Zeszyty Problemowe Postępów Nauk Rolniczych
nr 588, 2017, 37–45
DOI 10.22630/ZPPNR.2017.588.4

EFFECTS OF CONTINUOUS AND PERIODIC WATER STRESS ON COLD HARDINESS OF RHODODENDRON CULTIVARS

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Summary. The purpose of the present study was to determine whether water deficit affects cold hardiness of rhododendron 'Catawbiense Boursault', 'Lee's Dark Purple', 'Prinz Karneval' and 'Old Port' shrubs. Plants were grown in unheated greenhouse and for 14 weeks from June to mid-September were subjected to six irrigation treatments. In the end of September shrubs were left in an unheated greenhouse or planted into the ground and at the beginning of each month from December to March freezing tolerance tests were performed. The results showed that in all rhododendron cultivars the highest cold hardiness was noted in January and February, lower in March but the lowest in December. Application of four-week water deficit period during summer especially between the first and the second vegetative growth may improve the frost resistance of *Rhododendron* shrubs.

Key words: water deficit, irrigation method, frost tolerance, freezing temperature, electrolyte leakage measurements

INTRODUCTION

Polish climate is characterized by varying weather conditions and at the same time a high proportion of evaporation in the water balance leads to periodic water scarcity and droughts [Kuśmierek-Tomaszewska et al. 2011, Łabędzki and Bąk 2011]. Water stress and freezing stress are among the most severe environmental stresses that affect plant growth. In literature some studies demonstrate the relationship between tolerance to freezing and drought [Kreyling et al. 2012, Walter et al. 2013]. Cold hardiness and changes in plant water relations are connected and the water content in plant tissues is reduced during

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cold acclimation [Pagter 2008]. Several woody plants subjected to drought stress applied for few weeks have been shown to increase cold hardiness [Poirier and Améglio 2006, Kreyling et al. 2012, Pembleton and Sathish 2014]. Anisko and Lindstrom [1996a, b] examined the effects of reduced irrigation on cold hardiness of *Rhododendron* cultivars. Their results show that 3–6 weeks reduced water supply in late summer or in autumn increased freezing resistance. Moreover these authors observed that cold hardiness was dependent on the intensity of water deficit in irrigation treatment applied.

In 2012, experiments were conducted whose aim was to analyse the effect of regulated deficit irrigation (RDI) on growth and development of potted rhododendron 'Catawbiense Boursault' and 'Old Port' plants [Koniarski and Matysiak 2013]. Those studies found that moderate and severe water deficit maintained throughout the 14-week period of growing of shrubs *Rhododendron* 'Catawbiense Boursault' and 'Old Port' as well as severe water deficit applied only during the vegetative growth limits the elongation growth of shoots, improves plant habit and quality. Moreover the application of water stress during four--week period corresponding with floral buds initiation in these rhododendron cultivars increases the number of flower buds made.

The purpose of the present study was to examine the subsequent impact of RDI on cold hardiness of rhododendron cultivars 'Catawbiense Boursault', 'Lee's Dark Purple', 'Prinz Karneval' and 'Old Port'.

MATERIAL AND METHODS

Plant material and growth conditions

Experiments were conducted at the beginning of each month in two research seasons from December 2013 to March 2014 and from December 2014 to March 2015 in the Research Institute of Horticulture in Skierniewice, Poland. The subject of studies were four *Rhododendron* cultivars represented by four-year-old 'Catawbiense Boursault' and 'Old Port' shrubs in the first research season and three-year-old *Rhododendron* 'Lee's Dark Purple' and 'Prinz Karneval' plants in the second, respectively.

During first experimental season cold hardiness was tested on leaves of plants grown in plastic containers in unheated greenhouse. Before the experiment with evaluating of cold hardiness started shrubs had been subjected to differentiated irrigation from early June to mid-September 2013. Water deficit treatments were established by applying irrigation in proportions to the estimated evapotranspiration (ETp) that was determined by monitoring weight loss from the containers over 24 h. Shrubs were subjected to six irrigation regimes: 1 ETp (control, well watered plants with irrigation rate balancing water loses by evapotranspiration – T1), 0.75 ETp (moderate deficit irrigation – T2), 0.5 ETp (strong deficit irrigation) during the entire period of experiment – T3, and the others three were: 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 – T4), 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 – T5), and 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 – T6). After the end of this experimental part of the study, shrubs were left in an unheated greenhouse and each container with plant was irrigated with 300 ml of water. The methodology concerned this stage of study was the same as in study of Koniarski and Matysiak [2013] and this is the continuation of that research.

