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Effect of Nutrient Solution Composition on Growth, Flowering, Nutrient Status and Cold Hardiness of *Rhododendron yakushimanum* Grown on Ebb-and-flow Benches

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Summary

Growth, flowering and cold hardiness of *Rhododendron yakushimanum* 'Blurettia' and 'Percy Wiseman' cultivated on ebb-and-flow benches and flooded with six different nutrient solutions was compared to plants fertilized with controlled release fertilizer (2 g L^{-1} Osmocote 15-9-9) under overhead irrigation. The following nutrient solutions were used for fertigation 60-20-60, 120-20-60, 180-20-60, 120-40-60, 120-60-60 and 120-20-120 (N-P-K levels in mg L^{-1}). 'Blurettia' plants fertigated with the highest N level were higher then in other treatments including controlled release fertilizer but number of leaves per plant was not affected. The lowest N level decreased both height and number of leaves of 'Percy Wiseman'. In both cultivars low N level as well as fertilization with controlled release fertilizer resulted in poor flowering. Also, increased P and K levels reduced number of flowers per plant in 'Blurettia' but in 'Percy Wiseman' the opposite was true. Overall EC values of growing media were several-fold higher in pots fertigated with ebb-and-flow system then in these given overhead irrigation and fertilization with Osmocote. In contrast, pH increase in the medium was more evident under overhead irrigation. Subirrigation resulted in significant salt accumulation in the upper part of growing medium even though plants were cultivated outdoor and some leaching due to rain should be expected. Nutrient content of leaves generally reflected composition of nutrient solution. However, plants fertilized with controlled release fertilizer had relatively low P and high Ca content in leaves. High N and K levels increased cold hardiness of *Rhododendron* leaves compared to both low N nutrient solution as well as Osmocote treatment.

Zusammenfassung

Wirkung der Zusammensetzung der Nährlösung auf Wachstum, Blüte, Ernährungsstatus und Frosthärte von *Rhododendron yakushimanum* auf Ebbe-Flut-Systemtischen. Es wurden Wachstum, Blüte und Frosthärte der *Rhododendron*-Sorten 'Blurettia' und 'Percy Wiseman' verglichen, die auf den Ebbe-Flut-Systemtischen mit Verwendung von 6 verschiedenen Nährmedien oder unter Sprühnebel gedüngt mit Langzeitdünger (2 g L^{-1} Osmocote Exact 15-9-9) angebaut wurden. Für die Fertigation wurden folgende Nährmedien verwendet: 60-20-60, 120-20-60, 180-20-60, 120-40-60, 120-60-60 und 120-20-120 (N-P-K in mg L^{-1}). Die Pflanzen der Sorte 'Blurettia', die mit dem höchsten N-Gehalt gedüngt wurden, waren höher als alle anderen Kombinationen einschließlich der mit Langzeitdünger. Die Anzahl Blätter pro Pflanze war für alle Kombinationen gleich. Der niedrigste N-Gehalt verminderte bei 'Percy Wiseman' nicht nur die Pflanzenhöhe, sondern auch die Anzahl Blätter. Bei beiden Sorten führten niedriger N-Gehalt wie auch Langzeitdüngung zu schwacher Blüte. Die Erhöhung von P und K verursachte bei der Sorte 'Blurettia' eine Verringerung der Blütenknospen, wohingegen bei 'Percy Wiseman' eine umgekehrte Tendenz festgestellt wurde. Der mittlere EC-Wert der Substrate in den Pflanzentöpfen auf den Ebbe-Flutsystem-Tischen war um ein mehrfaches höher als der in den mit Osmocote gedüngten und beregneten Töpfen. Im Gegensatz dazu war der Anstieg des pH-Wertes des Substrates bei der Beregnung viel deutlicher. Die Bewässerung auf den Ebbe-Flut-Systemtischen hat dazu beigetragen, dass sich in der oberen Substratschicht Salze akkumuliert haben, obgleich die Pflanzen im Freiland angebaut wurden und man annehmen konnte, dass der Regen diese auswaschen würde. Die Nährstoffgehalte in den Blättern entsprachen denen des Substrats. Es wurde aber festgestellt, dass, die mit Langzeitdünger gedüngten Pflanzen ziemlich geringe P-Gehalte und hohe Ca-Gehalte in den Blättern aufgewiesen. Der hohe N- und P-Gehalt erhöhte die Frosthärte der Rhododendronblätter im Vergleich zu Nährmedien mit niedrigem N-Gehalt und zu der Kombination mit Osmocote.

