that observed in the other plants (Fig. 4D, \( P < 0.001 \)).

There was no significant difference between cultivar or an influence of either the production or post-production water availability on the photosynthetic performance of the plants (data not shown). \( P_n \) was approximately 9 \( \mu \text{mol} \text{ m}^{-2} \text{ s}^{-1} \) for all plants. Control plants had a \( g_s \) of approximately 37 \( \text{mmol} \text{ m}^{-2} \text{ s}^{-1} \) and water deficit-grown plants of 30 \( \text{mmol} \text{ m}^{-2} \text{ s}^{-1} \). \( C_i \) for control plants was about 260 and 250 \( \mu \text{l} \text{l}^{-1} \) for drought-grown plants. ITE was approximately 0.5 \( \text{CO}_2 (1000 \text{H}_2\text{O})^{-1} \) for control plants and 0.6 \( \text{CO}_2 (1000 \text{H}_2\text{O})^{-1} \) for drought-grown plants.

4. Discussion

Rose plants are able to adjust water consumption to utilize water when it becomes available. Control plants had a higher water content and tended to wilt earlier than those plants produced with reduced water availability. Delayed wilting by plants produced with reduced water could be attributed to the smaller leaf area and consequently a lower water consumption per plant (Williams et al., 1999). However, it was likely that reduced transpiration rates due to modified stomatal behaviour contributes to delayed wilting (Edwards and Dixon, 1995a,b). Similarly, maple trees which experienced four stress cycles during production wilted at a lower plant and soil water status than control plants (Zwack et al., 1998). Delayed wilting as observed in rose plants could prove to be advantageous during the post-production phase as the plants would be more likely to survive periods of inadequate water without compromising plant quality.

When rose plants receive adequate water during the post-production phase the effect of reduced production water availability on post-production plant quality is cultivar-dependent. When Charm ing plants were watered optimally in the post-production phase, there was a low percentage of damaged buds and flowers irrespective of water availability during production. In contrast, the quality of Bianca plants was positively influenced by reduced water availability during production. These results indicate that it is possible to produce potted miniature roses with reduced water availability and to maintain or improve the post-production quality.

During the post-production period it is extremely likely that a rose plant will experience water deficit due to the high water consumption and limited supply of water in a small pot (Williams et al., 1999). Roses grown with deficit water opened a larger percentage of their buds and the cyclic-produced plants had less damaged buds and flowers than control plants. Rose plants grown with cyclic water availability survived subsequent water stress better than plants produced with a constant supply of water, irrespective of whether the constant supply of water was adequate, or not. The results show that rose plants which experienced stressful conditions during production were better acclimatised to adverse post-production conditions. A possible explanation for this is that the plants developed better stomatal control either due to closing earlier or more completely in response to stress, and consequently they can regulate transpiration more efficiently than control plants (Edwards and Dixon, 1995a,b).

During production, reducing water availability decreased \( P_n \) by stomatal closure, thereby reducing \( C_i \) available for \( \text{CO}_2 \) fixation (Williams et al., 1999). After 2 weeks in the interior room all plants had a lower \( P_n \) despite a slightly higher \( C_i \).
as compared to during production. The data indicate that all plants acclimatise to the low light conditions. As there were no significant differences in $g_s$, $C_i$ or $P_n$ during post-production we conclude that the plants have identical potential for carbon gain. However, during production control plants operated at the highest $g_s$ and $P_n$ and when they are moved into the interior room their drop in carbon gain was relatively greater than for other plants. In addition, during the post-production evaluation all plants had a stomatal conductance similar to that of water deficit plants during production, indicating that control plants also had to reduce stomatal conductance relatively more than the other plants. These observations suggest that the plants produced under deficit irrigation are more preconditioned to low light in the interior room compared to control plants and this could explain why deficit-irrigated plants continued to develop and open buds during the post-production phase.

An increase in proline clearly illustrates that rose plants undergo osmotic adjustment in response to severe water stress. Proline levels were only determined at the point of wilting and there was no influence of production water availability on proline accumulation. Within one week of wilting the proline levels had decreased to control levels. Other studies have reported a positive correlation between proline accumulation and the degree of drought tolerance (van Heerden and de Villiers, 1996). These authors reported a distinct difference in the onset of proline accumulation, and also reported that the magnitude of the differences between treatments decreased the longer the stress treatment occurred. If there is a positive correlation between proline accumulation and drought tolerance, we would expect that the drought-stressed plants would accumulate proline earlier during the wilting process. In subsequent experiments we will determine if acclimatisation of rose plants to stress is influenced by their ability to adjust osmotically.

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