doi: 10.17221/12/2015-HORTSCI

Impact of fertilization strategies on the growth of lavender and nitrates leaching to environment

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Abstract

Matysiak B., Nogowska A. (2016): **Impact of fertilization strategies on the growth of lavender and nitrates leaching to environment**. Hort. Sci. (Prague): 43: 76–83.

Horticultural industry significantly affects the environment. In particular, large amounts of irrigation water and fertilizers required for intensive plant production can result in an increased nutrient runoff to surface and ground water. The objective of the study was to evaluate the effect of different fertilization strategies on the growth and flowering of container-grown English lavender cv. Dwarf Blue and the composition of the leachates generated by this crop. Three types of controlled-release fertilizers (Osmocote 16-9-12, Plantacote 15-10-15 and Multicote 17-17-17) at three rates (1.5, 3.0 and 4.5 g/l) were compared to fast-acting fertilizers. The application of Multicote promoted vegetative growth of lavender but inhibited the appearance of flower spikes. Plants fertilized with Osmocote and Plantacote at the highest rate produced the highest fresh weight and the highest number of flowering spikes, as well as the best quality. However, these rates gave relatively high values of nitrogen nitrate content after 4 weeks of plant cultivation. Among the applied controlled-release fertilizers, Multicote had the lowest potential to contribute nitrate pollutants discharged from containers.

Keywords: container-grown plants; *Lavandula angustifolia*; nursery production

Polish horticulture is an important agricultural sector accounting for about 30% of total cash crop production with over 0.5 million hectares of agricultural land area devoted to horticultural crops. On the other hand, horticulture has potential for negative impact on the environment. In particular, large amounts of irrigation water and fertilizers are required for intensive plant production, which can result in a significant nutrient runoff and pollution of ground and surface waters (Yeager et al. 1993; Taylor et al. 2006; Newman et al. 2014). Mineral nitrogen ($N\text{-}NO_3^-$) is the most frequently detected horticultural pollutant in water systems, which is due to the low anion-holding capacity of most substrate media used in plant production (Newman et al. 2006). Mineral nitrogen also has the greatest impact on plant growth and development and is applied at the highest rate relative to other plant nutrients (Marschner 1995). *Enrichment* of aquatic ecosystems with $N\text{-}NO_3^-$ may stimulate many undesirable changes associated with eutrophication, resulting in the loss of valuable aquatic habitats and changes of natural ecosystems.

Leaching of $N\text{-}NO_3^-$ from horticultural crops is well documented. Cabrera et al. (1993) found that up to 50–60% of the N applied to a crop of greenhouse roses was lost due to leaching, which amounted to 2,000 kg/ha per year. Breś (2009) reported the total loss up to 231 kg $N\text{-}NO_3^-$/month/ha for greenhouse production systems using soilless culture in open fertigation system. Kowalczyk et al. (2013) surveyed $N\text{-}NO_3^-$ concentrations in different water intakes of the major areas of greenhouse production in Poland. They showed that the $N\text{-}NO_3^-$

doi: 10.17221/12/2015-HORTSCI

content may be as high as 128 mg/l, exciding the current EU maximum of 11.3 mg/l in surface and groundwater (The Nitrates Directive, Council Directive 91/676/EEC of 12 December 1991). Thus, unless properly managed, greenhouse production is a serious pollutant of the environment.

Controlled-release fertilizers (CRFs) are extensively used in container production of horticultural plants due to benefits deriving from greater nutrient use efficiency, better plant growth and quality, lower labour and management costs and, compared to fast-acting fertilizers, reduced mineral nutrient losses (Cabrera 1997; Harris et al. 1997; Husby et al. 2003; Wilson, Albano 2011). Nutrient release from CRFs is primarily influenced by temperature and time, with higher temperature generally causing an increase in nutrient release rate. Longevity of nutrient release can be defined as the length of time for a fertilizer to release a high percentage (about 80%) of its nutrients at a given temperature (20–21°C). However, nursery containers can show wide diurnal fluctuations in temperature. For example, substrate temperature increased from 21 to 40°C in as little as 6 hours in black containers exposed to the sun (Ingram et al. 1989), so nutrients losses might be higher than expected. However, only limited research was carried out to document $N\text{-}NO_3^-$ leaching from containerized nursery crops. Concentrations of $N\text{-}NO_3^-$ in runoff recorded by different workers were 0.1 to 135 mg/l (Yeager et al. 1993), 7.2 to 12.7 mg/l (Colangelo, Brand 1997), 2.8 to 29.9 mg/l (Taylor et al. 2006) and 0.7 to 26.3 mg/l (Wilson et al. 2010). A better understanding of nutrient dynamics of crops growing in containers is required in order to insure efficient use of fertilizer, maximum yield and quality with minimum nutrient runoff.

