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GROWTH RESPONSE OF CONTAINER GROWN JAPANESE AZALEA AND EUONYMUS AND CONCENTRATION OF NITRATES AND PHOSPHATES IN THE RUNOFF WATER UNDER DIFFERENT IRRIGATION AND FERTILIZATION

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ABSTRACT

In this study a growth response of two container-grown ornamentals (*Euonymus japonicus* 'Ovatus Aureus' and *Rhododendron* 'Geisha Orange') grown under different irrigation and fertilization rates was examined. The content of nitrogen (N) and phosphorus (P) in the plant leaves and in leachates was measured. Two levels of irrigation – standard irrigation (SI) and – high irrigation rate (HI), and three control-release fertilizers (CRFs) – Multicote 17-17-17, Osmocote Exact Standard 16-9-12 and Plantacote 15-10-15, applied at the rate of 1.5, 3.0 or 4.5 $g \cdot l^{-1}$, were applied. Fast-acting fertilizers were used as the control. HI adversely affected the growth and quality of *Euonymus* but stimulated the growth and increased quality of *Rhododendron* within two years of cultivation in relation to SI. There were no significant interactions between the irrigation and fertilization treatments; irrespective of water regimes, growth responses of both plant species to used fertilizers were similar. Osmocote and Plantacote at the rate of 3 $g \cdot l^{-1}$ were the most effective for the growth of *Euonymus* and *Rhododendron* plants, except of *Euonymus* in the second year, when 4.5 $g \cdot l^{-1}$ CRFs resulted in the best growth of plants. HI increased the amount of runoff water as well as $N\text{-}NO_3$ and $P\text{-}PO_4$ losses from containers during the entire growing period, irrespective of a fertilizer type. The amount of the nitrate and phosphate in leakage was higher when higher rates of CRFs were applied. Maximum nitrate concentration in leakage was the highest 14 days after the application of CRFs.

Key words: CRFs, *Euonymus japonicus* 'Ovatus Aureus', overhead irrigation, nursery production, *Rhododendron* 'Geisha Orange'

INTRODUCTION

Poland is one of the largest producer of ornamental nursery plants in Europe with the production value of more than one billion PLN (GUS 2012; Marosz 2013). The land area dedicated to the production of woody ornamental nursery plants in Poland was 6747 ha in 2010 and this production should continue to increase because the market demand for ornamental plants is very high.

Saving water and reducing the environmental impact because of lowering a runoff are two important issues presently concerning container nurseries (Newman et al. 2014). Current regulations in European Union limit nutrient concentration in runoff and water consumption in agriculture (i.e. Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy; Council Directive 91/676/EEC of 12 December 1991 concerning the protection of water against pollution caused by nitrates from agricultural sources). As environmental directives are increasingly enforced, it will have far reaching implications for the horticultural sector including nursery production.

Overhead irrigation is the most practical and the most commonly used irrigation system in the container production of woody ornamentals. However,

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such a system is easy to over-applicate water because it does not react to daily changes in precipitation or evapotranspiration and concomitant fertilizer and pesticide leaching. Existing irrigation estimates for container nursery production are as high as 2900 mm annually with as much as 33 mm daily (Fare et al. 1992; Beeson & Brooks 2008). With overhead irrigation, the percentage of irrigation water that is intercepted by the plant/container ranges from 25% to 37%. What it means is that over the course of a production period, only 13-20% of the applied water is retained for plant growth and the rest leaks or evaporates (Weatherspoon & Harrell 1980). If not captured, water, fertilizers, and other agricultural chemicals can leave the production area and enter surrounding water resources with the potential for environmental pollution. A survey of nurseries found that the over-optimal watering of plants was widespread especially during the hot summer due to more frequent and longer irrigations, and fertilizer losses reached 60% (Grant et al. 2009). Similarly, the high losses of fertilizers may occur during the wet, rainy summer.

Fertilization with nitrogen (N) and phosphorus (P) is essential for the production of high-quality ornamental nursery plants. Nitrate (NO_3^-) and phosphate (PO_4^{3-}) readily dissolve in water and have a high potential for moving with water. Leaching of NO_3^- and PO_4^{3-} is enhanced by the low anion-holding capacity of most substrates used for plant production. In an effort to reduce nutrient runoff and improve nutrient use efficiency, coated fertilizers have been developed that allow a slow release of nutrients into the substrate throughout the period of plant growth (Colangelo & Brand 1997; Marfà et al. 2002; Cabrera 2003; Fernández-Escobar et al. 2004; Merhaut et al. 2006; Newman et al. 2006). Most of the commonly used controlled-release fertilizers (CRFs) are coated with polymers, which release nutrients through osmosis at the rate that is positively correlated with increasing substrate temperature. Therefore, CRFs can be quite inefficient when nutrient release patterns do not match nutritional requirements of plants, which often vary with both plant species and environmental conditions (Sandrock et al. 2005). To improve fertilizer formulations and schedules for nurseries, more information on fertilizer use and fertilizer uptake efficiency is needed (Groves et al. 1998; Juntunen et al. 2003; Oliet et al. 2004; Šrámek & Dubský 2007; Wilson & Albano 2011; Fulcher et al. 2012; Narváez et al. 2013).

