Increased water use efficiency and plant quality in *Pelargonium* x *hortorum* in response to reduced irrigation frequency

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ABSTRACT

Limiting irrigation frequency may present an alternative approach to conventional irrigation practices, leading to water savings whilst maintaining crop yield and/or quality. This may be particularly relevant in commercial nurseries with appropriate irrigation technology. *Pelargonium x hortorum* Bullseye Cherry plants were grown under glasshouse conditions under either well-watered (WW; daily replacement of 100% of evapotranspiration (ET)), frequent (FDI), or infrequent (IDI) deficit irrigation regimes (50% of ET supplied daily or cumulatively every 4 days, respectively) for 24 days. Stomatal conductance (g_s) and leaf water potential (Ψ_{leaf}) were measured as indicators of plant water relations. Plant quality was determined by canopy volume. Water use efficiency (WUE) was established as the ratio of shoot dry biomass to total water applied. Both FDI and IDI decreased g_s but there were treatment differences in Ψ_{leaf}. FDI resulted in a more positive Ψ_{leaf}, whilst IDI decreased Ψ_{leaf} over the experimental period. Deficit irrigation frequency had no effect on either plant volume or biomass during the initial 12 days of the experiment, although by Day 24, both IDI and FDI were significantly lower than WW plants (albeit FDI plants had a greater biomass than IDI plants). This corresponded with IDI and FDI showing a higher WUE than WW plants during the first half of the experiment, but this effect was diminished as growth decreased under both deficit irrigation treatments. During deficit irrigation, irrigation frequency had two main effects on *P.hortorum*. FDI prevents the onset of leaf water deficit and partially maintains biomass accumulation. However, IDI reduces growth compared to FDI and produces more compact plants, thereby increasing ornamental quality, whilst also enhancing WUE during the early stages of the experiment. This suggests that irrigation frequency can be altered to deliver specific grower objectives.

INTRODUCTION

Growers of ornamental nursery crops are often criticised for using inefficient irrigation practices during production (Briercliffe et al., 2000). Irrigation frequency is a key aspect of irrigation scheduling in horticulture, and by reducing the irrigation frequency, growers may prevent excessive water loss. Furthermore, this approach may provide greater control of plant growth (and thus enhanced ornamental value (Cameron et al., 2008)), and also increased water use efficiency (WUE) (Fereres and Soriano, 2007). Increased accuracy of irrigation scheduling by delaying irrigation frequency may be achieved by adapting it to the water status of the plant. Deficit irrigation (applying irrigation at a lower volume than the plants water requirements) is widely used as an alternative to conventional irrigation (Fereres and Soriano, 2007). However, although the benefits of this approach are well recognised the benefits of manipulating irrigation frequency are less well understood. Container-based plant production allows accurate measurements of evapotransiration (ET), as well as paired measurements of stomatal conductance (g_s) and leaf water potential (Ψ_{leaf}) at known whole-pot soil moisture content (θ_{pot}). This level of understanding may allow growers to optimise their irrigation scheduling for optimal production of an ornamental bedding plant species.

MATERIALS & METHODS

Pelargonium x *hortorum* Bullseye plants were raised in glasshouse conditions under a 14 h photoperiod (0600 h – 2000 h), 27/17 °C temperature range, and 330±4.3 µmol m^{-2} s^{-1} photosynthetically active radiation (PAR) provided by high pressure sodium lamps (Osram Plantastar 600W). Seeds were sown in individual 1.05 lt pots (13 x 11.3 cm; Pöppelman TEKU®, Germany) containing a peat-based compost (Levington's M3, Levington Horticulture Ltd., UK). All plants were watered daily for 5 weeks from germination until different watering regimes were imposed.