English lavender (*Lavandula angustifolia* Mill.) is a popular plant for home gardens as well as being a highly valued commercial crop with increasing economic importance due to its aromatic and medical properties (Biesiada et al. 2008; Pisulewska et al. 2009; Prusinowska, Śmigielski 2014). It is drought-tolerant and therefore suitable for greenroofing, which is becoming a popular sustainable option for contemporary buildings in many cities (Kotsiris et al. 2012). Biesiada et al. (2008) found that vegetative growth of field-grown *L. angustifolia* was stimulated by increasing of nitrogen rate from 50 to 200 kg N/ha, while lower nitrogen rate (100 kg/ha) produced higher numbers of flowers per plant. Too high rate of N may cause excessive gain in the green parts and simultaneously reduce the amount of flowers or delay flowering. For commercial production of container-grown lavender, a well-draining substrate media and moderate fertilization levels are required (Aenderkerk 1997). However, there is limited information on nutrient dynamics of growing lavender in pots.

The aim of the study was to evaluate the effect of different fertilization strategies on the growth and flowering of container-grown English lavender and on the composition of the leachates generated by this crop. Three types of controlled-release fertilizers (CRF) with the same release timeframe of nutrients were used at three rates and compared to fast-acting fertilizers.

MATERIAL AND METHODS

The experiment was conducted at the Research Institute of Horticulture in Skierniewice, Poland in 2013–2014. English lavender (*Lavandula angustifolia* Mill.) cv. Dwarf Blue, plant with moderate nutritional needs, was chosen for the study. Rooted stem cuttings purchased from a commercial nursery were transplanted on May 21, 2013 into 0.8 l black polyethylene pots with side and bottom drainage holes. Substrate consisted of *Sphagnum* peat moss (Klasmann Lithuanian Peat Moss), with structure 0–25 mm (pH 3.5–4.5 in H_2O, no NPK fertilizer was added, salt level < 0.2 g/l). The substrate was amended with chalk at a rate of 6 g/l with a target pH of 6.5.

Pots were placed on 6 benches (2 m × 1.2 m) in polyethylene-clad greenhouse. Each bench comprised 60 plants with 10 treatments arranged in randomized block design and 6 replications per treatment. The treatments comprised three types of 3–4 month release controlled release fertilizers (CRF) at doses of 1.5, 3.0, 4.5 g/l and one treatment with fast acting fertilizer. CRF's were Multicote 17-17-17 + minors (Haifa Chemicals, Matam-Haifa, Israel), Osmocote Exact Standard 16-9-12 + minors (Everris International B.V., Geldermalsen, the Netherlands) and Plantacote 15-10-15 + minors (AGLUKON Spezialduenger GmbH & Co., Dusseldorf, Germany). All CRFs were applied by blending with the substrate before planting. Fertilization rates corresponded to low (1.5 g/l), medium (3.0 g/l) and high (4.5 g/l) manufacturer-recom-

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Table 1. Sources and amount (% w.t.) 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 + minors	17	3.7	4.8	8.5	7.4	14.1
Osmocote 16-9-12 + minors	16	8.6	7.4	0	3.9	10.0
Plantacote 15-10-15 + minors	15	8.5	6.5	0	4.3	12.5

mended rate. The control treatment was PG-Mix 14-16-18 + minors (Yara, Oslo, Norway) added to the substrate before planting at 1 g/l together with Symfo-vita A 12-5-22-5 + micro (Pro-Lab, Wloclawek, Poland) added by plant feeding with 100 ml of 0.1% fertilizer solution per pot, 3 times every 2 weeks. The amount of each CRF was adjusted so that total N contents were almost equal (Table 1).

Irrigation was applied using overhead sprinklers with two micro-sprinklers per bench set 2–3 events per week, depending upon climatic conditions, applying a uniform depth of 25 mm at each event. Plants were irrigated with municipal tap water that contained an (in mg/l) 0.12 $N\text{-}NO_3^-$, < 0.05 $N\text{-}NH_4^+$, < 0.1 P, 3.33 K^+, 104 Ca^{2+}, 17.6 Mg^{2+}, 12.4 Na^+, 23.4 Cl^-, 24.9 SO_4^{2-}, and had a pH 7.2 and an electrical conductivity (EC) 0.59 mS/cm.