Information regarding the water and fertilizer requirements of many species and cultivars of woody ornamentals is scarce. Then, improved knowledge of the combined influence of irrigation and nutrient management during container nursery production is needed to develop integrated production optimizing nutrient and water managements.

The objective of this study was to investigate the effects of three types of CRFs on the growth and quality of *Euonymus japonicus* 'Ovatus Aureus' and *Rhododendron* 'Geisha Orange', N and P status in plants, and leaching of these nutrients from containers depending on the intensity of irrigation.

MATERIALS AND METHODS

Plant materials and growth conditions

The experiment was conducted at Research Institute of Horticulture in Skierniewice, Poland, in the years 2011 and 2012. 'Ovatus Aureus' Japanese euonymus (*Euonymus japonicus*) and 'Geisha Orange' Japanese azalea (*Rhododendron*) having medium and low nutritional requirements, respectively, were the subject of the experiment.

Rooted stem cuttings from commercial nursery (Dendra, Poland) were transplanted on 23 May 2011 into 0.8 l black polyethylene pots with side and bottom drainage holes. Substrate consisted of *Sphagnum* peat moss (Klasmann Lithuanian Peat Moss) of a structure of 0-25 mm (pH 3.5-4.5 in H_2O, salt level < 0.2 g $NaCl \cdot l^{-1}$) was used. For *Euonymus* the substrate was amended with chalk to reach a pH value of 6.5. Pots were placed on 12 benches (2 × 1.2 m) in polyethylene-clad greenhouse. Each bench comprised of 60 pots (30 *Euonymus* and 30 *Rhododendron* plants).

The studied treatments

The treatments included the application of different fertilizers and irrigation intensities. Fertilizer treatments consisted of 3- to 4-month release CRFs: Multicote 17-17-17 + micronutrients (Haifa Chemicals Ltd), Osmocote Exact Standard 16-9-12 + micronutrients (Scotts) and Plantacote 15-10-15 + micronutrients (Aglukon).

Each of the CRFs was applied by mixing with the top layer of substrate 24 May 2011 (one day after planting) and 2 June 2012. Fertilizer rates corresponded to low (1.5 $g \cdot l^{-1}$), medium (3.0 $g \cdot l^{-1}$) and high (4.5 $g \cdot l^{-1}$) manufacturer-recommended rate. Appropriate amount of CRFs were added individually to each pot. All CRFs are polymer-coated formulations and release rates of nutrients that are positively correlated with substrate temperature. As a control, fast-acting, water soluble fertilizers were applied, that is, PG-Mix (14-16-18 + micronutrients, Yara) by adding to the substrate before planting at 1 $g \cdot l^{-1}$), and Symfo-vita (12-5-22-5 + micronutrients, Pro-Lab) by plant feeding after one month at 0.1% by using of 100 ml per pot, three times every two weeks. Elements concentrations and compounds used in each CRFs were different; however, N contents were almost equal (Table 1).

Table 1. Amounts (percent by weight) of N, P and K in Multicote 17-17-17, Osmocote 16-9-12 and Plantacote 15-10-15

Fertilizer type	N total	NH_4^+	$N\text{-}NO_3^-$	NH_2	P	K
Multicote 17-17-17 + micronutrients	17	3.7	4.8	8.5	7.4	14.1
Osmocote 16-9-12 + micronutrients	16	8.6	7.4	0	3.9	10.0
Plantacote 15-10-15 + micronutrients	15	8.5	6.5	0	4.3	12.5

Irrigation was applied using an overhead sprinkler. Two micro sprinklers (output of each stake was one liter per min at water pressure 2 atm) were installed per bench and set to run two to three times per week depending upon climatic conditions and plant growth stage. Two rates of irrigation were applied. These were standard irrigation rate (SI), that is, sufficient to meet crop requirements, and high irrigation rate (HI), two times the SI rate to simulate a wet season or over application. Irrigation treatment of SI was imposed to create a leaching fraction (LF) of 0.2 LF was calculated in the beginning of experiment (separately in 2011 and 2012) by dividing the volume of water leached from container and the volume of water applied to a container. Ten containers were taken to measure LF. Sprinklers were adjusted to deliver water uniformly at 12.5 mm (SI) and 25.0 mm (HI) in 2011 and at 25 (SI) and 50 mm (HI) in 2012. Plants were irrigated with tap water at a pH value of 7.2, an electrical conductivity of 0.59 $mS \cdot cm^{-1}$ and mineral composition (in $mg \cdot l^{-1}$) given as follows: 0.12 $N\text{-}NO_3^-$, < 0.05 $N\text{-}NH_4^+$, < 0.1 P, 3.3 K^+, 104 Ca^{2+}, 17.6 Mg^{2+}, 12.4 Na^+, 23.4 Cl^-, 24.9 SO_4^{2-} (average values of two years of the study).

Measurements and observations

Plant measurements

At the end of the experiment height, chlorophyll content index (CCI), and plant quality (visual assessment according to scale from 1 – the weakest to 4 – the highest) were evaluated. The main parameters of quality were shape, size and color of leaves. During the overwintering period, lasting until the end of March of the second year (2013), the greenhouse temperatures were maintained at 0-2 °C. At this time, the number of flowers per plant was counted for *Rhododendron.* In September, in the second year of the study, fresh weight and total length of shoots per plant for *Euonymus* were also evaluated. Chlorophyll content index (CCI) was measured using Chlorophyll Content Meter (CCM-200 Opti-Sciences). Three measurements were taken per each plant (the newest fully developed leaves).