Key words. ebb-and-flow – fertigation – plant nutrition – water recirculation

Introduction

Ground water contamination as well as pollution of lakes and rivers caused by nitrate and phosphate runoff from agricultural land has become a major global environmental concern. These issue and the related problem of shrinking water reserves due to contamination and depletion of water resources are of growing interest to the environmental plant industry. In the near future, restrictions both on amounts of water use and fertilizers runoff in greenhouses and nurseries will probably be enforced (MOREY 1987; MAC CARTHAIGH 1994). New production methods like ebb-and-flow irrigation systems have been currently the most effective means of eliminating or substantial reducing of nutrient leaching and runoff from plant production. Ebb-and-flow irrigation is becoming increasingly popular in pot plant production in greenhouses and it is also more and more often used in nursery stock production (MOLITOR 1990; MEGGELEN-LAAGLAAN 1992). Subirrigation including ebb-and-flow irrigation systems has many advantages compared to overhead watering, such as more efficient use of water and fertilizer and lower labor requirements (KREIJ and STRAVER 1988; POOLE and CONOVER 1992; IERSEL 1996; PURVIS et al. 2000). With recirculation system water use is reduced by as much as 40 to 70 % compared to conventional drip or sprinkler irrigation (PURVIS et al. 2000). Ebb-and-flow irrigation can produce excellent quality plants (MORVANT et al. 1997; TODD and REED 1998) and improve uniformity thanks to more even watering and fertilization (IERSEL 1996). However, salt accumulation in the growing medium, especially in the top layer, is anticipated and may become one of ebb-and-flow's major drawbacks due to the absence of leaching. This process is caused by high water evaporation from soil surface and it can negatively affect plant growth. Salt accumulation in the growing medium is correlated with concentration of nutrient solution and depends on potting medium, frequency of irrigation, weather conditions, and plant species (KREIJ and STRAVER 1988; YELANICH and BIERNBAUM 1990; POOLE and CONOVER 1992; TREDER et al. 1998; MATYSIAK et al. 2001; MAROSZ et al. 2002). In outdoor ebb-and-flow systems e.g. in ornamental nurseries, the severity of this process should be reduced, thanks to some leaching occurring during rain.

Rhododendrons are among the most popular landscape plants in Europe and North America. New taxons of rhododendrons enter the market every year. *Rhododendron yakushimanum* cvs. plants are compact shrubs with crème to rose flowers produced abundantly already on young plants (FLANAGAN and MILLAIS 1999) which makes them especially suitable for pot production. Rhododendrons require acid soils and they are known to be sensitive to high fertilizer level. There is no specific nutrient formula for fertigation of *Rhododendron yakushimanum* cvs. For other groups of rhododendrons produced in greenhouses the following nutrient solution for fertigation are recommended, N-P-K (mg L^{-1}) 105-15.5-78 for *Rhododendron catawbiense* group and 84-23-68 for Japanese rhododendrons group (BEEL and PIENS 1979; AENDEKERK 1999).

Level of macroelements in the nutrient solution may affect growth, flowering and cold hardiness of rhododendrons. High concentration of nitrogen in the nutrient solution favor leaves and shoots production and flower bud formation of rhododendrons (WRIGHT 1992). RYAN (1979) reported that phosphorus content in the leaves of rhododendron was correlated with percent of shoots forming flower buds. Rhododendrons set flowers in July and feeding with potassium in this time can also improve flower bud initiation (VEEN 1992). Potassium also hardens the cell walls, which can improve winter hardiness (PELLETT and CARTER 1981). There are many reports that application of high doses of nitrogen late in the growing season cause very lush growth of rhododendrons and can negate potassium effects (PELLETT and CARTER 1981; VEEN 1992).