At the termination height, plant diameter was measured and plant visual quality ranked from 1 to 4, where 1 was the weakest and 4 was the highest. The number of flower spikes per plant were counted one month after beginning of the study (June 25, 2013) and again at the termination (September 17, 2013). Regrowth of plants was evaluated after the over-wintering period, which lasted until the end of March of the following year, during which the greenhouse temperatures were monitored using a Metos Compact Weather Station (Pessl Instruments, Austria) and maintained at 0–2°C.

Leachate from the potting substrate was collected using a pour-through extraction procedure (Bilderback 2002) by holding a 500 ml vial beneath a drain hole and catching the leachate from the pot. Samples were collected at two week intervals, starting 14 days from the date of CRFs application (June 5, 2013) with the total of seven sample dates. Leachate EC was measured with a conductivity meter and nitrate-N was determined using a nitrate ion-selective electrode ISE (Orion 4-Star Portable pH/ISE Meter, Thermo Scientific Inc., Beverly, USA).

The analysis of variance ANOVA was conducted using the Statistica software. When the ANOVA indicated significant effects, means were separated using the Tukey's HSD test, with $P < 0.05$ considered to be statistically significant.

RESULTS AND DISCUSSION

For most of the trial average air temperatures (Fig. 1, weeks 3 to 11) were close to the optimum

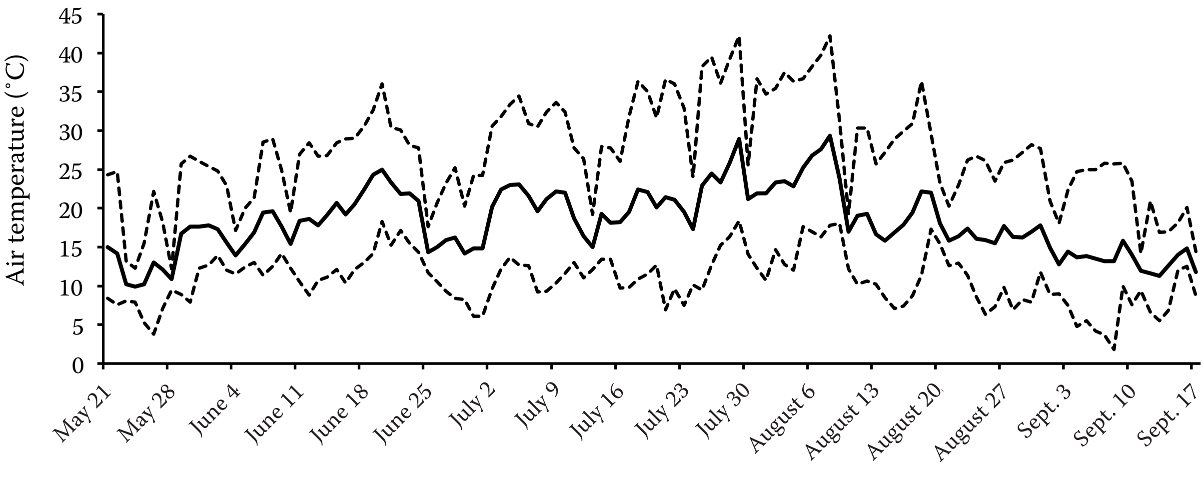

Fig 1. Daily average (solid line), minimum (lower dashed line), and maximum (upper dashed line) air temperatures over a 17-weeks period (May 21, 2013 to September 17, 2013)

doi: 10.17221/12/2015-HORTSCI

soil temperature for all CRFs (20–21°C) as specified by the respective manufacturers of the used CRFs. Nutrient release by the CRFs, which is positively correlated with temperature, might thus be expected to be close to intended rates for most of the period of plant cultivation. During the first 2 weeks and the last 3 weeks of the trial, average temperatures were usually lower than optimum, so nutrient release rate could have been correspondingly lower as observed in previous studies (Newman et al. 2006; Carson et al. 2013). In fact, leachate EC from both controlled- and fast-release fertilizer treatments was mainly the highest at the second week and then decreased during the next several weeks (Fig. 2a–d). The exceptions were the highest doses of Osmocote and Plantacote CRFs (4.5 g/l), where EC was the greatest at the fourth week at 3.3 and 2.0 mS/cm, respectively (Fig. 2c,d).