Plant status of N and P

The first fully expanded leaves of both species were collected in September 2012 and analysed for N and P content. Fifteen leaves were collected from each treatment unit comprising three plants (five leaves per each plant) and six samples (replications) were analysed for each treatment. Leaves were rinsed with deionized water, dried in a forced-draft oven at 70 °C and ashed in a muffle furnace at 480 °C for 12 h. Leaf samples were digested with HNO_3 and $HClO_4$. Nitrogen was determined according to Kjeldahl method and phosphorus colorimetrically using ammonium molybdate.

Nitrate and phosphate in leachate

We used the pour-through extraction procedure (Bilderback 2002) to collect leachate from potting substrate. Amounts of nitrate and phosphate in leachate were determined in the second year of plant cultivation, like N and P contents in leaf material. Leakage samples were collected seven times per year, every two weeks, starting 14 days from the date of CRFs application (from 16 June to 16 September 2012). The leachate was collected in plastic vials fixed beneath drain holes and catching the leachate from each pot and solution from three pots representing each treatment unit were combined, so that there were six samples (replications) for each treatment for each of seven times leachate monitoring. On the same day, nitrate and phosphate analysis was conducted in the laboratory. Nitrate-N was determined using a nitrate ion-selective electrode ISE (Orion 4 Stars Meter, Thermo Scientific) and phosphate was determined colorimetrically, using spectrophotometer (DU640B).

Experimental design and statistical analysis

The experiment was a split-plot factorial design with two irrigation levels (SI and HI) as main plots and ten fertilization methods (three types of CRFs at 1.5, 3.0, 4.5 $g \cdot l^{-1}$ and fast-acting fertilizers) as subplots. Each treatment unit subplot was comprised of three plants. There were six replications. The analysis of variance (ANOVA) was conducted using STATISTICA software. When the ANOVA indicated significant effects, means were separated using Tukey's HSD test, with $p < 0.05$ considered to be statistically significant.

RESULTS AND DISCUSSION

Growth responses

The growth responses to the applied irrigation treatments were different for the studied plant species (Tables 2 & 3). HI adversely affected the growth and quality of *Euonymus* plants in two years of cultivation in relation to SI, except the height of plants in the first year, which was not dependent on the level of irrigation. As a result, after two years of cultivation at the HI, plants were lower by 9% and had lower fresh weight by 26% than at the SI. Similarly, CCI values at the HI treatment were also lower than in plants at the SI treatment. For *Rhododendron*, HI stimulated vegetative growth, improved visual quality of plants and increased CCI value in both years of cultivation. After two years, at the HI treatment plants were higher by 10% than at the SI treatment. The intensity of irrigation of the *Rhododendron* plants did not affect the abundance of flowering evaluated in the spring of the year after treatment.

Significant differences in growth and quality of *Euonymus* and *Rhododendron* plants were found among the studied CRFs. The most effective for the cultivation of both plant species were Osmocote and Plantacote (Tables 2 & 3). Vegetative growth of both plant species, their visual quality, the abundance of flowering for *Rhododendron* fertilized with Multicote, containing a high share of N as amide form (8.5%) were much weaker than for plants fertilized with Osmocote or Plantacote. N in the amide form is not absorbed by the roots, until it is hydrolyzed to the ammonium form. This process requires the constant presence of water in a substrate. Thus, variable water conditions in the substrate commonly found in containers can adversely affect the efficiency of utilization of $N\text{-}NH_2$ by plants. In our experiment, this phenomenon could result in a weaker growth of *Euonymus* and *Rhododendron* plants fertilized with Multicote compared to plants treated with Osmocote and Plantacote.

The dose of 3 $g \cdot l^{-1}$ of Osmocote and Plantacote fertilizers was generally sufficient to obtain a good quality of *Rhododendron* both in the first and second year of experiment and abundant flowering in the second year (Table 3). For *Euonymus,* representing higher fertilizer requirements (Aendekerk 1997), the rate of 3 $g \cdot l^{-1}$ Osmocote and Plantacote was adequate in the first year of cultivation; however, in the second year, the highest dose of Osmocote (4.5 $g \cdot l^{-1}$) resulted in greater plant fresh weight and the highest dose of Plantacote (4.5 $g \cdot l^{-1}$) resulted in higher plants (Table 2). Additionally, in the second year of *Euonymus* cultivation, the use of Osmocote was more effective in promoting plant growth and increasing CCI reading values than the application of Plantacote.

For both species, plants treated with fast-acting, water-soluble fertilizers were smaller and of lower quality than those fertilized with CRFs. Moreover, irrespective of the irrigation regimes, *Rhododendron* fertilized with water-soluble fertilizers produced less flowers than plants treated with CRFs.