The objective of this study was to find optimal nutrient solution for good growth and flowering of *Rhododendron yakushimanum* cvs. grown on ebb-and-flow benches. The second objective was to determine the effect of nutrient solution composition on nutrient status of the plants and the accumulation and distribution of soluble salts and pH change in the growing medium as well as on cold hardiness of rhododendrons determined in midwinter by electrolyte leakage test of leaves.

Material and Methods

The experiment was established at Research Institute of Pomology and Floriculture in Skierniewice in Poland (latitude 52 °N, longitude 20 °E). Two popular evergreen rhododendrons (*Rhododendron yakushimanum* Nakai) 'Blurettia' (USDA Hardiness Zone 5b) and 'Percy Wiseman' (USDA Hardiness Zone 6b) were chosen for the experiment. One-year-old micro-propagated plants obtained from a commercial propagator were potted on 24 April 2001 in 1.6 L plastic pots filled with a mixture of sphagnum peat moss and composted pine bark (3:1, v/v). Potting medium pH was 4.5. Rhododendrons were cultivated outside in closed fertigation system on ebb-and flow benches (Clauhan, Denmark). On average, plants were flooded two times a week, for 10 min to a depth of 1 cm; however, actual frequency of flooding depended on weather conditions. Six nutrient solutions (treatments) with different nitrogen, phosphorus and potassium levels i.e. N-P-K (in mg L^{-1}) 60-20-60, 120-20-60, 180-20-60, 120-40-60, 120-60-60 and 120-20-120 were used for fertigation. As Ca content in tap water used for nutrient solutions preparation was 80 mg L^{-1}, which is sufficient for rhododendrons, no additional calcium was added. Content of Mg was increased to 20 mg L^{-1} in all nutrient solutions. As a source of microelements a completely soluble fertilizer Libremix B (B 0.8, Zn 0.6, Mn 1.5, Mn 1.5, Cu 1,6, Mo 2.5 and Fe 3.3, in %) was added at the dose of 0.8 g per 100 L for all nutrient solutions. Growth, flowering, leaf nutrient content, EC and pH of potting medium as well as cold hardiness of rhododendrons cultivated on ebb-and-flow benches were compared with plants fertilized with control release fertilizer Osmocote Exact (Scotts), 3-4 M (15 % N, 9 % P_2O_5, 9 % K_2O, 0.4 % Fe, 0.06 % Mn, 0.05 % Cu, 0.02 % B, 0.02 % Mo, 0.015 % Zn) at the dose 2 g L^{-1} incorporated into the potting medium before planting (standard treatment). The plants in standard treatment were irrigated overhead by sprinklers as needed and no additional fertilization was applied.

Plants were fertigated till the end of August at which time the following growth measurements were made; plant height (measured from the pot rim to the top of the plant), number of leaves, number of plants with formed flower buds and number of flower buds per plant. Recently matured leaves were sampled for nutrient analysis. The leaf tissue was oven-dried at 70 °C, milled to homogeneous samples, and than treated with mixture of HNO_3 and $HClO_4$. N was determined using the Kjeldahl method with an automatic distillation system with boric acid (Kjeltec, Tecator, Sweden). The concentrations of K, Ca and Mg were measured using atomic absorption spectrophotometry (PU 9100X, Philips, Holland) and P was determined colorimetrically using vanadium-molybdate complex. After the leaves for nutrient analysis were collected, the growth medium was sampled for EC and pH measurements. Electrical conductivity and pH were determined using the 1:2 (growth medium : deionized water, v/v) method using 40 cm^3 soil samples and 80 cm^3 of deionized water. Growth medium and water were mixed thoroughly and left for 30 min prior to EC and pH measurements.

Weather data (rainfall and air temperature) during the period of cultivation were monitored at 12-minute intervals, and collected by an automatic weather station (Metos, Pessl Instruments, Austria). Monthly average temperatures (°C) and respective sums of rainfall (mm) were in April 8.1 and 93, in May 14.2 and 31, in June 15.2 and 75, in July 20.2 and 104, in August 19.1 and 51, in September 12.1 and 79 and in October 11.1 and 22.