During the first weeks of the study, leachate EC generally varied among CRFs and the applied rates. Average EC was the highest with Osmocote, slightly lower with Plantacote, and the lowest with Multicote treatment. The higher rate of Osmocote and Plantacote resulted in greater leakage EC during the first six weeks of cultivation. Multicote showed a more stable leaching EC pattern, not exciding 1 mS/cm over the entire period irrespective of the applied rate. After 14 weeks all CRFs treatments in our study approached an EC value of 0.6 mS/cm, which was close to EC of water used for irrigation (0.59 mS/cm). Thus, nutrient release duration of each CRF, as implied by EC measurements, was consistent with the stated manufacturer specification of 3–4 months.

$N\text{-}NO_3^-$ concentration showed temporal patterns that were generally consistent with those of leachate EC for all applied fertilizers (Fig. 2e–h). Narváez et al. (2012) found significant linear relationship between the EC of the leachates and their N content. In our study leachate $N\text{-}NO_3^-$ concentrations for the highest applied rate of Osmocote and Plantacote were lower than 10 mg/l during the first 2 weeks of the study and then increased to 29.3 and 19.2 mg/l, respectively, at week 4. This was around twice the 11.3 mg/l $N\text{-}NO_3^-$ water limit set by the European Union (The Nitrates Directive). After the 6th week, leachate $N\text{-}NO_3^-$ concentration for all rates of Osmocote and Plantacote mostly decreased reaching around 5 mg/l by the end of the study. For Multicote, $N\text{-}NO_3^-$ concentration over the entire period was much more stable than other CRFs, and did not exceed the value of 10 mg/l.

For spring potted English lavender, as for the other ornamental woody plants with a relatively short production time, it might be preferable if nutrients were delivered in an exponentially increasing manner to better match supply with plant demands (Aendekerk 1997). However, the actual pattern of nutrient release of some CRF types may be to dispel a large portion of nutrients in the early stages of the designated release period when plant demand is low. For instance, in a study where Osmocote and Nutricote (3- to 4-month release) were tested, the most rapid nitrogen release occurred within the first 2 weeks after potting, resulting in significant nutrient leaching and poor efficiency of fertilizer use (Huett 1997). In our study a relatively high leachate EC and $N\text{-}NO_3^-$ content occurred after 4 weeks from CRFs application (Fig. 2), but only if Osmocote and Plantacote were used at the highest dose.

For Multicote, patterns of nutrient leaching (EC and $N\text{-}NO_3^-$) were more stable than for Osmocote and Plantacote during the 14-weeks assessment period, which may be caused by variation in coating technology, either the coating thickness or chemical composition of the polymer itself (Douglass 2005) resulting in better buffering against fluctuations in temperature. Other possibilities are differences in nutrient content other than nitrogen, a relatively high share of nitrogen in amide form (50% of the total N content in Multicote), different temporal patterns of nutrient release to the growing substrate (Cabrera 1997) or better matching the rate of release of nutrients to the growth of lavender plants. Nitrogen in amide form is not directly available to plants, but only after conversion to ammonium and nitrate forms by soil microorganisms (Marschner 1995). Consequently, factors affecting microbial activity, such as higher temperature, moisture, pH and oxygen availability, affect the release of nitrogen, and this process usually takes from one day to one week. Thus, amide nitrogen has a relatively long lasting effect. Its intermediate products are not leached to the soil, which may explain lower and more stable EC in drainage water using Multicote than Osmocote and Plantacote CRFs.

The fertilization method had a significant effect on the growth and quality of container-grown English lavender cv. Dwarf Blue. With the CRFs used at recommended (3 g/l) and half higher than recommended (4.5 g/l) rates, fresh weight of above ground parts of the plants was higher and plant