Table 2. Growth response, and N and P contents (% d.w.) in the leaves of container-grown *Euonymus japonicus* 'Ovatus Aureus' under two irrigation regimes (SI – standard irrigation and HI – high irrigation rate) and three control-release fertilizers (Multicote, Osmocote and Plantacote) applied at three levels (1.5, 3.0 and 4.5 $g \cdot l^{-1}$) compared to control, fast-acting fertilizers

Treatment	2011			2012					
	Height (cm)	CCI	Quality (1-4)	Height (cm)	CCI	Quality (1-4)	Fresh weight (g)	N (%)	P (%)
Irrigation (I)									
SI	20.3 a[1]	84 b	3.5 b	18.2 b	69 b	3.1 b	20.4 b	1.90 b	0.23 b
HI	19.6 a	74 a	3.1 a	16.5 a	63 a	2.8 a	15.0 a	1.75 a	0.20 a
Fertilization (F)									
Control	18.6 b-d	58 a	2.8 cd	9.4 a	42 a	1.7 a	6.9 a	1.35 a	0.14 ab
Multicote 1.5	12.8 a	43 a	1.6 a	10.5 a	42 a	1.8 a	7.6 a	2.30 e	0.25 cd
Multicote 3.0	15.6 ab	56 a	2.0 ab	11.3 ab	53 ab	2.0 a	9.9 a	2.32 e	0.32 de
Multicote 4.5	16.7 a-c	61 a	2.4 bc	11.5 ab	57 ab	2.0 a	10.2 a	2.43 e	0.35 e
Osmocote 1.5	20.6 cd	81 bc	3.5 e	15.8 bc	79 cd	3.1 bc	18.0 bc	1.39 a	0.12 a
Osmocote 3.0	22.1 de	96 cd	4.2 f	25.6 d	90 de	4.2 e	27.5 d	1.86 cd	0.21 abc
Osmocote 4.5	24.8 e	107 d	4.4 f	27.9 d	103 e	4.5 e	37.0 e	1.71 bc	0.23 b-d
Plantacote 1.5	18.9 b-d	64 ab	3.3 de	15.2 b	52 ab	2.7 b	12.7 ab	1.47 ab	0.14 ab
Plantacote 3.0	22.5 de	88 c	4.1 f	20.0 c	63 bc	3.6 cd	20.8 cd	1.49 ab	0.21 a-c
Plantacote 4.5	24.7 e	98 cd	4.3 f	26.2 d	78 cd	4.1 de	26.5 d	1.95 d	0.22 bc
Significance I × F interactions[2]	ns	*	ns	ns	ns	ns	ns	ns	ns

[1] The means in column within irrigation and fertilization treatments followed by the same letter do not differ significantly according to Tukey HSD test at $p < 0.05$.
[2] Irrigation and fertilization interactions: *, **, ns, significant at $p < 0.05$, 0.01, or not significant, respectively.

Table 3. Growth response, and N and P contents (% d.w.) in the leaves of container-grown *Rhododendron* 'Geisha Orange' under two irrigation regimes (SI – standard irrigation and HI – high irrigation rate) and three control-release fertilizers (Multicote, Osmocote and Plantacote) applied at three levels (1.5, 3.0 and 4.5 $g \cdot l^{-1}$) compared to control, fast-acting fertilizers

Treatment	2011				2012					
	Height (cm)	CCI	Number of flowers per plant	Quality (1-4)	Height (cm)	CCI	Number of flowers per plant	Quality (1-4)	N (%)	P (%)
Irrigation										
SI	10.7 a[1]	67 a	15 a	3.5 a	22.4 a	44 a	28 a	3.4 a	1.80 a	0.14 a
HI	13.0 b	75 b	14 a	3.9 b	24.6 b	52 b	27 a	3.7 b	1.86 a	0.13 a
Fertilization										
Control	11.2 a	58 a	10 ab	3.3 ab	22.5 bc	35 a	22 a	2.6 a	1.58 a-c	0.14 bc
Multicote 1.5	11.8 a-c	71 b-e	3 a	3.6 a-c	17.9 a	36 a	23 a	2.6 a	2.01 b-d	0.14 bc
Multicote 3.0	11.0 a	69 bd	2 a	3.4 a-c	18.4 ab	57 bd	25 ab	2.6 a	2.02 b-d	0.15 bc
Multicote 4.5	11.3 ab	70 b-d	2 a	3.1 a	18.4 ab	63 d	23 a	2.5 a	2.26 d	0.16 c
Osmocote 1.5	12.1 a-c	70 b-d	16 bc	4.0 cd	24.1 cd	32 a	27 a-c	3.6 b	1.69 a-c	0.11 a
Osmocote 3.0	11.4 ab	76 c-e	19 cd	3.9 b-d	25.6 c-e	43 a-c	32 cd	4.6 c	2.01 b-d	0.14 bc
Osmocote 4.5	11.9 a-c	79 e	17 b-d	3.7 a-d	26.9 de	55 bd	27 a-c	4.5 c	2.06 cd	0.14 bc
Plantacote 1.5	13.2 bc	65 ab	14 bc	3.9 b-d	25.8 c-e	39 ac	29 bc	3.7 b	1.38 a	0.12 ab
Plantacote 3.0	13.4 c	75 de	21 cd	4.3 d	28.6 e	52 b-d	32 cd	4.4 c	1.54 ab	0.11 a
Plantacote 4.5	11.8 a-c	78 c-e	25 d	4.0 cd	28.2 de	64 d	35 d	4.5 c	1.79 a-d	0.15 bc
I × F Interactions[2]	ns	*	ns	*	ns	ns	ns	ns	ns	ns

Explanation: see Table 1

Leaf N and P

Leaves of *Euonymus* plants at HI contained less N and P than those at SI (Table 2). In contrast to the *Euonymus*, there were no significant differences in N and P contents in the leaves of *Rhododendron* plants between irrigation treatments (Table 3).