Prior to imposing different watering regimes, individual plants were weighed using a balance with a 0.1 g resolution (Scout Pro Portable balance, Ohaus, Switzerland). All plants were initially irrigated daily to well-watered (WW) conditions (watered until drainage was visible from the bottom of the pot, and then left to freely drain overnight), which was used as a reference value. To calculate daily ET, pots were weighed at 0800 h each day, accounting for any irrigation supplied in the previous 24 h. During the experimental period, plants were subject to three irrigation treatments; maintained at WW conditions, or subject to deficit irrigation at two irrigation frequencies (Fig. 1a). The two deficit irrigation treatments were infrequent (IDI; with-holding water with regular re-watering events) or frequent deficit irrigation (FDI; daily irrigation at 50% of WW plants ET). After 4 days of withholding water, plants subject to IDI received the same cumulative irrigation volume as applied to plants under FDI over the same period. Irrigation regimes were applied at week 5 for both treatments, with a 24 days experimental period. Plants under IDI were subject to 6 cycles of drying and re-watering.

Measurements of g_s were made between 1100 h and 1300 h on the youngest, fully expanded abaxial side of one leaf per plant using a porometer (Model AP4, Delta-T Devices, Cambridge, UK). Ψ_{leaf} was determined immediately after sampling for g_s on the same leaf as described previously (Scholander et al., 1965), using a pressure chamber (Model 3000F01 Plant Water Status Console; Soil Moisture Equipment Corp. Santa Barbara, CA, USA). Measurements of g_s and Ψ_{leaf} were carried out every 2 days from the beginning of the treatment period until the final day of Cycle 6. Canopy volume was measured at the end of each drying cycle to assess the overall compactness of each plant, which was measured as the total height, width and breadth of the plant. After physiological measurements, plant material was harvested and shoot fresh weight was measured. Plant material was dried in an oven at 80°C until a constant mass. θ_{pot} was obtained gravimetrically by weighing the soil fresh weight, and then re-weighing after oven drying. WUE was determined by the volume of water applied to produce the shoot dry biomass of each plant.

RESULTS AND DISCUSSION

Manipulation of the frequency of irrigation represents and attractive water saving technique for nurseries. In this study, 50 % of WW plants' daily ET demand was applied to both deficit irrigation treatment groups, but at different irrigation frequencies. To ensure irrigation frequency was the main factor varied, plants subject to both IDI and FDI received the same volume of water over the experimental period (Fig. 1b). Available θ_{pot} decreased under both deficit irrigation treatments, but with a more rapid response under IDI (Fig. 2a). Towards the end of the experimental period, FDI showed a more stable θ_{pot}, while θ_{pot} fluctuated in IDI, coinciding with re-watering.

ET of WW plants steadily increased over the experimental period (Fig. 2b). In contrast, FDI resulted in a more stable ET, which was typically lower than WW plants, whilst IDI showed a series of increases and decreases in ET, corresponding with each re-watering event. Recovery time of ET for IDI plants was similar under each cycle, generally increasing over 48 h after re-watering, before declining over the subsequent 24-48 h. The peaks of ET under IDI suggest partial recovery of leaf gas exchange (increased transpiration) occurred quickly (1-2 d) upon re-watering. It was therefore hypothesised that this response under IDI was due to fluctuations in g_s, possibly as a consequence of changes in Ψ_{leaf} due to re-watering events.

Stomatal closure is a well characterised response to soil drying, which is tightly regulated to limit water loss (Bahrun et al., 2002). In the current study, g_s decreased as soil moisture decreased under both deficit irrigation treatments (Fig. 3). However, stomata closed earlier under IDI. This may be due to quicker depletion of soil moisture under IDI (Fig. 2a) and an extended duration of soil drying that enhanced the severity of the stress. Reduced g_s along with partial recovery upon re-watering (typically occurring 24-48 h after irrigation), indicates that stomatal closure is at least partly responsible for the fluctuations observed in ET.