Plants were transferred to unheated greenhouse on 15 October 2001 and temperature was kept above freezing. During winter, controlled freezing tests of leaves were conducted to determine cold hardiness of rhododendrons from selected treatments, where differences in cold hardiness of plants were expected. Cold hardiness of plants fertigated with the following nutrient solutions N-P-K (mg L^{-1}): 60-20-60, 180-20-60 and 120-20-120 and those fertilized with Osmocote were determined. Sampling for freezing tests was carried out in two series on 7 and 21 January 2002. The leaves were wrapped in moist paper towels and placed in a programmable, walk-in controlled climate chamber (Heraeus Vötsch, Austria). In order to avoid excessive supercooling, samples were nucleated with ice at –2 °C and maintained at this temperature for 18 h. A cooling rate of 3 °C per h was employed and leaf samples were kept for one hour at each test temperature (–16 °C, –19 °C, –22 °C, –25 °C, and for 'Blurettia' also –28 °C. Unfrozen control was kept at 4 °C for the duration of the test. After the freezing treatments, samples were thawed at 4 °C for 18 h. Electrolyte leakage measurements of leaves were used to evaluate the injury caused by the freezing procedure as described by FLINT et al. (1967). Leaf discs, 1 cm in diameter were prepared the day after the freezing test. Samples consisting of four leaf discs per vial were incubated and shaken in 15 ml of deionized water for 24 h at 21 °C. Following initial leakage measurements, samples were autoclaved at 121 °C for 20 min to ensure death. Then they were shaken for 24 h prior to final leakage measurements. Injury I_T (%) resulting from exposure to temperature T was defined according to LIM et al. (1998) as:

$$I_T = (t\%–k\%)/(100–k\%) \times 100$$

where t is the fractional release of total electrolytes from samples exposed to temperature T and k is the fractional releases from the unfrozen sample. In each series, five leaves per treatment were taken out at each test temperature for both cultivars. As differences in the cold hardiness levels for two sampling dates were very small the data were analysed statistically with ANOVA and are presented as means for two series.

The experiment design had 7 treatments (six compositions of nutrient solution used for ebb-and-flow irrigation and one Osmocote treatment) and there were 4 replicates with 5 plants per replicate. The data were analysed statistically with ANOVA.

Results and Discussion

Plant growth

'Blurettia' and 'Percy Wiseman' rhododendrons cultivated on ebb-and-flow benches grew very well compared to these given controlled release fertilizer and by the end of the growing period they were of high marketable quality. Composition of nutrient solution used for subirrigation affected plant height, leaves and flower production of plants and some differences between cultivars occurred (Table 1). 'Blurettia' plants fertigated with nutrient solution N180-P20-K60 were the highest but number of leaves per plant was not affected by kind of fertilization used in the experiment. For 'Percy Wiseman' the lowest content of N in the nutrient solution (N60-P20-K60) had negative effect on plant height and also on leaf production. Besides, plant foliage of both tested cultivars in this treatment as well as plants fertilized with Osmocote at the dose 2 g L^{-1} displayed moderate signs of chlorosis. On the contrary, the other treatments produced dark green foliage.

Rhododendron yakushimanum cvs. plants set flower buds in the early age. In our experiment with two years old plants, in the end of growing season at least 1.5 per 5 plant of 'Blurettia' and 2.8 per 5 plants of 'Percy Wiseman' had formed flower buds (Table 1). The lowest N content in nutrient solution (N60-P20-K60) as well as Osmocote fertilization resulted in poor flower bud set. The number of plants with flower buds and mean number of flower buds per plant in these treatments were the lowest, especially for 'Blurettia'. The highest flower buds production of 'Blurettia' was noted at nutrient composition N120-P20-K60 and N180-P20-K60. Increasing P or K concentration in the nutrient solution at nitrogen level 120 mg L^{-1} resulted in lower number of flower buds per plant of 'Blurettia'. However, for 'Percy Wiseman' the highest number of flower buds per plant occurred at increased potassium (120 mg L^{-1}) and phosphorus (40 and 60 mg L^{-1}) content in the nutrient solution.