In the second research season similar experiment was conducted. In the end of September after the completion of experimental part concerned the impact of water stress on the growth of shrubs, plants were planted into the ground. The temperature in the field ranged from: average 3.4°C; max. 7.1°C; min. 1.3°C in December, 1.4°C, 11.9°C, –10.4°C in January, 1°C, 8.5°C, –6.1°C in February, 5.1°C; 17.5°C; –5.3°C in March, respectively. The meteorological data was recorded by means of the meteorological station Metos (Pessl Instruments, Austria).

Measurements of cold hardiness

At the beginning of each month from December 2013 to March 2014 in the first study season and from December 2014 to March 2015 in the second experimental season it was taken three annual leaves from different parts of each shrub. The leaves were packed in plastic bags, transported to the laboratory and placed in a fridge for 16 h storage at a temperature 4°C. Next day leaves were removed from the fridge, covered with ice crystals and wrapped in moist cheesecloth. Thus prepared samples were placed in a programmable, controlled climate chamber (Binder IFC 720, Germany) and in order to ensuring ice nucleation, were frozen at the temperature range 0.5°C/–2.5°C for 2 h. Next a cooling rate of 3°C per hour was employed and leaf sample were kept for one hour at each test temperature (–10°C, –20°C, –25°C, –30°C) in the first research season and (–20°C, –25°C, –30°C) during the second experimental season. After freezing, leaf discs about 1 cm in diameter were prepared and placed in vials. Samples consisting of five leaf discs per vial were incubated and shaken (amplitude 7, 100 rpm) in 15 ml of redistilled water for 2 h at 22°C. Each irrigation treatment was represented by five vials, i.e. four vials – replications, and one control vial not frozen. In total it was 30 vials for each *Rhododendron* cultivar. On thus prepared electrolyte solution, which leaked from the damaged leaves, electrical conductivity – EC [$mS \cdot cm^{-1}$] value was measured by using a conductivity meter (Eijkelkamp, Netherlands). After completing the conductivity measurements, the plant material in the same vials was autoclaved at 121°C for 20 min for its total destruction. In this way the released electrolyte was measured again by the same method as before. The control material obtained from the same leaves were treated and measured similarly, but without freezing phase. The percentage of ions leakage that occurred as a result of frost damage of leaves was calculated according to the formula $t\% = C1/C2$, where $C1$ is the conductivity of frozen leaves, but $C2$ is the conductivity of frozen and autoclaved leaves. The percentage of ions leakage in control combination was calculated according to the formula $k\% = K1/K2$, where $K1$ is conductivity of leaf discs that were not frozen, while $K2$ is the conductivity of leaf discs that were frozen and autoclaved. Injury I_T [%] resulting from exposure to temperature T was defined according to Lim et al. [1998], i.e. $I_T = (t\% - k\%) / (100 - k\%) \times 100$.

Statistical analysis

Experiments was set up in 4 replications (experimental blocks), each consisted of 10 plants. The analysis of variance (ANOVA) was conducted using Statistica 10 PL 2012 (StatSoft Poland) software. When the ANOVA indicated significant effects, means were separated using Duncan's Multiple Range Test, with $p < 0.05$ considered to be statistically significant.

RESULTS AND DISCUSSION

In our study in all rhododendron cultivars in the experiment, along with the reduction of temperature values, leaf frost injury were significantly increasing. Among the four examined cultivars the largest frost damage was observed in 'Prinz Karneval' and the smallest in 'Catawbiense Boursault' (Tables 1–4). The greatest percentage of leaf freeze damage averaged for all water treatments was observed in all tested cultivars in December at the temperature –30°C.

Changes in photoperiod and temperature may significantly influence of cold hardiness. In autumn along with reducing of temperature plants cold acclimate, maximum hardiness is reached in mid-winter and in spring plants loose acclimated frost tolerance by deacclimation [Salazar-Gutiérrez et al. 2014]. Our results show that in all rhododendron cultivars the lowest cold hardiness was noted in the beginning of December, however in January and February it was significantly higher (Tables 1–4). For 'Catawbiense Boursault' and 'Prinz Karneval' the lowest percentage of freezing injury at a temperature of –30°C was observed in January (Tables 1, 4), but for 'Lee's Dark Purple' and 'Old Port' in February (Tables 2, 3). In the beginning of March cold hardiness was lower than in the previous two months, but still better than in December (Tables 1–4). Morin et al. [2007] conducting research on cold hardiness of three oak species, *Quercus ilex*, *Q. pubescens*, *Q. robur* observed that in January the mean temperature causing 50% cell lysis (LT_{50}) were –27.8°C, –45.4°C, –56.2°C and were significantly higher than in October, when they were –11,8°C, –14.6°C, –20.7°C respectively. In turn, in the March–April period (LT_{50}) were –24.6°C, –37.6°C, –46.9°C, respectively. Similarly, Swiderski et al. [2004] reported that cold hardiness of several cultivars of rhododendrons varied, especially at the beginning and end of winter. According to these authors, plants showed maximum cold hardiness in mid-winter, in January.