Decreased leaf water status can also indicate stress, and can regulate stomatal responses (Buckley, 2005). There was no difference in Ψ_{leaf} between treatments until Day 8, after which IDI plants exhibited a reduction in Ψ_{leaf} compared to FDI plants which was maintained over the rest of the sampling period (Fig. 4). The ability of FDI plants to maintain a more positive Ψ_{leaf} may reflect the slower imposition of soil drying along with regular re-watering and the more gradual reductions in g_s. *P.hortorum* has previously been shown to have a low lethal Ψ_{leaf} threshold, but instead have particularly sensitive stomata which provide a regulatory mechanism for water loss (Auge et al., 2003). This may have a useful application in conditioning plants for future, unexpected periods of drought stress, although the lowest Ψ_{leaf} observed under IDI may have more deleterious effects on plant growth and development.

Significant differences in growth and biomass (for all reported characteristics) between WW plants and those under the two deficit irrigation treatments (Table. 1) were detected by Day 12. By the end of the experimental period IDI plants also had significantly smaller biomass than FDI plants, implying that prolonged exposure to cycles of withholding irrigation and re-watering eventually decreased plant growth. However, the smaller plants grown under IDI may be considered ornamentally favourable for growers, provided this can be achieved without decreasing foliar quality. Interestingly, for the first 12 days of the experiment, no differences were observed for shoot dry weight under any of the irrigation treatments, which correlated with the higher WUE of both IDI and FDI plants compared to WW plants (Fig. 5). In particular, IDI plants had a significantly higher WUE than WW plants on Days 6 and 10 (in both cases 48 h after re-watering; Fig. 5b). However, after Day 12 there was a large reduction in WUE in both IDI and FDI treatments, and by the end of the experimental period, WW plants had a significantly higher WUE (Fig. 5a). Therefore, it is clear that applying 50 % ET (either frequently or infrequently) over the short term significantly increase water productivity (albeit with an eventual loss of effect), whilst applied over the longer term can lead to greater control over growth, and enhance ornamental compactness.

Taken together, these results show that irrigation frequency can be tailored to match grower requirements. Less frequent irrigation results in a series of peaks and declines in ET, earlier reduction in g_s and a lower Ψ_{leaf} compared to plants subject to FDI. IDI and FDI both result in decreased plant growth over time compared to WW plants, with IDI plants the smallest by the end of the experimental period. This was reflected in WUE, which was higher under both IDI and FDI over the first 10 days, but was lower after Day 10. These results suggest that growers can adapt their irrigation scheduling dependent upon whether their aims are to reduce water consumption, improve water productivity, or increase ornamental quality.

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TABLES

Table 1. Plant height and volume, and shoot fresh (FW) and dry (DW) weights of *P.hortorum* plants subject to either well-watered (WW) conditions, or either frequent (FDI) or infrequent (IDI) deficit irrigation. Values are means ± SEM (n=4-5). Different letters within a column on each day indicate significant differences between treatments according to a one-way ANOVA ($p<0.05$).

		Growth		Shoot	
Day		Height (cm)	Volume (cm^3)	FW (g)	DW (g)
0	WW	76±2a	1952±124a	15.2±0.7a	1.9±0.1a
	FDI	78±4a	1610±178a	16.6±2.4a	2.0±0.3a
	IDI	76±4a	1920±186a	16.5±1.1a	2.0±0.1a
12	WW	141±3a	7582±462a	53.7±2.4a	5.4±0.3a
	FDI	133±6a	6545±634ab	39.8±1.8b	4.0±0.2b
	IDI	128±3a	5681±198b	38.1±2.5b	4.2±0.4b
24	WW	205±14a	16512±618a	98.3±2.4a	13.3±0.1a
	FDI	161±6b	9089±734b	71.1±1.4b	8.5±0.3b
	IDI	159±10b	7858±682b	60.1±3.8c	7.6±0.2b