Based on these results nutrient solution N180-P20-K60 for 'Blurettia' and N120-P20-K120 can be recommended for plants cultivated outdoors on ebb-and-flow benches. While P and K levels in the nutrient solution generally do not differ from recommended levels for other groups of rhododendrons cultivated under glass (AENDEKERK 1999) N level is slightly higher. Higher nitrogen requirements for plants cultivated outdoor than under glass can result from differ-

Table 1. Growth and flowering of *Rhododendron yakushimanum* 'Blurettia' and 'Percy Wiseman' as affected by composition of nutrient solution used in ebb-and-flow irrigation compared to controlled release fertilizer Osmocote Exact Standard 15-9-9.

Treatment	'Blurettia' Plant height (cm)	Number of leaves per plant	Number of plants with flower buds (n=5)	Mean number of flower buds per plant	'Percy Wiseman' Plant height (cm)	Number of leaves per plant	Number of plants with flower buds (n=5)	Mean number of flower buds per plant
Nutrient solution N – P - K (mg L^{-1})								
60-20-60	17.6 a[1]	86 a	1.5 a	0.6 ab	19.1 a	86 a	3.8 ab	1.6 ab
120-20-60	18.2 a	99 a	4.0 c	2.1 d	22.0 b	113 bc	4.5 bc	2.3 bc
180-20-60	21.5 b	99 a	4.0 c	3.3 d	22.0 b	122 c	3.8 ab	2.3 bc
120-40-60	19.6 ab	103 a	3.0 a–c	1.3 a–c	22.3 b	112 bc	4.3 bc	2.7 d
120-60-60	19.5 ab	93 a	4.0 c	1.9 bc	22.2 b	102 ab	4.3 bc	2.6 d
120-20-120	17.3 a	100 a	3.5 bc	1.6 a–c	22.6 b	112 bc	5.0 c	3.2 d
Osmocote 2 g L^{-1}	17.9 a	96 a	1.8 ab	0.5 a	21.5 b	127 c	2.8 a	0.9 a

[1]Means of each parameter followed by the same letter within a column are not significantly different according to Duncan's multiple range test, P = 0.05.

Table 2. Overall effects of composition of nutrient solution used in ebb-and-flow irrigation versus controlled release fertilizer Osmocote Exact Standard 15-9-9 and sample type on EC and pH (in H_2O) of the growth medium.

Treatment	'Blurettia' EC (dS m^{-1})	pH (H_2O)	'Percy Wiseman' EC(dS m^{-1})	pH (H_2O)
(A) Fertilization				
Nutrient solution N - P- K (mg L^{-1})				
60-20-60	0.7 b[1]	4.5 a	0.6 b	4.6 b
120-20-60	0.8 b	4.5 a	0.7 bc	4.6 b
180-20-60	0.9 b	4.4 a	0.8 bc	4.4 ab
120-40-60	0.8 b	4.5 a	0.7 bc	4.5 ab
120-60-60	0.7 b	4.5 a	0.7 bc	4.4 a
120-20-120	0.8 b	4.9 b	0.8 c	4.9 c
Osmocote 2 g L^{-1}	0.1 a	5.3 c	0.1 a	4.9 c
(B) Sample Type				
Upper One-third	1.0 b	4.5 a	1.1 c	4.3 a
Medium One-third	0.6 a	4.4 a	0.5 b	4.3 a
Bottom One-third	0.4 a	5.1 b	0.4 a	5.2 b
ANOVA significances				
A	**[2]	**	**	**
B	**	**	**	**
A × B	**	**	**	**

[1]Means of each parameter followed by the same letter are not significantly different within one factor according to Duncan's multiple range test, P=0.05.
[2]** = significant at P=0.05.

ences in N requirements for cultivars as was reported by WRIGHT (1992) or some leaching occurring during rainfalls, even though recirculation irrigation is used. It is known that nitrogen is more readily leached then P and K. Increased nitrogen fertilization results in high chlorophyll content in the leaves, improves their colour (ALT et al. 1992) and consequently increases market quality of evergreen rhododendrons.

Growth medium electrical conductivity and pH

Measurements of growth medium EC during cultivation proved that fertilization method used in the experiment significantly affected salt accumulation in the peat and composted pine bark (3:1, v/v) medium (Table 2). Overall, EC of the potting medium was much higher with subirrigation on ebb-and-flow benches ir-

Table 3. Nutrient content of *Rhododendron* leaves (% d.w.) as affected by composition of nutrient solution used in ebb-and-flow irrigation or fertilized with controlled release fertilizer Osmocote Exact Standard 15-9-9.