In our experiment the level of water deficit significantly affected cold hardiness in all rhododendron cultivars. Along with the reduction of water rates in T2 and T3 irrigation regimes in comparison to control plants (T1), cold hardiness of plants decreased significantly for all months (Tables 1–4). In general 'Catawbiense Boursault' plants under T4, T5, T6 water treatments as well as 'Lee's Dark Purple' and 'Prinz Karneval' shrubs under T4 and T5 irrigation treatments were characterized by a significantly higher values of cold hardiness than in T2 and T3 water regimes (Tables 1, 2, 4). Similarly cold hardiness in 'Old Port' shrubs were higher in T4, T5, T6 water treatments than under T2 and T3 irrigation regimes but only in December and February (Table 3). During most experimental months the highest values of frost tolerance was observed under T4 water regime for

Table 1. Injury I_T [%] of leaves of *Rhododendron* 'Catawbiense Boursault' as affected by irrigation method and temperature

Tabela 1. Uszkodzenia mrozowe I_T [%] liści *Rhododendron* 'Catawbiense Boursault' w zależności od zastosowanej metody nawadniania oraz temperatury

Treatment	December 2013					January 2014				
	–10°C	–20°C	–25°C	–30°C	mean	–10°C	–20°C	–25°C	–30°C	mean
T1	2.3 a-c*	4.1 de	10.7 i-k	12.9 mn	7.5 cd	0.1 a	0.8 a	3.0 b-e	4.0 ef	2.0 bc
T2	2.4 a-c	4.3 de	11.1 j-l	13.4 n	7.8 d	0.1 a	0.9 a	3.4 c-e	4.5 fg	2.2 cd
T3	2.7 a-d	4.8 e	12.5 l-n	15.1 o	8.8 e	0.1 a	1.0 a	3.9 d-f	5.2 g	2.6 d
T4	1.7 a	3.0 a-d	7.7 f	9.3 gh	5.4 a	0.1 a	0.6 a	2.1 b	2.8 bc	1.4 a
T5	2.1 a-c	3.7 c-e	9.7 h-k	11.7 k-m	6.8 bc	0.1 a	0.7 a	2.6 bc	3.5 c-e	1.7 ab
T6	1.9 ab	3.5 b-e	9.0 fg	10.8 i-k	6.3 b	0.1 a	0.6 a	2.2 b	2.9 b-d	1.4 a
Mean	2.2 a	3.9 b	10.1 c	12.2 d	×	0.1 a	0.8 b	2.9 c	3.8 d	×
Treatment	**February 2014**					**March 2014**				
	–10°C	–20°C	–25°C	–30°C	mean	–10°C	–20°C	–25°C	–30°C	mean
T1	0.9 a	1.7 cd	4.9 fg	6.1 ij	3.4 bc	1.2 a	2.6 cd	8.9 gh	10.8 k	5.9 b
T2	1.0 ab	1.8 d	5.3 gh	6.5 j	3.7 cd	1.5 ab	3.4 de	11.7 l	15.1 n	7.9 c
T3	1.1 a-c	1.9 d	5.6 hi	7.1 k	3.9 d	1.8 a-c	3.9 e	13.3 m	16.2 o	8.8 d
T4	0.9 a	1.5 b-d	4.5 ef	5.8 h-j	3.2 ab	1.0 a	2.2 bc	7.5 f	9.1 gh	5.0 a
T5	0.8 a	1.5 b-d	4.4 ef	5.6 hi	3.1 a	1.2 a	2.6 cd	8.9 gh	9.7 hi	5.6 b
T6	0.8 a	1.5 b-d	4.3 e	5.4 gh	3.0 a	1.1 a	2.4 c	8.2 fg	10.0 jk	5.4 b
Mean	0.9 a	1.7 b	4.8 c	6.1 d	×	1.3 a	2.9 b	9.8 c	11.8 d	×

*Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test, $p < 0.05$; the assessment of significance of differences was done for each month separately.

