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GROWTH AND DEVELOPMENT OF POTTED RHODODENDRON CULTIVARS 'CATAWBIENSE BOURSAULT' AND 'OLD PORT' IN RESPONSE TO REGULATED DEFICIT IRRIGATION

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ABSTRACT

The aim of this study was to analyse the effect of regulated deficit irrigation (RDI) on growth and development of potted rhododendron 'Catawbiense Boursault' and 'Old Port' plants and to evaluate the usefulness of this technique for saving water in nursery production and promoting flowering. Plants were grown in 1.9 litre plastic containers in unheated greenhouse and were subjected to six irrigation treatments lasting for 14 weeks from June to mid-September. A drip irrigation system with one 2 $dm^3 \cdot h^{-1}$ emitter per container was used. Six treatments of irrigation were applied: T1) 1 ETp (evapotranspiration) (control, well watered plants); T2) 0.75 ETp (moderate deficit irrigation); T3) 0.5 ETp (strong deficit irrigation) during the entire period of the experiment and the others three were: T4) 1 ETp for 5 weeks followed by 0.5 ETp for 4 weeks and 1 ETp for 5 weeks (strong deficit irrigation in phase II); T5) 1 ETp for 5 weeks followed by 0.25 ETp for 4 weeks and 1 ETp for 5 weeks (very strong deficit irrigation in phase II) and T6) 0.5 ETp for 5 weeks followed by 1 ETp for 4 weeks and 0.5 ETp for 5 weeks (strong deficit irrigation in phases I and III and well watered plants in phase II). The results showed that exposing plants to moderate water deficit (0.75 ETp) for 14 weeks had the best effect on quality of *Rhododendron* 'Old Port' plants. In this cultivar the application of very strong water deficit (0.25 ETp) for 4 weeks during floral buds initiation improved significantly floral bud set. Reduction of water supply by 50% during 14 weeks of *Rhododendron* 'Catawbiense Boursault' cultivation resulted in both the enhanced plant quality and increased number of floral buds set. Rhododendrons has adapted to reduced water supplies through stomatal control. At the end of the experiment, chlorophyll fluorescence parameter F_v/F_m (quantum efficiency of photosystem II) did not indicate damage to photosynthetic apparatus and relative chlorophyll content in leaves of plants subjected to all irrigation regimes did not differ significantly between each other.

Key words: water deficit, rhododendron, greenhouse potted cultivation, ornamental plant quality index, regulated deficit irrigation

INTRODUCTION

Regulated deficit irrigation (RDI) usually refers to an irrigation strategy that maintains plants at some degree of water deficit for a part (or parts) of the season, aiming to control plant growth and development and/or to improve water use efficiency (Kriedemann and Goodwin 2004). Recently, there are more and more reports in the literature concerning application of RDI in cultivation of many tree crops and bushes as a means of reducing total water use (Egea *et al*. 2009; Gijón *et al*. 2009; Iniesta *et al*. 2009; Tejero *et al*. 2011) and also for manipulating crop quality (Acevedo-Opazo *et al*. 2010; García-Tejero *et al*. 2010; Marsal *et al*. 2010). In fruit trees, a reasonable plant water stress can enhance partitioning of carbohydrate to fruits, thus improving fruit quality,

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and at the same time provide control of excessive canopy growth (Chalmers *et al*. 1981). Similarly, it can be expected that implementing RDI in ornamental plants cultivation might result in improved crop quality and water savings.