	'Blurettia'					'Percy Wiseman'				
Treatment	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Nutrient solution N - P -K (mg L^{-1})										
60-20-60	0.97 a[1]	0.14 ab	1.05 a	0.47 a	0.24 a	1.14 a	0.18 b	0.91 b	0.31 a	0.24 a
120-20-60	1.34 c	0.16 a–c	0.99 a	0.47 a	0.22 a	1.60 b	0.18 b	0.94 b	0.37 a	0.24 a
180-20-60	1.71 d	0.18 a–d	0.99 a	0.43 a	0.22 a	2.10 c	0.19 bc	0.89 ab	0.32 a	0.25 a
120-40-60	1.23 bc	0.21 d	0.10 a	0.45 a	0.22 a	1.34 ab	0.24 d	0.88 ab	0.31 a	0.25 a
120-60-60	1.17 b	0.23 d	1.02 a	0.42 a	0.22 a	1.17 a	0.26 d	0.90 b	0.32 a	0.25 a
120-20-120	1.22 bc	0.19 b–d	1.14 b	0.46 a	0.22 a	1.53 b	0.20 bc	1.22 c	0.34 a	0.23 a
Osmocote 2 g L^{-1}	1.21 bc	0.13 a	1.01 a	0.62 b	0.21 a	1.34 ab	0.10 a	0.78 a	0.64 b	0.24 a

[1]In each column, means followed by the same letter are not significantly different according to Duncan's multiple range test, P=0.05.

Table 4. Injury I_T (%) of leaves *Rhododendron yakushimanum* 'Blurettia' and 'Percy Wiseman' as affected by composition of nutrient solution used in ebb-and-flow irrigation or fertilized with controlled release fertilizer Osmocote Exact Standard 15-9-9.

Treatment	'Blurettia'						'Percy Wiseman'				
	–16 °C	–19 °C	–22 °C	–25 °C	–28 °C	Mean	–16 °C	–19 °C	–22 °C	–25 °C	Mean
Nutrient solution N - P - K (mg L^{-1})											
60-20-60	2.3 ab[1]	5.1 bc	11.4 de	16.9 fg	18.1 g	10.7 c	19.4 b	37.2 ef	43.5 f	57.3 g	39.4 c
180-20-60	0.9 a	2.9 a–c	5.4 bc	13.3 de	14.1 ef	7.3 a	6.9 a	22.5 bc	26.9 d	32.2 de	22.1 ab
120-20-120	0.9 a	3.0 a–c	6.3 c	11.9 de	13.3 de	7.1 a	9.3 a	22.4 bc	22.7 bc	31.1 de	21.4 a
Osmocote 2 g L^{-1}	2.9 a–c	4.5 bc	10.4 d	14.2 ef	13.9 ef	9.2 b	8.7 a	20.5 bc	31.7 de	40.1 f	25.2 b
Mean	1.7 a	3.9 b	8.4 c	14.1 d	14.9 d		11.1 a	25.7 b	31.2 c	40.2 d	

[1]For each cultivar, means followed by the same letter are not significantly different according to Duncan's multiple range test, $P < 0.05$.

respective of the composition of nutrient solution than with Osmocote fertilization for both tested cultivars. For 'Blurettia' cultivated on ebb-and-flow benches, composition of nutrient solution did not affect EC of the potting medium, and for 'Percy Wiseman' lower EC was measured at N60-P20-K60 than at N120-P20-K120.