doi: 10.17221/12/2015-HORTSCI

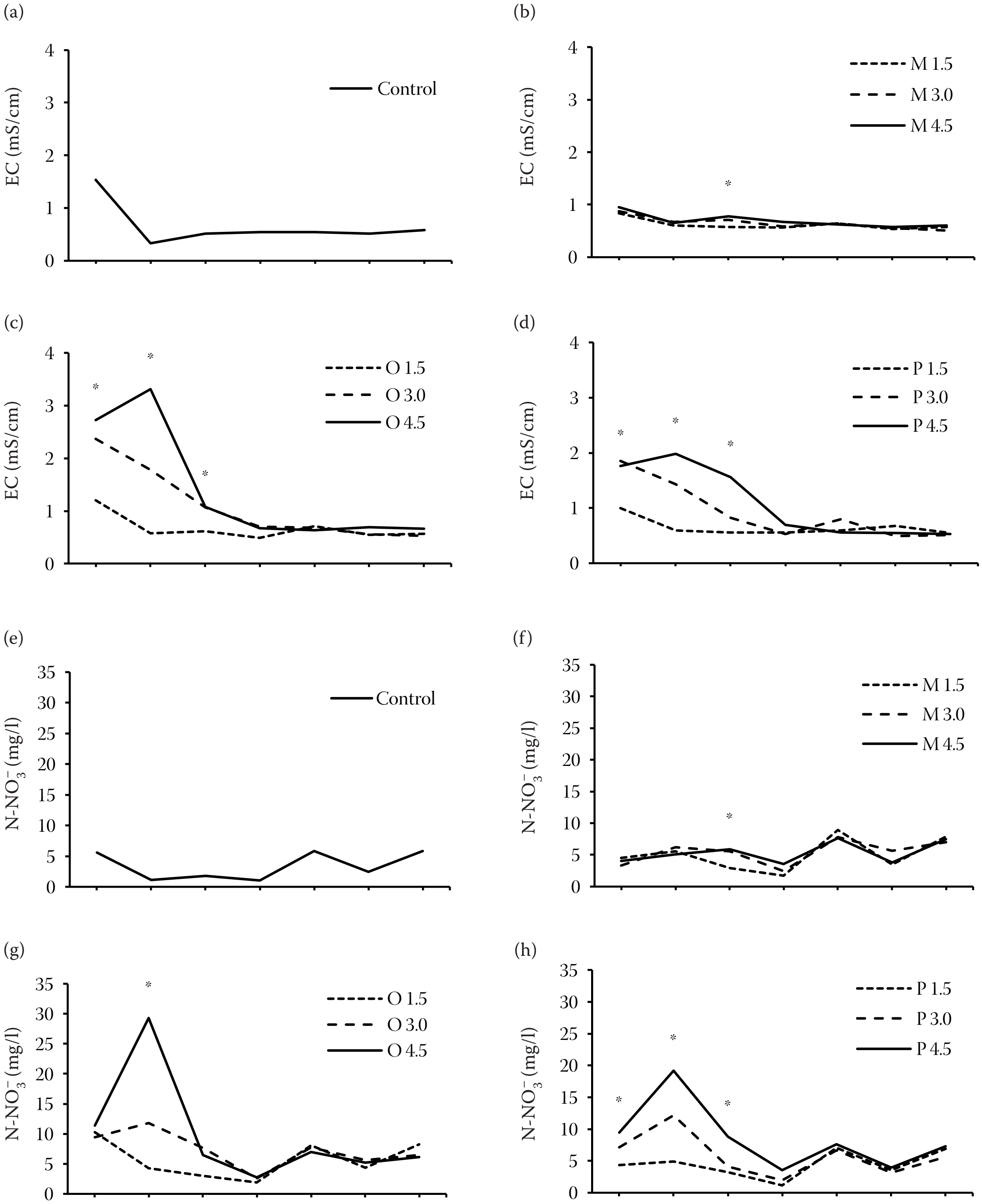

Fig. 2. Electrical conductivity (EC) (a–d) and nitrate nitrogen content ($N\text{-}NO_3^-$) (e–h) in leachate solutions collected every two weeks over a 14-week period (May 21, 2013 to August 27, 2013) from peat substrate prepared with three controlled-release fertilizers CRFs (M – Multicote, O – Osmocote, P – Plantacote) and fast-acting fertilizers (Control) for *Lavandula angustifolia* cv. Dwarf Blue. Each data point is average for 3 rates of CRFs (1.5, 3.0 and 4.5 g/l) and 3 replications per one rate; *idicates difference ($P < 0.05$) between the rates of CRFs

doi: 10.17221/12/2015-HORTSCI

Table 2. Growth response of container-grown *Lavandula angustifolia* cv. Dwarf Blue under three controlled-release fertilizers (Multicote, Osmocote and Plantacote) applied at three rates (1.5, 3.0 and 4.5 g/l) compared to control, fast-acting fertilizers