Generally, in ornamental plant nurseries imprecise top sprinkler irrigation is applied, which is difficult to control and thus adapt to the water requirements of different species, cultivars, or plant developmental phases. Excessive watering is not only wasteful but it may also lower the quality of plants causing growth irregularities like inordinate apical growth, which could result in exuberant plants with long internodes, limited axillary shoot development and the large variation in the size of the leaves. In order to mitigate these adverse effects of overwatering some nurserymen use pruning or plant growth retardants, which additionally increase the cost of nursery production. Whereas, there are observations that the use of moderate water deficits in cultivation of woody ornamentals may increase the number of shoots, shorten internodes, and thus improve the habit and quality of the plants (Cameron *et al*. 2006; Sánchez-Blanco *et al*. 2004). Likewise, there are reports that moderate plant water deficits enhance flowering in many important horticultural species including, for example *Litchi* (Stern *et al*. 1993), *Citrus* (Krajewski and Rabe 1995) and *Loquat* (Cuevas *et al*. 2012). On the other hand, strong water deficit causes inhibition of plant grow, chlorosis, leaves withering, blooming and flower formation disorders (Chimonidou-Pavlidou 1996, 1999), often followed by a decrease of photosynthetic activity and thus reduced assimilation (Chaves *et al*. 2002). Understanding water requirements of shrubs and using appropriately regulated irrigation regimes adjusted to the specific needs of different species and cultivars and stages of plant development would be important for water-efficient cultivation of good quality ornamental plants.

Plant responses to water deprivation are usually monitored at the level of selected physiological parameters, which has been proven to be good indicators of drought stress in several different studies. Among them are stomatal conductance (g_s), chlorophyll fluorescence and relative chlorophyll content (RCCI) (Nakai *et al*. 2010; Dias and Brüggemann 2010; Taulavuori *et al*. 2010).

Rhododendrons are very popular woody ornamental plants and are important crops in nursery production. Previous horticultural observations and research on this plant species suggest that appropriately applied irrigation deficits may improve shrubs quality and enhance flowering. Cameron *et al*. (1999) demonstrated that controlled water stress improved plant quality in container-grown *Rhododendron* 'Hoppy'. Sharp *et al*. (2009) noted that limited water stress applied to *Rhododendron yakushimanum* resulted in earlier induction of flower buds set, forming more flowers per inflorescence and shortening branch length.

The aim of the experiment presented was to analyse the morphological and physiological response of rhododendron cultivars 'Catawbiense Boursault' and 'Old Port' to different levels of irrigation and to evaluate usefulness of regulated deficit irrigation (RDI) as a technique for saving water in nursery production and improving plant quality.

MATERIALS AND METHODS

The experiment was conducted from early June to mid-September 2012 in the experimental greenhouses of the Research Institute of Horticulture in Skierniewice, Poland. The temperature in the greenhouse ranged from: average 23.5 ^{o}C; max. 41 ^{o}C and min. 13 ^{o}C during the day and respectively 16.7 ^{o}C; 29 ^{o}C and 9 ^{o}C at night. Relative humidity ranged from: average 61.6%; max. 94% and min. 25% during the day and respectively 76%; 95% and 46% at night. In early April 2012 two-year-old *Rhododendron* 'Catawbiense Boursault' and 'Old Port' plants were planted to 1.9 dm^3 large cubic PVC containers filled with Kronen Klassmann medium grade sphagnum peat at pH 3.6, supplied with 1 $g \cdot dm^{-3}$ PG-Mix fertilizer (Chemirol.com.pl) (14:16:18 w/w N:P:K + microelements), and placed on tables in the greenhouse. Before experiments with RDI started at the beginning of June, the plants were irrigated with the equal water rates and fertilized weekly with 1 $g \cdot dm^{-3}$ aqueous Symfo-vita D fertilizer (Azeco.pl) (N:P:K -

17:17:17 w/w + 3.0 Mg + microelements chelated by EDTA) in the rate of 0.1 dm^3 per container till mid-June.