FIGURES

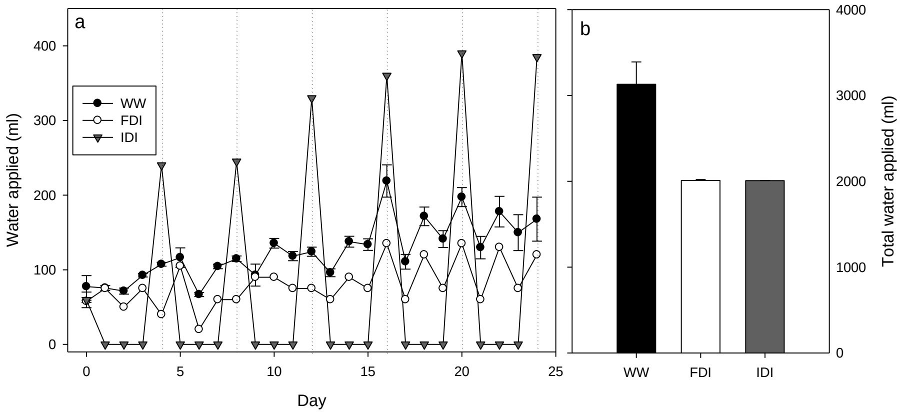

Figure 1. a) Volume of water applied per treatment per day, and b) total volume of water applied to each treatment over the entire experimental period, of *P.hortorum* plants subject to either well watered (WW) conditions, or either frequent (FDI) or infrequent (IDI) deficit irrigation. Bars represent means ± SEM (n=13). Vertical lines indicate each re-watering event for the IDI treatment.

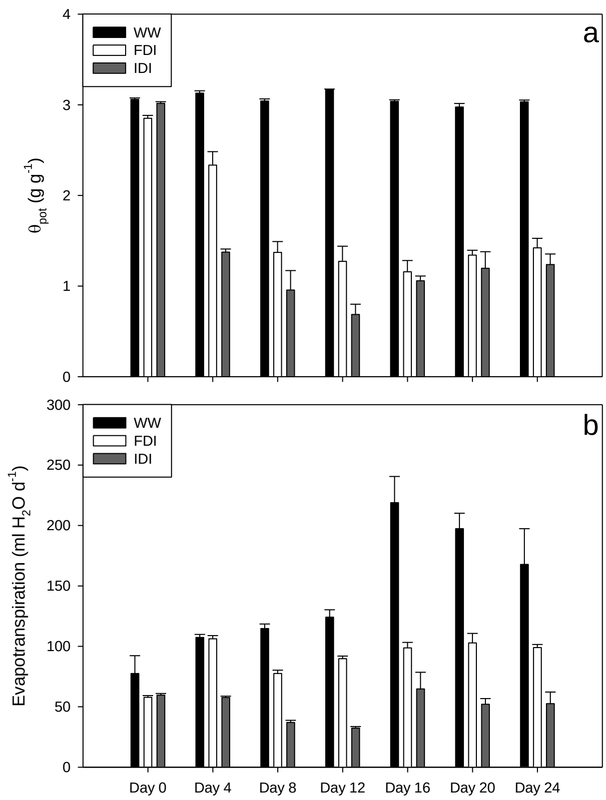

Figure 2. a) Whole-pot gravimetric water content, and b) evapotranspiration of *P.hortorum* plants subject to either well watered (WW) conditions, or either frequent (FDI) or infrequent (IDI) deficit irrigation. Each day is the point of re-watering for IDI at the end of a drying cycle. Bars represent means ± SEM (n=13).