Fertilization		Number of flower spikes		Plant height (cm)	Plant diameter (cm)	Plant quality (1–4)*	Fresh weight (g)
		June 25	September 17				
Control		2.4	$5.7^{a–d}$	23.6^{a}	17.6^{a}	2.1^{a}	32.3^{a}
Multicote	1.5	2.4	2.9^{a}	27.4^{bc}	18.2^{a}	2.8^{b}	40.0^{b}
Multicote	3.0	3.1	4.4^{a-c}	28.8^{bc}	21.9^{cd}	2.9^{b}	57.2^{c}
Multicote	4.5	2.8	3.9^{ab}	29.5^{c}	23.2^{de}	3.6^{c}	70.2^{e}
Osmocote	1.5	2.7	$7.1^{b–e}$	25.9^{ab}	18.8^{ab}	2.4^{a}	39.6^{ab}
Osmocote	3.0	2.3	8.9^{de}	29.8^{c}	21.9^{cd}	3.1^{b}	59.3^{cd}
Osmocote	4.5	2.8	$8.2^{c–e}$	29.4^{c}	24.0^{e}	3.5^{c}	66.0^{de}
Plantacote	1.5	2.5	$5.2^{a–d}$	25.9^{ab}	17.5^{a}	2.3^{a}	35.1^{ab}
Plantacote	3.0	3.0	8.8^{de}	29.4^{c}	20.6^{bc}	2.9^{b}	53.9^{c}
Plantacote	4.5	2.4	9.1^{e}	29.9^{c}	2.3^{de}	3.7^{c}	66.3^{de}

means in column followed by the same letter do not differ significantly according to the Tukey's *HSD* test at $P < 0.05$; *visual assessment, scale from 1 to 4, where 1 is the weakest and 4 is the highest quality

quality better than corresponding results for control plants fertilized by fast-acting fertilizers (Table 2). Although the plants in the control treatment were regularly fed by fast-acting fertilizers (three times every two weeks) during the growth phase, this fertilization method did not ensure an adequate supply of nutrients, probably due to their excessive leakage out of the container. Plants fertilized with all CRFs at the highest rate (4.5 g/l) had the largest diameter, the best quality and the highest fresh weight. Moreover, Osmocote and Plantacote CRFs applied at 3.0 or 4.5 g/l resulted in abundant flowering of lavender with 8.6 and 9.0 flower spikes per plant, respectively. By contrast, Multicote, stimulated vegetative growth but inhibited the appearance of flower spikes, regardless of the applied rate. These results are consistent with previous research showing that fast vegetative growth of lavender plants decreases flower yield (Kochaki, Sabet-Teimori 2011). Regrowth of lavender measured in April was one week faster for plants fertilized by even the lowest rate of CRF compared to fast-acting fertilization.

Several management best management practices are available to growers using CRFs for optimizing nutrient uptake into crops and minimising the likelihood of nutrient leaching from the containers (Newman et al. 2006; Wilson et al. 2010). One way is using CRFs that last throughout the production period and monitoring substrate and leaching nutrient levels (Yeager et al. 2010). Another is avoiding excessive irrigation volumes during each irrigation event (Bilderback 2002; Warsaw et al. 2009) especially during warm or hot weather when the rate of nutrient release from CRF prills is higher. Lower irrigation volumes reduced nutrient losses and led to increased plant growth by keeping greater quantities of nutrients in the substrate available for plant absorption, thereby maximizing fertilizer benefits and minimizing the potential for environmental contamination (Newman et al. 2014). Another option which requires further research is to use a variety of soil amendments to increase the anion exchange capacity of substrates used in container-grown nurseries.

CONCLUSION

Container-grown English lavender cv. Dwarf Blue fertilized with controlled-release fertilizers (CRFs) Osmocote 16-9-12 and Plantacote 15-10-15 at the rate of 4.5 g/l produced the highest fresh weight, the most flowering spikes, as well as they had the best quality. However, these CRFs used at the rate of 4.5 g/l gave relatively high values of leachate EC and nitrate nitrogen content after 4 weeks of plant production, exceeding from two to three times the 11.3 mg/l N-NO3– surface and ground water limit set by the European Union (The Nitrates Directive).

doi: 10.17221/12/2015-HORTSCI

The application of Multicote 17-17-17 CRF promoted vegetative growth of English lavender cv. Dwarf Blue, but inhibited the appearance of flower spikes. Among the applied CRFs, Multicote 17-17-17 had a lowest potential to contribute nitrogen nitrate pollutants discharged from containers.

To optimize nutrient uptake into crops while simultaneously minimizing the likelihood of nutrient leaching from the containers, consistent monitoring of electrical conductivity of leachate should be performed.

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Received for publication January 22, 2015
Accepted after correction November 18, 2015

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