*Średnie oznaczone tą samą literą nie różnią się istotnie według testu Duncana, p < 0,05; ocena istotności różnic była określana oddzielnie dla każdego miesiąca.

'Lee's Dark Purple' plants (Table 2) but under T5 treatment for 'Prinz Karneval' shrubs, where the exception was T4 water regime in February accordingly (Table 4). Mentioned T4 irrigation treatment caused the highest cold hardiness for 'Catawbiense Boursault', the exception was T5 water regime (Table 1). In turn for 'Prinz Karneval' cultivar the highest values of frost resistance was noted for T4 water regime in December and February but for T5 water regime in January and March (Table 4). Anisko and Lindstrom [1996a] reported that severe drought stress increased frost hardiness of 'Catawbiense Boursault' leaves and stems compared with well watered plants in the first winter, but decreased it in the subsequent winter, while moderate continuous water stress did not increase the cold hardiness during the first winter, but increased it in the second winter. Similarly, Anisko and Lindstrom [1996b] observed that leaves and stems of 'Catawbiense Boursault' shrubs under a continuous dry irrigation treatment were less hardy than those under a medium or wet watering treatment.

Table 2. Injury I_T [%] of leaves of *Rhododendron* 'Lee's Dark Purple' as affected by irrigation method and temperature

Tabela 2. Uszkodzenia mrozowe I_T [%] liści *Rhododendron* 'Lee's Dark Purple' w zależności od zastosowanej metody nawadniania oraz temperatury

Treat-ment	December 2014				January 2015			
	–20°C	–25°C	–30°C	mean	–20°C	–25°C	–30°C	mean
T1	5.2 ab*	14.0 e	17.9 gh	12.4 cd	0.9 a	13.3 cd	15.0 fg	9.7 b
T2	5.4 ab	14.6 ef	19.5 h	13.2 d	1.1 a	15.5 g	15.7 gh	10.8 c
T3	6.1 b	16.4 fg	24.7 i	15.7 e	1.2 a	16.6 hi	17.4 i	11.7 d
T4	3.7 a	10.1 c	17.6 gh	10.5 a	0.7 a	10.6 b	13.5 de	8.3 a
T5	4.7 ab	12.7 de	16.0 fg	11.1 ab	0.8 a	12.5 c	14.4 ef	9.2 b
T6	4.4 ab	11.7 cd	19.4 h	11.8 ab	0.7 a	13.7 de	14.9 fg	9.8 b
Mean	4.9 a	13.3 b	19.2 c	×	0.9 a	13.7 b	15.2 c	×
Treat-ment	February 2015				March 2015			
	–20°C	–25°C	–30°C	mean	–20°C	–25°C	–30°C	mean
T1	2.0 a	5.9 b	13.1 de	7.0 a-c	3.3 a	11.8 b-d	14.9 e	10.0 b
T2	2.1 a	6.3 b	15.5 fg	8.0 cd	4.4 a	15.6 e	19.8 g	13.3 c
T3	2.3 a	6.8 b	17.3 g	8.8 d	5.0 a	17.7 f	22.4 h	15.0 d
T4	1.8 a	5.4 b	10.5 c	5.9 a	2.8 a	9.9 b	12.6 cd	8.4 a
T5	1.8 a	5.4 b	12.3 cd	6.5 ab	3.3 a	11.8 b-d	12.7 cd	9.3 ab
T6	1.7 a	5.2 b	14.8 ef	7.2 bc	3.1 a	10.9 bc	13.8 de	9.3 ab
Mean	2.0 a	5.8 b	13.9 c	×	3.7 a	13.0 b	16.0 c	×

* For explanation see Table 1.

* Objaśnienia takie jak w tabeli 1.

Table 3. Injury I_T [%] of leaves of *Rhododendron* 'Old Port' as affected by irrigation method and temperature

Tabela 3. Uszkodzenia mrozowe I_T [%] liści *Rhododendron* 'Old Port' w zależności od zastosowanej metody nawadniania oraz temperatury