Water deficit treatments were established by applying irrigation in proportions to the estimated evapotranspiration (ETp), which was determined by monitoring weight loss from the containers over 24 h. Two planted containers (so called reference plants) chosen at random from control plant combinations (8 containers in total for all replications in this treatment) were watered to full water capacity by submerging the planted container in tap water for 2 h and allowing them to drain for 1 h before weighing. After 24 h the containers were weighted once again. Based on weight difference, the average amount of water lost daily through transpiration and evaporation from the substrate was calculated. This represented the actual crop evapotranspiration (ETp). ETp value was estimated normally every two weeks but every one week at times when plants growth was intensive, especially at the beginning of experiment, or in the situation when greenhouse conditions varied considerably during a week. Plants were irrigated 3-5 times per week, depending on the evaporative demand, using a drip irrigation system with one emitter per container (2 $dm^3 \cdot h^{-1}$, Netafim drippers PCJ CNL; Israel). Under each container a saucer was placed to enable reabsorption of any leachate. Water application was dosed by irrigation controller (8056 Ac-6s, Galcon, Israel). The EC of water used to irrigation was 0.58 $mS \cdot cm^{-1}$.

Plants were subjected to six irrigation regimes: T1) 1 ETp (control, well watered plants with irrigation rate balancing water loses by evapotranspiration); T2) 0.75 ETp (moderate deficit irrigation); T3) 0.5 ETp (strong deficit irrigation) during the entire period of the experiment, and the others three were: T4) 1 ETp for 5 weeks followed by 0.5 ETp for 4 weeks and 1 ETP for 5 weeks (strong deficit irrigation in phase II); T5) 1 ETp for 5 weeks followed by 0.25 ETp for 4 weeks and 1 ETP for 5 weeks (very strong deficit irrigation in phase II) and T6) 0.5 ETp for 5 weeks followed by 1 ETp for 4 weeks and 0.5 ETP for 5 weeks (strong deficit irrigation in phases I and III and well watered plants in phase II). The II phase of irrigation, lasting 4 weeks, was correlated with the period of floral bud set initiation, while irrigation phases I and III corresponded to the stage of vegetative plant growth. The experiment was set up in 4 replications (experimental blocks), each consisted of 10 plants.

At the end of the each irrigation phase stomatal conductance (g_s), chlorophyll fluorescence parameter F_v/F_m (maximum quantum efficiency of photosystem II photochemistry) and relative chlorophyll content index (RCCI) were measured. Stomatal conductance (g_s) was measured on fully developed leaves in early afternoon (between 12:00 and 15:00) using a steady state porometer (Li-Cor LI-1600 DMP). The measurements were made on three leaves of five plants selected at random from each treatment replication. Maximum quantum efficiency of photosystem II photochemistry (F_v/F_m) was measured on two leaves on five plants selected from each treatment replication using chlorophyll fluorometer (OS-30p OPTI-SCIENCES, USA). CCI was measured on two mature leaves per plant with relative chlorophyll content analyser (CCM-200, OPTI-SCIENCES, USA).

At the end of the experiment, plant height and leaf blade area were measured. The leaf blade area was measured using WinDIAS image analysis system (Delta-T Devices, UK). Plants were also assessed for quality value based on their morphology (i.e., by means of index of visual quality scored 1-5, where grade 5 obtained well balanced plant with three to four, 25-40 cm long properly growing, uniform shoots with regularly sized leaves (leaf blade area in the range of 20-40 cm^2); 4 - plants with at least two, 25-40 cm long properly growing uniform shoots with regularly sized leaves; 3 - plants with at least one, 25-40 cm long, properly growing shoot with prevailing regularly sized leaves; 2 - plants with shoots shorter than 25 cm but with prevailing regularly sized leaves; 1 - plants with shoots shorter than 25 cm and with leaves variable in size.

In the mid-September, inflorescence buds on the plants were counted. In case of poorly developed, difficult to distinguish buds, nodes were dissected longitudinally and analysed under stereoscopic microscope (CX41, Olympus, Japan).

The data were analysed statistically by one-factorial analysis of variance. In case of the plant quality indices statistical analyses were conducted after subjecting data to transformation according to the formula: Y = , where means index of visual quality of plant scored (1-5). To establish significance of differences between means, Duncan's Multiple Range Test was used.