Leaf status of N and P for both tested plant species, in general, steeply increased with increasing the rate of CRFs (Table 2, 3). The interaction between the irrigation and fertilization factors was not significant.

The N and P concentrations in *Euonymus* leaves at maximum growth were within the range of 1.71-1.95% for N, and 0.21-0.23% for P. The optimum leaf N concentration range reported for container-grown spindle tree (*Euonymus europaeus* L.) is 1.05-2.32%, and for container- and field-grown winged euonymus (*Euonymus alatus* Sieb.) is 2.37-2.62% (Mills et al. 1996). According to Smith (1978), optimum leaf N is 2.41% and P 0.2% for *Euonymus fortunei* 'Coloratus'. For autumn potted and raised in unheated glasshouse *Euonymus japonicus* 'Ovatus Aureus' plants, optimum leaf concentrations of N and P, determined in spring, were 1.7% N and 0.21% P (Monaghan 2004).

In general, ericaceous plants have lower fertilizer requirements than most ornamental plants. Recommended leaf N concentrations for Rhododendrons vary between 1.5% and 2.8% (Aendekerk 1997; Matysiak & Bielenin 2005; Michałojć & Koter 2012). In our study Japanese Azaleas 'Geisha Orange' had maximum growth when leaf N levels ranged from 1.54 to 2.01%. These values are within the range given by the above authors.

Leaf P content in *Rhododendron* 'Geisha Orange' ranged from 0.11 to 0.16% P. A level below 0.15% P is considered to be critical in the indicator parts of *Rhododendron*. The standard contents range from 0.20 to 0.40% P (Breś et al. 1997). According to Aendekerk (1997), the optimal P content in *Rhododendron* leaves is 0.25-0.41% P, whereas leaves of plants with P deficient symptoms contain from 0.06 to 0.11% P. However, for deciduous azaleas with optimal growth, low P content in leaves (0.09%) was reported (Michałojć & Koter 2012). In our study, leaf P concentration of Japanese Azaleas 'Geisha Orange', corresponding with maximum growth and abundant flowering ranged from 0.11 to 0.14%. Thus, we can conclude that the Japanese azaleas, as deciduous plant, has lesser P requirements than other groups of rhododendrons.

Nitrogen and phosphorus concentrations in the leaves of *Euonymus* under control treatment (1.35% N and 0.14% P) were below the optimal range that was determined in the study. For Japanese azaleas, which have low nutrient requirements, plants fertilized with fast-acting fertilizers also contained low nitrogen (1.58%) and phosphorus (0.14%); however, these values were in the range of the optimal concentrations corresponding with maximum growth and abundant flowering of plants.

Nitrate and phosphate in leachate

HI increased runoff water from containers compared with SI during growing season (data not shown). There were no significant differences in the volumes of runoff water between *Euonymus* and *Rhododendron*. Across all collection days, average daily runoff volumes for both selected taxa were at HI 110 and 172 ml while at SI were 40 and 77 ml per plant in 2011 and 2012, respectively. It means that two-fold increase of irrigation rate (from 12.5 to 25 mm in 2011 and from 25 to 50 mm in 2012) resulted in 2.75- and 2.23-fold (respectively in 2011 and 2012) increase in the amount of water leakage to the soil environment. The lower runoff volumes resulting from lower irrigation rates in this study are consistent with results reported by Fare et al. (1992), Warsaw et al. (2009a, b) and Sammons and Struve (2010). An efficient alternative to the standard practice of overhead irrigation can also be cyclic irrigation. Although water use may increase with cyclic irrigation, the leached fraction is less, which leads to water and fertilizer savings (Karam & Niemiera 1994).