Treat-ment	December 2013					January 2014				
	–10°C	–20°C	–25°C	–30°C	mean	–10°C	–20°C	–25°C	–30°C	mean
T1	6.7 a*	10.6 cd	17.4 g	19.3 h-j	13.5 b	0.7 a	2.9 b	11.2 d-f	11.5 ef	6.6 bc
T2	7.1 a	11.7 de	18.1 gh	21.0 j	14.5 c	0.7 a	2.9 b	11.1 d-f	11.3 ef	6.5 a-c
T3	9.0 b	14.7 f	20.4 ij	26.7 k	17.7 d	1.0 a	4.5 c	17.4 g	17.9 g	10.2 d
T4	6.4 a	10.4 cd	12.6 e	18.9 h	12.1 a	0.6 a	2.7 b	10.7 de	10.8 de	6.2 ab
T5	5.8 a	9.5 bc	15.8 f	17.2 g	12.1 a	0.6 a	2.7 b	10.3 d	10.6 de	6.0 a
T6	6.8 a	11.2 d	14.6 f	20.4 ij	13.3 b	0.7 a	3.0 b	11.8 f	12.0 f	6.9 c
Mean	7.0 a	11.4 b	16.5 c	20.6 d	×	0.7 a	3.1 b	12.1 c	12.3 c	×

Table 3 – cont.
Tabela 3 – cd.

Treat-ment	February 2014					March 2014				
	–10°C	–20°C	–25°C	–30°C	mean	–10°C	–20°C	–25°C	–30°C	mean
T1	4.2 a-c	5.6 de	11.6 h-j	12.8 jk	8.5 c	3.5 a	6.1 de	15.3 gh	17.4 ij	10.6 b
T2	4.6 b-d	6.5 ef	12.5 h-k	13.6 k	9.3 d	4.0 ab	6.7 de	17.3 ij	19.5 kl	11.9 c
T3	5.2 cd	7.4 f	15.3 l	19.8 m	11.9 e	4.3 a-c	7.3 e	18.8 jk	21.3 m	12.9 d
T4	3.1 a	4.4 b-d	9.3 g	11.5 hi	7.1 a	3.4 a	5.7 c-e	14.6 fg	16.6 hi	10.1 b
T5	3.7 ab	5.3 cd	10.7 h	11.7 h-j	7.8 b	3.2 a	5.2 b-d	13.3 f	15.2 gh	9.2 a
T6	4.4 b-d	6.4 ef	13.1 k	13.3 k	9.3 d	4.2 a-c	7.0 e	18.2 jk	20.7 lm	12.5 cd
Mean	4.2 a	5.9 b	12.1 c	13.8 d	×	3.8 a	6.3 b	16.3 c	18.5 d	×

[*] For explanation see Table 1.
[*] Objaśnienia takie jak w tabeli 1.

Table 4. Injury I_T [%] of leaves of *Rhododendron* 'Prinz Karneval' as affected by irrigation method and temperature

Tabela 4. Uszkodzenia mrozowe I_T [%] liści *Rhododendron* 'Prinz Karneval' w zależności od zastosowanej metody nawadniania oraz temperatury

Treat-ment	December 2014				January 2015			
	–20°C	–25°C	–30°C	mean	–20°C	–25°C	–30°C	mean
T1	11.9 a[*]	20.8 cd	23.0 d-f	18.6 b	3.2 a	10.3 c	13.7 d-f	9.1 ab
T2	12.9 a	22.7 d-f	25.1 f	20.2 c	3.2 a	10.0 c	14.2 ef	9.1 b
T3	16.4 b	28.7 g	31.7 h	25.6 d	5.0 b	14.8 fg	15.7 g	11.8 c
T4	11.6 a	20.4 cd	22.5 d-f	18.1 b	3.0 a	9.6 c	12.6 d	8.4 a
T5	10.6 a	18.6 bc	20.5 cd	16.6 a	2.7 a	9.4 c	13.2 de	8.4 a
T6	12.6 a	22.0 de	24.3 ef	19.6 bc	3.4 a	10.6 c	12.7 d	8.9 ab
Mean	12.7 a	22.2 b	24.5 c	×	3.4 a	10.8 b	13.7 c	×
Treat-ment	February 2015				March 2015			
	–20°C	–25°C	–30°C	mean	–20°C	–25°C	–30°C	mean
T1	6.2 a-c	7.7 bc	15.2 ef	9.7 b	6.9 ab	14.8 c-e	18.2 f	13.3 b
T2	7.3 a-c	8.2 bc	17.9 gh	11.1 cd	7.8 ab	16.7 ef	20.5 g	15.0 c
T3	8.1 bc	8.8 c	20.0 h	12.3 d	8.5 b	18.2 f	20.4 g	15.7 d
T4	4.9 a	7.1 a-c	12.2 d	8.1 a	6.6 ab	14.3 cd	17.4 f	12.8 ab
T5	5.8 ab	6.9 a-c	14.3 de	9.0 ab	6.1 a	12.9 c	15.9 d-f	11.6 a
T6	6.9 a-c	6.7 a-c	17.1 fg	10.2 b	8.2 ab	17.7 f	21.7 g	15.9 cd
Mean	6.5 a	7.6 b	16.1 c	×	7.4 a	15.8 b	19.0 c	×

[*] For explanation see Table 1.
[*] Objaśnienia takie jak w tabeli 1.