RESULTS AND DISCUSSION

Rhododendron cultivars examined in our study differed slightly between each other in water requirements. 'Catawbiense Boursault' shrubs in control treatment consumed about 12% less water than 'Old Port' (Fig. 1). Water deficits significantly affected the studied growth parameters in both rhododendron cultivars. The reduction of water rates during entire cultivation period and in treatments with water deficiencies during I and III stages (vegetative plant growth) caused growth inhibition, which was expressed as the lowering of plant height and decreasing leaf blade area, while at the same time it significantly improved the plant decorative value. Plant height of 'Old Port' rhododendron subjected to water regimes T2, T3 and T6 was lower in comparison with the control by 12%; 25% and 21%, and leaf area by 36%, 57% and 52%, respectively. For 'Catawbiense Boursault' plants grown under T3 and T6 water regimes plant height was lower by 21% and 16% and leaf area by 52% and 43%, accordingly. Plants of this cultivar irrigated under T2 water regime had the same height, but leaf area smaller by about 38% as compared to the control (Table 1). Application of water rates as equivalents of 0.5 and 0.25 ETp during II phase (generative phase; floral buds development) in 'Old Port' caused reduction of plant height and leaf blade area under treatments T4 and T5 by about 8% and 13%, and 18% and 29%, respectively, in relation to the control. In 'Catawbiense Boursault' these water treatments caused marked decrease of average leaf blade area by about 37% and 44%, respectively (Table 1).

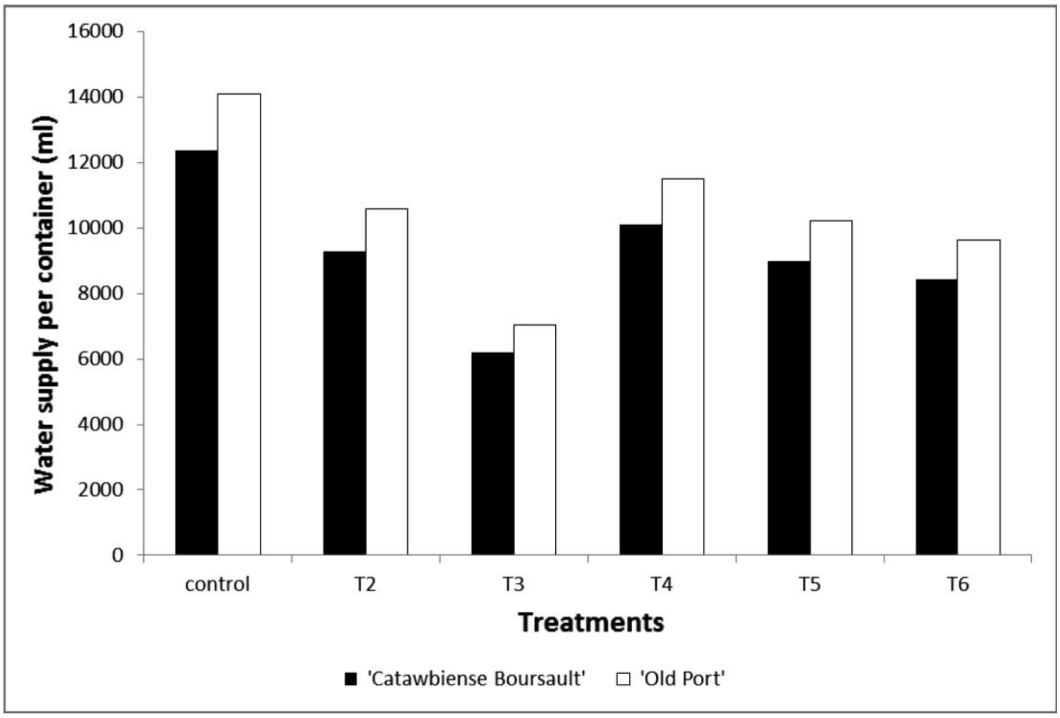

Figure 1. Total water supply per container during the entire period of experiment depending on irrigation programme and cultivar