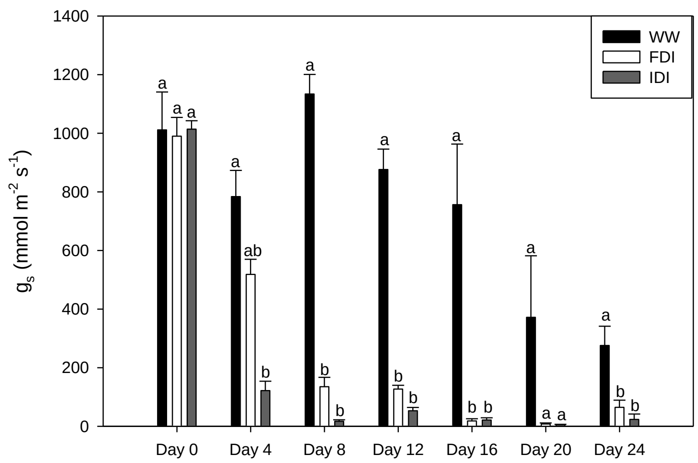

Figure 3. Stomatal conductance every four days of *P.hortorum* plants subject to well watered (WW) conditions, or either frequent (FDI) or infrequent (IDI) deficit irrigation. Bars represent means ± SEM (n=4). Each day is the point of re-watering for IDI at the end of a drying cycle. Different letters on each day indicate significant differences between irrigation treatments according to a one-way ANOVA ($p<0.05$).

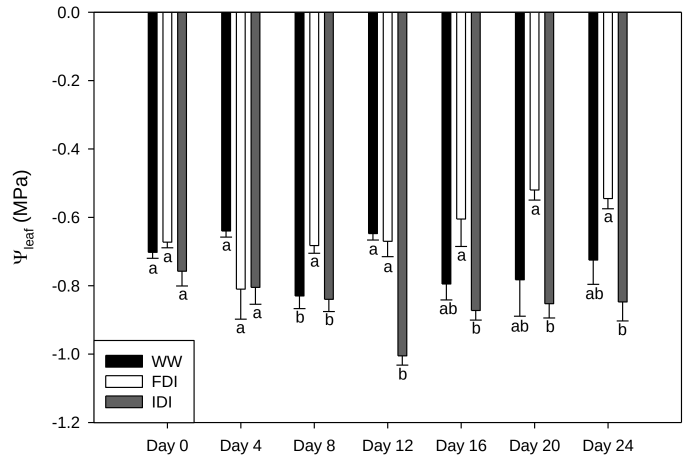

Figure 4. Leaf water potential every four days of *P.hortorum* plants subject to either well watered (WW) conditions, or either frequent (FDI) or infrequent (IDI) deficit irrigation.Bars represent means ± SEM (n=4). Each day is the point of re-watering for IDI at the end of a drying cycle. Different letters on each day indicate significant differences between irrigation treatments according to a one-way ANOVA (p<0.05).

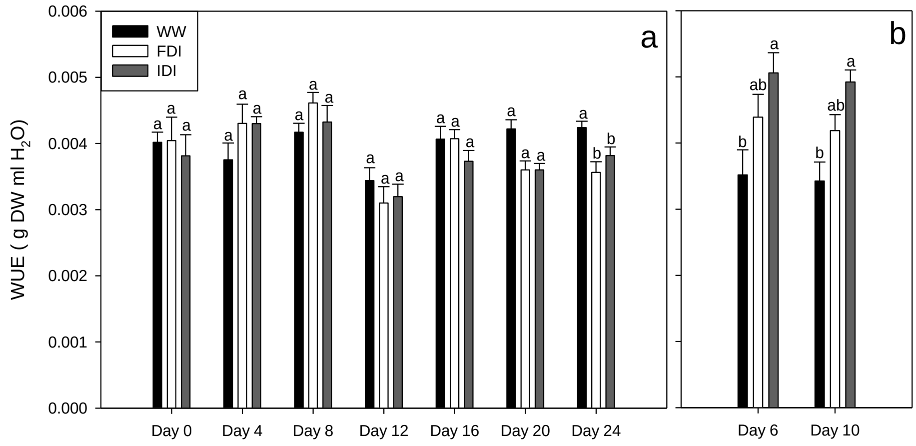

Figure 5. Water use efficiency a) every four days; b) on Days 6 and 10 of *P.hortorum* plants subject to either well watered (WW) conditions, or either frequent (FDI) or infrequent (IDI) deficit irrigation. Bars represent means ± SEM (n=4). Each day is the point of re-watering for IDI at the end of a drying cycle. Different letters on each day indicate significant differences between irrigation treatments according to a one-way ANOVA (p<0.05).