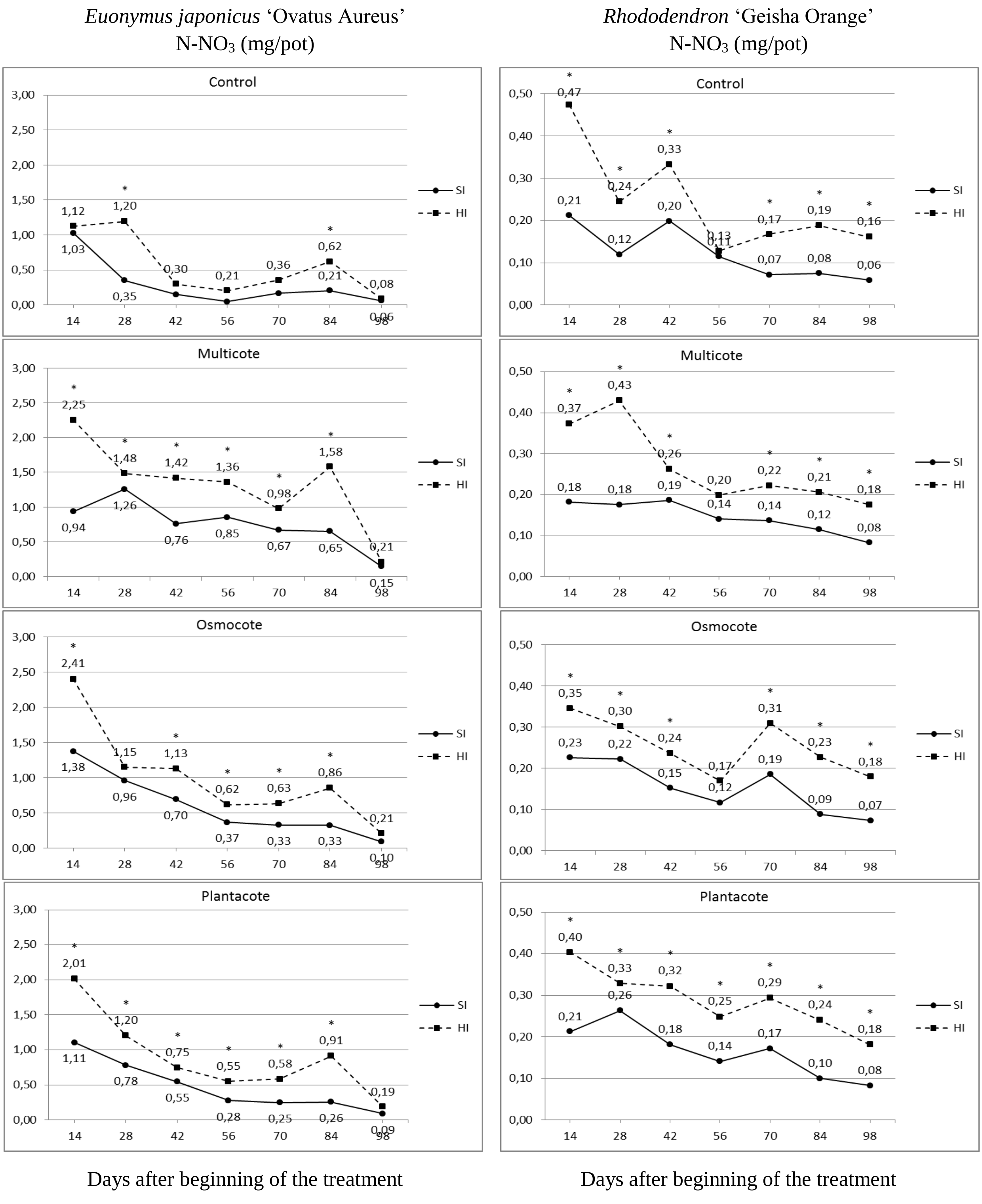
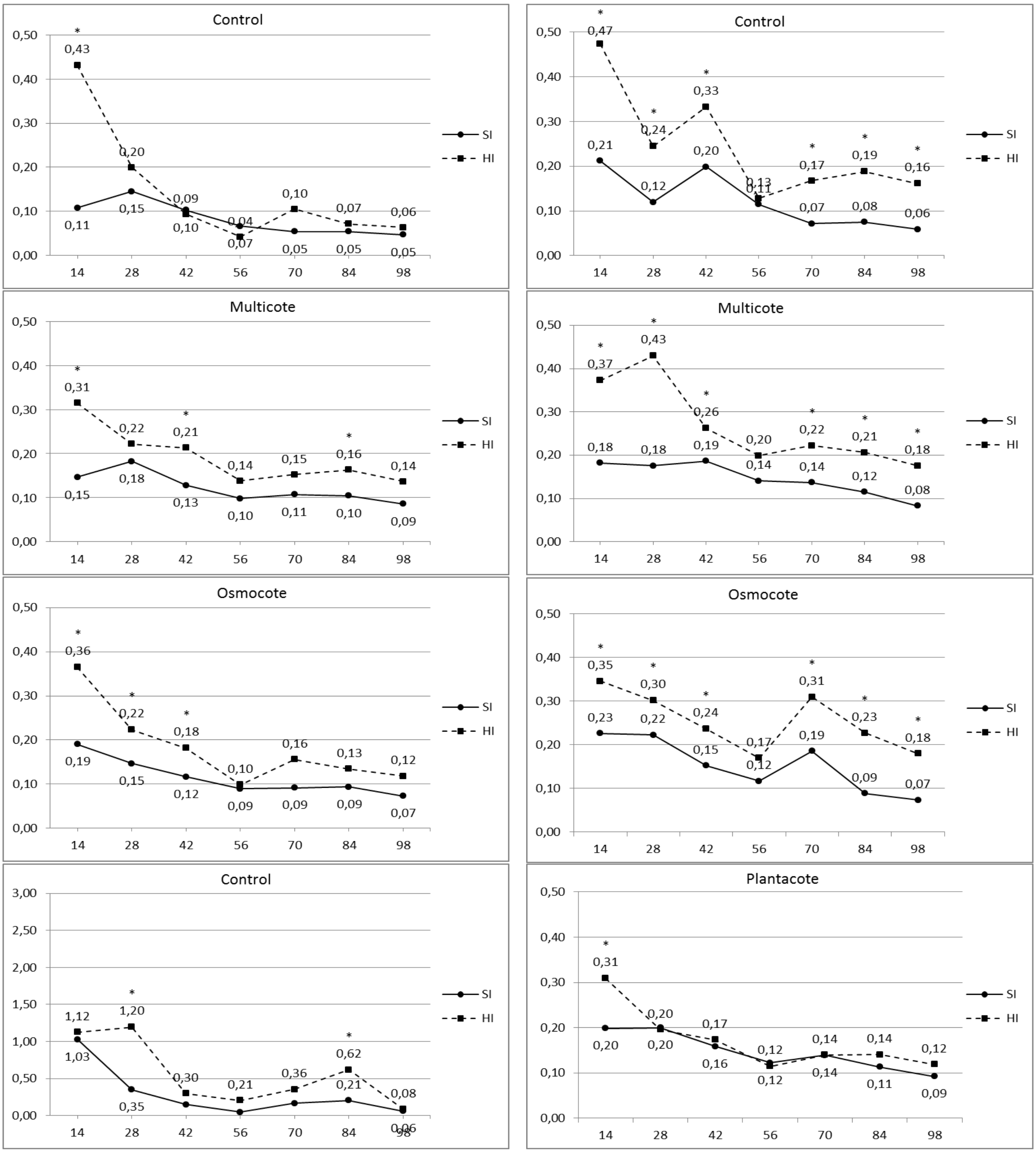