Gradient of growth medium EC depended on fertilization method. There were no differences in EC between the three sample types with Osmocote fertilization, but with ebb-and-flow subirrigation EC of the top layer was higher than the EC of the bottom sample. Higher EC values with subirrigation, especially at the surface of the growth medium, can be expected because evaporation of water from the surface and reduced leaching favour the accumulation of salt residues. GUTTORMSEN (1969), MORVANT et al. (1997) and COX (2001) have reported similar patterns of salt accumulation with subirrigation. In our experiment the highest ECs were found in the top samples of ebb-and-flow subirrigated plants and they exceeded slightly the upper limit (1.0 dS m^{-1}) for established rhododendron plants irrigated overhead. The salts accumulation in the upper medium generally is not a problem when plants grown on ebb-and-flow benches receive a low fertilizer concentration (DOLE et al. 1994) because root systems are usually concentrated in the middle and bottom layers of the rooting medium. The root system of rhododendrons, similarly to other ericaceous, consists of a network of fine roots called hair roots (DOUGLAS et al. 1990). These delicate roots are very susceptible to high salt concentration in the growth medium, resulting in smaller plants and reduced flowering (ANDERSEN and PEDERSEN 1978). Use of nutrient solution with EC above 1.1 dS m^{-1} for *Erica carnea* 'Nathalie' and *Gaultheria procumbens* and above 1.7 dS m^{-1} for *Calluna vulgaris* 'Allegretto' cultivated on ebb-and-flow benches progressively decreased growth and plant quality (MATYSIAK et al. 2001; MAROSZ et al. 2002).

During cultivation the pH of the potting medium slightly increased in the bottom layer but not in the upper one for plants cultivated on ebb-and-flow benches. The increase of pH of the potting medium was the most evident when Osmocote was used. However, in this treatment there was no difference in pH of the top,

medium, and bottom sample. In our study calcium was not added to the nutrient solution because of its high concentration in top water (80 mg L^{-1}). Rhododendrons fertilized with Osmocote were overhead irrigated and water passed through the whole profile of the growing medium, which resulted in pH increasing of all sample types. As ericaceous plants are sensitive to high pH level, long-term overhead irrigation with hard water can negatively affect growth and quality of plants. Opposite to overhead irrigation in ebb-and-flow benches water is applied from the bottom and capillary flows to the top of the growing containers. Water retention in the bottom layer and direction of water flow with subirrigation systems are probably the reason of pH increasing mainly in the bottom layer. The highest pH values measured in the bottom layer of growing medium were also found for *Calluna vulgaris* (MATYSIAK et al. 2001), *Gaultheria procumbens* and *Erica carnea* (MAROSZ et al. 2002) and *Ficus benjamina* (TREDER et al. 1998), cultivated on ebb-and-flow benches.

Leaf analysis

Nitrogen content of rhododendron leaves was affected mainly by nitrogen level in the nutrient solution used for plants grown on ebb-and-flow benches (Table 3). For both tested cultivars, N content in the leaves increased with increasing N level in the nutrient solution and this value was the lowest at N60-P20-K60. Also rhododendrons fertilized with Osmocote 2 g L^{-1} contained low N in the leaves but this value did not significantly differ with the plants fertigated with N120-P20-K60. Moderate signs of chlorosis observed in these two treatments could result from insufficient nitrogen nutrition of the rhododendrons. Increased K level in the nutrient solution to 120 mg L^{-1} did not affect N content of the leaves significantly but a tendency of decreasing N content with increasing P concentration in the nutrient solution for both cultivars was observed.

Increasing P level in the nutrient solution resulted in increased P content in the leaves. P content of the leaves of 'Percy Wiseman' fertilized with Osmocote was significantly lower that for plants fertigated with nutrient solution irrespectively of the nutrient composition but this difference was less evident for 'Blurettia' plants.

For both tested cultivars K content in the leaves was the highest at increased K level in the nutrient solution (N120-P20-K120). Leaves of 'Percy Wiseman' fertilized with Osmocote 2 g L^{-1} contained on average less potassium than plants cultivated on ebb-and-flow benches but for 'Blurettia' there were no major differences in K content in the leaves between treatments except of high level of K in the nutrient solution N120-P20-K120.

Calcium content of the leaves was strongly affected by kind of fertilization used in experiment and was higher in leaves of rhododendrons of both tested cultivars fertilized with Osmocote than in leaves of plants cultivated on ebb-and-flow benches, irrespectively of the nutrient solution composition.

For both tested cultivars, leaf content of Mg was not affected by composition of the nutrient solution used in the experiment and was at the same level as in plants fertilized with Osmocote.