Table 1. Influence of irrigation treatment on growth and flowering of potted *Rhododendron* plants

Cultivar	Treatment	Parameter			
		Plant height (cm)	Mean leaf blade area (cm²)	Visual quality index (1-5)	Number of inflorescence buds per plant
'Catawbiense Boursault'	control	35.1 c*	46.8 d	3.4 a	1.8 a
	T2	32.1 bc	28.9 bc	4.2 b	2.5 b
	T3	27.6 a	22.6 a	4.1 b	2.6 b
	T4	33.7 c	29.5 c	3.6 a	2.4 b
	T5	31.7 bc	26.2 b	3.6 a	2.6 b
	T6	29.5 ab	26.9 bc	4.1 b	2.1 ab
'Old Port'	control	39.2 c	56.0 e	3.5 a	2.5 a
	T2	34.6 b	35.7 b	4.8 c	2.6 a
	T3	29.3 a	24.2 a	4.1 b	3.0 ab
	T4	35.9 b	46.2 d	3.5 a	2.8 ab
	T5	34.1 b	39.5 c	3.5 a	3.1 b
	T6	31.1 a	26.8 a	4.3 b	2.7 ab

*means in the columns followed by the same letter do not differ significantly according to Duncan's Multiple Range Test at α=0.05; the assessment of significance of differences was done for each cultivar separately

Growth restriction is a morphological adaptation of a plant to water stress in order to reduce the transpiration. The reduction of leaf area not only leads to reduction of transpiration, but also to reduction of the photosynthetic surface area, and consequently reduced growth (Sánchez-Blanco *et al*. 2004). Cameron *et al*. (1999) noted that growth of eighteen-month-old *Rhododendron yakushimanum* cv. 'Hoppy' plants in the 0.75 ETp irrigation regime for 8 weeks was suppressed significantly only during the July-August period compared with plants grown under 1.5 ETp regime. In turn, exposing plants to severe drought (0.25 ETp) during June-July and July-August resulted in a significant reduction in shoot growth and in number of laterals produced. Sharp *et al*. (2009) reported that two-year-old *Rhododendron* 'Hatsugiri' under 0.25 ETp and 0.5 ETp irrigation deficits produced fewer vegetative nodes before floral initiation compared to 1.5 ETp. For other woody ornamental plant species Cameron *et al*. (2006) reported that even 80% irrigation deficit reduced vegetative growth during the same period of treatment. Steinberg *et al*. (1990) observed that in young peach trees, which were supplied with only 25% of full irrigation rate, leaf size was reduced by 27% compared to well-watered controls. Sánchez-Blanco *et al*. (2009) submitted geranium plants to 60% and 40% deficit irrigation and noticed reduction of leaf area by about 28 and 37%, respectively, compared to plants irrigated optimally.

Water deficit may affect plant habit and thereby the quality of the crop by acting on the growth of the plants. In our experiments, 'Old Port' shrubs with the highest visual quality index were obtained in T2 irrigation regime. *Rhododendron* 'Catawbiense Boursault' plants irrigated with moderately reduced water rates (T2) also had higher visual quality index in relation to plants in the control treatment (Table 1). The application of this irrigation regime allowed reducing the amount of water use by 25% as compared to the control (Fig. 1). Likewise, both 'Old Port' and 'Catawbiense Boursault' shrubs had significantly better decorative value both at strongly reduced water rates (T3) throughout the experimental period and at periodic water deficit at the beginning and at the end of the cultivation (T6) compared to the well-watered plants (Table 1). Under these irrigation regimes, water rates used for both rhododendron cultivars were lower by about 50% and 32% respectively, compared to the control (Fig. 1). Shrubs under these water treatments had more compact, well-branched, uniform habit and had smaller, uniformly sized leaves than well-watered plants (control). Plant specimens under the control irrigation regime were characterized by exuberant growth, uneven appearance with excessive apical growth, long internode sections, limited auxiliary shoot development and excessively grown leaf blades. Likewise, Cameron *et al*. (2006) reported that application of RDI at 50% ETp for 8 weeks during July-August resulted in inhibition of shoot elongation and formation of compact, good quality shrubs, in particular in *Cotinus* and *Forsythia*.