CONCLUSIONS

1. For all rhododendron cultivars examined the highest cold hardiness was noted in January and February, lower in March but the lowest in December.
2. The largest frost damage was observed in 'Prinz Karneval' and the smallest in 'Catawbiense Boursault' cultivar.
3. Reduction of water rates in irrigation (T4 and T5 irrigation treatments) during summer especially between the first and the second vegetative growth may improve the frost resistance of *Rhododendron* shrubs.

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WPŁYW STAŁEGO I OKRESOWEGO DEFICYTU WODY NA MROZOODPORNOŚĆ ODMIAN RÓŻANECZNIKA

Streszczenie. Badania mrozoodporności liści krzewów różanecznika były prowadzone w dwóch sezonach badawczych (od grudnia 2013 roku do marca 2014 roku oraz od grudnia 2014 roku do marca 2015 roku) w Instytucie Ogrodnictwa, w Skierniewicach. Celem przeprowadzonych badań było określenie następczego wpływu regulowanego deficytu nawadniania (RDI) na mrozoodporność krzewów różanecznika odmian 'Catawbiense Boursault', 'Lee's Dark Purple', 'Prinz Karneval' oraz 'Old Port'. W poprzednich sezonach wegetacyjnych rośliny były uprawiane w nieogrzewanej szklarni. Podczas 14 tygodni, od czerwca do połowy września, krzewy były nawadniane zgodnie z sześcioma wariantami nawodnieniowymi (T1–T6) wyznaczonymi na podstawie wartości ewapotranspiracji (ETp). Trzy z nich obejmowały jednakowe, stałe nawadnianie roślin: 1 ETp (rośliny kontrolne, dobrze nawodnione – T1), 0,75 ETp (średni deficyt wody – T2), 0,5 ETp (duży deficyt wody – T3). Pozostałe trzy warianty obejmowały zróżnicowane nawadnianie w czasie trzech faz wzrostu roślin: 1–0,5–1 ETp – silny deficyt wody w fazie II (T4), 1–0,25–1 ETp – bardzo silny deficyt wody w fazie II (T5) i 0,5–1–0,5 ETp – duży deficyt wody w fazach I oraz III, i dobrze nawodnione rośliny w fazie II (T6). Fazy nawadniania I i III (każda trwająca po 5 tygodni) odpowiadały wegetatywnej fazie rozwojowej krzewów. Z kolei faza II nawadniania, trwająca 4 tygodnie, odpowiadała fazie inicjacji kwitnienia oraz tworzenia pąków kwiatostanowych. W końcu września odmiany 'Lee's Dark Purple' i 'Prinz Karneval' posadzono do gruntu, a 'Catawbiense Boursault' i 'Old Port' pozostawały w zimie w szklarni. W obydwu sezonach badawczych na początku każdego miesiąca, od grudnia do marca, były przeprowadzane badania mrozoodporności liści, w których określono uszkodzenia mrozowe na podstawie wycieku elektrolitu z uszkodzonych komórek liścia. W pierwszym sezonie badawczym dla odmian 'Catawbiense Boursault' i 'Old Port' zastosowano wartości temperatury –10°C, –20°C, –25°C, –30°C, a w drugim doświadczeniu odpowiednio dla odmian 'Lee's Dark Purple' i 'Prinz Karneval' liście poddano temperaturze –20°C, –25°C, –30°C. Wyniki badań wykazały dla wszystkich czterech odmian różaneczników, że największa mrozoodporność była notowana w styczniu i lutym, średnia w marcu, zaś najmniejsza w grudniu. Wielkość stresu wodnego istotnie wpływała na mrozoodporność krzewów u wszystkich czterech badanych odmian różaneczników. W wyniku zastosowania traktowań nawodnieniowych T2 i T3 rośliny cechowały się gorszą mrozoodpornością, z kolei użycie traktowań nawodnieniowych T4, T5 oraz T6 poprawiało mrozoodporność krzewów podczas zimy w porównaniu do kontroli.

Słowa kluczowe: deficyt wody, metoda nawadniania, mrozoodporność, temperatura mrożenia, pomiary wycieku elektrolitu