Fig. 1. Average nitrogen content (N-NO$_3$ in mg per one pot) in leachate solutions collected every two weeks over a 98 day period (2 June 2012 to 16 September 2012) from peat substrate prepared with three controlled-release fertilizers CRFs (Multicote, Osmocote, Plantacote) and fast-acting fertilizers (control) for *Euonymus japonicus* 'Ovatus Aureus' and *Rhododendron* 'Geisha Orange' irrigated with standard (SI) and high rate (HI). Each data point is average for 3 rates of CRFs (1.5, 3.0 and 4.5 $g \cdot l^{-1}$) and 6 replications per one rate. Asterisk (*) indicates difference ($P < 0.05$) between SI and HI treatments (Tukey HSD test)

Euonymus japonicus 'Ovatus Aureus' P-PO_4 (mg/pot)

Rhododendron 'Geisha Orange' P-PO_4 (mg/pot)



Days after beginning of the treatment

Days after beginning of the treatment

Fig. 2. Average phosphorus content (P-PO_4 in mg per one pot) in leachate solutions collected every two weeks over a 98 day period (2 June 2012 to 16 September 2012) from peat substrate prepared with three controlled-release fertilizers CRFs (Multicote, Osmocote, Plantacote) and fast-acting fertilizers (control) for *Euonymus japonicus* 'Ovatus Aureus' and *Rhododendron* 'Geisha Orange' irrigated with standard (SI) and high rate (HI). Each data point is average for 3 rates of CRFs (1.5, 3.0 and 4.5 $g \cdot l^{-1}$) and 6 replications per one rate. Asterisk (*) indicates difference ($P < 0.05$) between SI and HI treatments (Tukey HSD test)

To assess impacts of irrigation and fertilization strategy applied in our study on nitrate and phosphate leaching from containers, the quantities of these nutrients were expressed per one pot (Fig. 1 & 2). Leachate amounts of $N\text{-}NO_3$ and $P\text{-}PO_4$ for all CRFs and fast-acting fertilizers (control) fluctuated throughout the 98-day period, with significant differences among treatments (Fig. 1 & 2). Overall, for all CRFs levels the $N\text{-}NO_3$ and $P\text{-}PO_4$ in leachates were the highest during the first 14-28 days of the study, and decreased to near 0 mg per pot in the end of the experimental period. Slightly increased amounts of nitrate in drainage water were recorded in the end of September (day 84) for both taxa. In this time, plants did not grow as fast as during spring and early summer, and for this reason they need less nutrients, which might lead to an increase of nitrate in drainage water.

Over application of irrigation significantly increased nitrate and phosphate losses from containers for almost whole cultivation period irrespective of the CRF, with the exception of phosphate in leachates for *Euonymus* plants fertilized with Plantacote (Fig. 1 & 2). Average nitrate leaching losses under HI (calculated for all collection days) were 1.8 times higher for *Euonymus* (1.1 mg $N\text{-}NO_3$ per pot at HI vs. 0.6 mg $N\text{-}NO_3$ per pot at SI) and 1.6 times higher for *Rhododendron* (0.8 mg $N\text{-}NO_3$ per pot at HI vs 0.5 mg $N\text{-}NO_3$ per pot at SI) than at SI (Fig. 1). Average phosphate leaching losses under HI were 1.4 times higher for *Euonymus* (0.18 mg $P\text{-}PO_4$ per pot at HI vs. 0.13 mg $P\text{-}PO_4$ per pot at SI) and 1.8 times higher for *Rhododendron* (0.27 mg $P\text{-}PO_4$ per pot at HI vs 0.15 mg $P\text{-}PO_4$ per pot at SI). Assuming average daily runoff volumes of 77 ml per plant at SI, and 172 ml per plant at HI, $N\text{-}NO_3$ concentration for all CRFs ranged from 1.2 to 17.9 $mg \cdot l^{-1}$ for *Euonymus* and from 1.4 to 12.3 $mg \cdot l^{-1}$ for *Rhododendron* at SI and ranged from 1.1 to 14.0 $mg \cdot l^{-1}$ for *Euonymus* and from 1.1 to 6.5 $mg \cdot l^{-1}$ for *Rhododendron* at HI. $N\text{-}NO_3$ concentrations in drainage water from the *Euonymus* and *Rhododendron* plants were usually similar to those reported for container-grown woody ornamentals, including 7.2-12.7 $mg \cdot l^{-1}$ (Colangelo & Brand 2001), 2.8-29.9 $mg \cdot l^{-1}$ N (Taylor et al. 2006), and 0.1-135 $mg \cdot l^{-1}$ N (Yeager et al. 1993) and 0.7-26.3 $mg \cdot l^{-1}$ (Wilson et al. 2010).