In our research, initiation of inflorescence bud development was observed first on RDI treated plants of both rhododendron cultivars at the end of the first half of July. It is worth to mention that in both cultivars no negative effect of water deficit on the number of inflorescence buds were observed, compared to the control treatment. In 'Catawbiense Boursault' grown under irrigation regimes with water rates used during the generative phase lower than 1 ETp, noticeably higher number of inflorescence buds was observed, as compared to the control. In case of this rhododendron cultivar, lowering water rates by just about 25% for 4 weeks during this phase caused significant increase in the number of inflorescence buds compared to the control (Table 1). In 'Old Port' only T5 water treatment significantly improved inflorescence buds development (by about 28%), while at the same time, the amount of water applied was reduced by 27% in relation to the control (Table 1; Fig. 1). Cameron *et al*. (1999) obtained contrary results concerning flower bud formation in *Rhododendron yakushimanum* cv. 'Hoopy' submitted to severe drought (0.25 ETp) for 8 weeks during June-July and July-August. Plants under this treatment made fewer floral buds than less stressed ones at 0.75 ETp and 1.5 ETp irrigation regimes. However, in the study of these authors, the greatest number of flower buds in mentioned rhododendron cultivar was associated with exposure of the plants to 0.75 ETp for 8 weeks, but only during September-October, after flower bud set initiation. On the other hand, Sharp *et al*. (2009) reported that irrigation regimes of 0.25 ETp and 0.5 ETp applied to two-year-old *Rhododendron* 'Hatsugiri' for 11 weeks, including generative development phase, had no significant effect on the number of floral buds per plant compared to 1.5 ETp treatment. The same authors in other experiment showed that application of 0.7 ETp irrigation regime for 11 weeks in cultivation of *Rhododendron yakushimanum* plants: 2.5-year-old 'Hoppy' and 3.5-year-old 'Scintillation' caused decrease of the number of flower buds set compared to 1.1 ETp-treated control plants. However, 0.7 ETp treatment in the 2.5-year-old 'Hoppy' plants increased the number of flowers per a bud in relation to the control.

In both rhododendron cultivars tested in the experiment presented, along with the reduction of water rates, leaf stomatal conductance was significantly decreasing. One of the first responses of plants to water deficit is to decrease the stomatal conductivity, which reduces the gas exchange and transpiration. This is the main mechanism for regulating water relations and carbon assimilation processes in plants (Hetherington and Woodward 2003). Reduced stomatal conductance prevents excessive water loss, but as well, it limits the infiltration of carbon dioxide into the assimilation parenchyma (Chaves *et al*. 2003). Cameron *et al*. (2006) demonstrated in experiments conducted on woody ornamentals that many, though not all, species tested managed to achieve equilibrium between water use and water supply *via* stomatal control, when exposed to RDI regimes between 50-100% ETp. In our research stomatal conductance (g_s) in 'Catawbiense Boursault' submitted to irrigation regimes T2, T3, T4, T5 and T6 amounted to 67%; 50%; 81%; 75% and 67% of that in the control plants, while in 'Old Port' to 65%; 46%; 78%; 70% and 64%, respectively (Table 2). Decrease in relative water content in leaves, as a result of water stress, initially induce stomatal closure, imposing a decrease in the supply of CO_2 to the mesophyll cells and, consequently, results in decrease in the rate of leaf photosynthesis (Lu and Zhang 1999). The potential for a species to tolerate water stress can be effectively assessed through a decline of quantum efficiency of photosystem II (F_v/F_m chlorophyll fluorescence parameter) (Resco *et al*. 2008). In our experiments, the value of F_v/F_m in rhododendron plants subjected to water stress decreased, which was observed particularly in 'Catawbiense Boursault' cultivar subjected to water rates reduction in treatment T3 at the end of experiment and during II phase of T5 water treatment.