In contrast to many other crops, no optimal ranges of foliar nutrient levels are established for *Rhododendron yakushimanum* cvs. Additionally, chemical composition of rhododendron leaves can differ between groups, cultivars, and plant's age (AENDEKERK 1999). The best growth and flowering of 'Blurettia' was obtained at N180-P20-K60 and the plants accumulated N 1.71 %, P 0.18 %, K 0.99 %, Ca 0.43 % and Mg 0.22 %. The best growth and flowering of 'Percy Wiseman' was obtained at N120-P20-K120 and the plants accumulated N 1.53 %, P 0.20 %, K 1.22 %, Ca 0.34 % and Mg 0.24 %. These values can be recognized as optimal for plants produced in subirrigation systems. Differences in nutrient content in the leaves of overhead irrigated and subirrigated plants were previously reported by DOLE et al. (1994) and COX (2001).

Freezing Test

Fertilization level during cultivation affected not only plant growth and flower bud formation but also cold hardiness of rhododendron leaves determined in midwinter by electrolyte leakage test (Table 4). 'Blurettia' was more tolerant to stress temperature than 'Percy Wiseman'. Overall percentage of leaf injuries in –25 °C for 'Blurettia' was 14.9 while for 'Percy Wiseman' this temperature caused injuries as high as 40.2 %. Percentage of leaf injuries was generally the lowest for 'Blurettia' cultivated on ebb-and-flow benches and flooded with nutrient solution containing the highest level of nitrogen i.e. N180-P20-K60 and increased level of potassium i.e. N120-P20-K120. For 'Percy Wiseman', the lowest percentage of leaf injuries was measured at increased potassium level i.e. N120-P20-K120. In spite of differences in cold hardiness of tested cultivars, leaf injuries of plants fertigated with the lowest nitrogen concentration (N60-P20-K60) were the highest which suggests their decreased tolerance to freezing stress. Percentage of leaf electrolyte leakage of plants fertilized with Osmocote at the dose 2 g L^{-1} was lower than for plants fertigated with nutrient solution with the lowest N content but higher then plants fertigated with N180-P20-K60 and N120-P20-K120. However, for 'Percy Wiseman' differences in leaf injuries between plants fertilized with Osmocote and fertigated with nutrient solution N180-P20-K120 were not statistically significant at $P=0.05$.

The results clearly demonstrate that optimal level of nitrogen nutrition of rhododendrons, which ensures optimal growth, flowering, and plant vitality, increases also cold hardiness of plants during the following dormancy period. Insufficient nitrogen nutrition decreases carbohydrate production because of reduced photosynthetic activity. High level of carbohydrates is recognized as pre-requisite for cold acclimatization (KRAUSE et al. 1982). Sugars are known to lower the freezing point and increase the intracellular osmotic potential. This would reduce the amount of dehydration during extracellular freezing (LEVITT 1980). Sugars also act as colligative cryoprotectants for cell membranes and proteins by diluting electrolytes and toxic compounds that accumulate during freezing (SANTARIUS 1982). Also enhanced potassium may increase cold tolerance by changing cell osmotic concentrations and depressing the freezing point. For rhododendrons, a short-day

photoperiod and low temperatures induce acclimatization and increase cold resistance, and plant in this treatment accumulate more potassium and sodium but less calcium and phosphorus, magnesium and manganese (CAMERON and DIXON 2000). Our trial proved that both nitrogen and potassium fertilization affects winter hardiness of rhododendrons and should be taken into consideration when evaluating cold hardiness of new hybrids.

Conclusions

High N content in nutrient solution (120 or 180 mg L^{-1}) stimulates both growth and flower buds formation on *Rhododendron yakushimanum* 'Blurettia' and 'Percy Wiseman' compared to low N level (60 mg L^{-1}) or standard application of Osmocote Plus 3-4M (2 g L^{-1}).

High P and K levels slightly increase number of flower buds on 'Percy Wiseman' while the opposite is true for 'Blurettia'.

EC value of growing media in ebb-and-flow system is much higher than under overhead irrigation. However, pH increase is more evident under overhead irrigation.

High N and K levels increase cold hardiness of leaves of rhododendrons compared both to low N nutrient solution or Osmocote treatment.

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