$P\text{-}PO_4$ concentration in drainage water in our study ranged from 0.9 to 2.6 $mg \cdot l^{-1}$ for *Euonymus* and from 0.7 to 2.1 $mg \cdot l^{-1}$ for *Rhododendron* at SI and from 0.9 to 3.4 $mg \cdot l^{-1}$ for *Euonymus* and from 0.1 to 2.5 $mg \cdot l^{-1}$ for *Rhododendron* at HI (Fig. 2).

Quantities of $N\text{-}NO_3$ in leachates from substrate amended with Multicote were greater than from the other CRFs during 12 weeks of experimental period (Fig. 1). Considering the weak vegetative growth and quality of plants fertilized with Multicote and high amount of nitrates in the drainage water, this CRF has proved to be the least useful in the production of *Euonymus* and *Rhododendron* plants. Considering amounts of NO_3 and PO_4 in leachates for the different fertilizer treatments, it appears that Osmocote and Plantacote resulted in a more stable release patterns than Multicote. Moreover, Osmocote and Plantacote had the strongest effect on vegetative growth of both plant species.

The chemical composition of the drainage water was also affected by the used rates of CRFs. In general, the higher rate of CRFs was used, the concentration of nitrate and phosphate in leachates were higher (data not presented). For *Euonymus*, increasing the rate of Osmocote and Plantacote from 3.0 to 4.5 $g \cdot l^{-1}$ resulted in improved vegetative growth and plant quality, however, maximum nitrate concentration in leakage was relatively high after 14 days (23.3 $mg \cdot l^{-1}$ $N\text{-}NO_3$ for Osmocote and 27.3 $mg \cdot l^{-1}$ $N\text{-}NO_3$ for Plantacote) and exceeded more than twice the limit set for drinking water by European Union (Drinking Water Directive), which is 11.3 mg $N\text{-}NO_3 \cdot l^{-1}$ or 50 mg NO_3^-. Similarly, the highest contents of $P\text{-}PO_4$ in the drainage water were also the highest during the first 14 days of the study (2.2 $mg \cdot l^{-1}$ for Osmocote and 2.7 $mg \cdot l^{-1}$ for Plantacote). It means that woody-ornamental nurseries can significantly contribute to groundwater contamination by fertilizers runoff, the more that the area is used for the same type of production for years (Juntunen et al. 2003; Pinto et al. 2008).

In the treatments where plants were fertilized with fast-acting, water soluble fertilizers, N-nitrate contents in drainage water for all collection dates were lower than after application of CRFs (average 0.56 mg per pot for *Euonymus* and 0.33 mg per pot for *Rhododendron* at HI and 0.29 mg per pot for *Euonymus* and 0.19 mg per pot for *Rhododendron* at SI), while the P-phosphate contents were similar (average 0.14 mg per pot for *Euonymus* and 0.24 per pot for *Rhododendron* at HI and 0.08 mg per pot for *Euonymus* and 0.12 mg per pot for *Rhododendron* at SI). Amounts of $N\text{-}NO_3$ and $P\text{-}PO_4$ that were used for control plants were similar to that after application of CRFs at the lowest rate of 1.5 $g \cdot l^{-1}$. However, *Euonymus* and *Rhododendron* qualities after Osmocote and Plantacote application at 1.5 $g \cdot l^{-1}$ were significantly higher than in the control treatment. This was probably due to a more stable release of nutrients from CRFs and better adjusted to the requirements of the plants.

CONCLUSIONS

1. Water requirements of container-grown *Euonymus japonicus* 'Ovatus Aureus' and *Rhododendron* 'Geisha Orange' were quite different. *Rhododendron* 'Geisha Orange' had higher water needs than *Euonymus japonicus* 'Ovatus Aureus'.
2. Application of Osmocote and Plantacote CRFs was the most effective for the container-grown *Euonymus* and *Rhododendron* plants. In the first growing season, the rate of 3 g of the above fertilizers per l liter of substrate was sufficient to obtain vigorous, good quality plants of both taxa. For *Euonymus*, the use of CRFs rate of 4.5 $g \cdot l^{-1}$ in the second year resulted in the strongest growth of plant.
3. Optimal N and P concentrations in leaf tissue of *Euonymus japonicus* 'Ovatus Aureus' were 1.71-1.95% for N and 0.21-0.23% for P. For *Rhododendron* 'Geisha Orange' optimal N and P levels were 1.54-2.01% for N and 0.11-0.14% for P.
4. Excessive irrigation rate (HI) significantly increased amount of runoff from containers compared with the SI treatment. Likewise, over-application of irrigation significantly increased nitrate and phosphate losses from containers during the entire growing period. With the higher rate of CRF, levels of nitrate and phosphate in leachates were higher. Maximum nitrate concentrations in leakage were the highest at the 14th day after application of fertilizers.

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