Table 2. The effect of irrigation treatments on stomatal conductance, chlorophyll fluorescence in leaves of potted *Rhododendron* plants at the end of each irrigation phase

Cultivar	Treatment	Parameter					
		Stomatal conductance (mmol m^{-2} s^{-1})			Chlorophyll fluorescence (F_v/F_m)		
		I phase	II phase	III phase	I phase	II phase	III phase
'Catawbiense Boursault'	control	151 c*	143 e	155 e	0.820 a	0.819 b	0.821 b
	T2	106 b	92 d	102 b	0.818 a	0.818 b	0.814 ab
	T3	85 a	68 c	71 a	0.815 a	0.812 b	0.813 a
	T4	159 d	56 b	147 d	0.819 a	0.811 b	0.818 ab
	T5	157 d	43 a	135 c	0.822 a	0.794 a	0.818 ab
	T6	80 a	150 f	73 a	0.816 a	0.817 b	0.817 ab
'Old Port'	control	175 c	143 e	169 f	0.821 b	0.820 c	0.820 b
	T2	111 b	88 d	117 c	0.817 ab	0.818 c	0.815 ab
	T3	78 a	57 c	90 b	0.812 a	0.812 b	0.811 a
	T4	183 d	44 b	155 e	0.818 ab	0.816 bc	0.818 ab
	T5	171 c	32 a	136 d	0.818 ab	0.807 a	0.816 ab
	T6	77 a	155 f	78 a	0.812 a	0.819 c	0.814 ab

*for explanations see Table 1

Table 3. The effect of irrigation treatments on relative chlorophyll content in leaves of potted *Rhododendron* plants at the end of experiment

Cultivar	Treatment	Relative chlorophyll content index (RCCI)
'Catawbiense Boursault'	control	51 a
	T2	49 a
	T3	47 a
	T4	49 a
	T5	47 a
	T6	48 a
'Old Port'	control	58 a
	T2	58 a
	T3	57 a
	T4	55 a
	T5	56 a
	T6	54 a

Note: see Table 1

Also in cv. 'Old Port' this parameter of chlorophyll fluorescence was affected by water deficit. Under irrigation treatment T3 at the end of each irrigation phases, F_v/F_m ratio was significantly lower than the control. Likewise lower value of this parameter was noticed for the II phase of T5 water regime and the end of the I phase in T6 irrigation treatment (Table 2).

Chlorophyll is one of the major chloroplast components for photosynthesis and relative chlorophyll content is positively correlated with photosynthesis rate (Guo and Li 1996). Flexas and Medrano (2002) reported that water stress always reduces leaf greenness in C_3 plants due to chlorophyll degradation. However, in our research water deficits did not affect significantly the relative chlorophyll content in leaves of both rhododendron cultivars (Table 3).

CONCLUSIONS

The results of our experiments show that controlled water deficit can substitute for pruning and growth regulators as a means for manipulating vegetative growth in *Rhododendron* and enhancing quality of nursery plants. Application of water stress during 4-week period coinciding with floral buds initiation potentially may also be applied as a horticultural practice to increase the number of floral buds in cultivated rhododendrons. Controlled water deficit allows also reducing water use in nursery production and thus contributing to the rational use of the limited water resources available for irrigations.

Further research is required to determine the most appropriate irrigation regimes (timing, degree, and duration of water stress) for different rhododendron cultivars in order to induce an optimum growth and flowering response.

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