

# Effects of climate and fertilization strategy on nitrogen balance in an outdoor potted crop of *Viburnum tinus* L.

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## Abstract

Little information is currently available on how fertilization management affects leachate composition and the plant nitrogen (N) uptake of crops under Mediterranean climate. The objectives of this study were to determine the effect of different fertilization strategies and doses on the composition of the leachates and the use of N by plants, to establish a N balance for the different fertilization strategies and doses used and to establish a linear regression model to predict N concentration in leachates from an outdoor potted crop of *Viburnum tinus* L. 'Eve Price'. Two fertilizations strategies, *i.e.* continuous fertigation (NS) and incorporated controlled-release fertilizer (CRF), were applied to the crop. The treatments were two NS doses (NSA: 57.4 mg NO<sub>3</sub>-N L<sup>-1</sup> and NSB: 43.4 mg NO<sub>3</sub>-N L<sup>-1</sup>) and two CRF doses (CRFC: 5 g L<sup>-1</sup> and CRFD: 7 g L<sup>-1</sup>). The NO<sub>3</sub>-N concentration in the leachates from the CRF treatments was high in the first weeks of growing (100-300 mg L<sup>-1</sup>). The efficiency of use of N was greater in the NSA treatment (9.2 g g<sup>-1</sup>). When CRFC was applied there was an increased loss of N by leaching (48 % of the total N). The concentration of N in the leachates for both fertilization strategies was found to be correlated with the variables substrate temperature and precipitation. Therefore, these variables must be considered when determining the dose of fertilizer to be added to a crop, especially when CRF are chosen, to avoid high losses of N by leaching.

**Additional key words:** controlled-release fertilizer; fertigation; Mediterranean climate; nitrate pollution; nitrogen efficiency; woody ornamental.

## Resumen

**Efectos del clima y de la estrategia de fertilización en el balance de nitrógeno en un cultivo al exterior en contenedor de *Viburnum tinus* L.**

Existe poca información sobre el efecto de la estrategia de fertilización en la composición de los lixiviados y la absorción de nitrógeno (N) por un cultivo en clima mediterráneo. Los objetivos de este estudio fueron determinar el efecto de diferentes estrategias de fertilización y dosis en la composición de los lixiviados y en el uso del N por las plantas, establecer un balance de N basado en la estrategia de fertilización y dosis aplicadas y establecer un modelo lineal para predecir la concentración de N en los lixiviados de un cultivo de *Viburnum tinus* L. 'Eve Price'. Se aplicaron al cultivo fertilizantes mediante fertirrigación continua (NS) o mediante la incorporación de fertilizantes de liberación controlada (CRF). Los tratamientos fueron dos dosis de NS (NSA: 57,4 mg NO<sub>3</sub>-NL<sup>-1</sup> y NSB: 43,4 mg NO<sub>3</sub>-NL<sup>-1</sup>) o dos dosis de CRF (CRFC: 5 g L<sup>-1</sup> y CRFD: 7 g L<sup>-1</sup>). La mayor concentración de NO<sub>3</sub>-N en los lixiviados se detectó al aplicar CRF (100-300 mg L<sup>-1</sup>). Las plantas del tratamiento NSA usaron el N más eficientemente (9,2 g g<sup>-1</sup>). Las pérdidas de N por lixiviación aumentaron significativamente al aplicar el tratamiento CRFC (48% del N total). La concentración de N en los lixiviados de todos los tratamientos se correlacionó con las variables temperatura del sustrato y precipitación, por lo que éstas deben ser consideradas para determinar la dosis de fertilizantes a añadir a un cultivo, especialmente cuando se usan CRF, y así evitar elevadas pérdidas de N por lixiviación.

**Palabras clave adicionales:** clima mediterráneo; contaminación por nitratos; eficiencia de nitrógeno; fertilizante de liberación controlada; fertirrigación; plantas ornamentales leñosas.

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Abbreviations used: CRF (controlled-release fertilizer); EC (electrical conductivity); IRTA (Institut de Recerca i Tecnologia Agroalimentàries); LF (leaching fraction); MCU (multi computer unit); MLRM (multiple linear regression models); NS (nutrient solution); PR (precipitation).

## Introduction

Water and nutrient use efficiency in nurseries growing potted ornamental plants is often low (Grant *et al.*, 2009). The loss of varying amounts of nutrients in nursery crops by leaching depends to a great extent on agricultural practices (Bilderback, 2001). Nitrates from fertilizers are the predominate form of nitrogen (N) in leachates from crops (Cabrera, 1997; Fernández-Escobar *et al.*, 2004; Oliet *et al.*, 2004). In general, the nitrates reaching the groundwater in a specific area vary spatially and temporally due to factors such as hydrology and soil characteristics (Liu *et al.*, 2005; van der Laan *et al.*, 2010), which is why it is thought that certain plant-growing areas such as those in the vicinity of greenhouses and outdoor crops cause non-point source nitrate pollution of the groundwater (OJ, 2000).

Fertilization programmers used by nurseries growing potted ornamental plants include the application of controlled-release fertilizers (CRF) and/or soluble fertilizers applied in nutrient solutions (NS) through fertigation (Cabrera, 1997; Merhaut *et al.*, 2006; Wilson *et al.*, 2010). CRF are easy to handle and one application progressively supplies crops with nutrients for a specific period. Some authors have shown that the use of CRF improves plant growth and reduces N losses by leaching compared to other modes of fertilization (Hanafi *et al.*, 2000). However, CRF do not make it possible to correct the dose if it is found to be excessive at any given time, because they are usually applied in a single dose at the beginning of the growing period. The release of nutrients contained in CRF prills can be speeded up or delayed compared to the specifications of the CRF due to temperature (T), especially temperatures over 21°C (Du *et al.*, 2008), or unanticipated alterations in granule coating materials (Shaviv, 2001). If substrate T is over 21°C, the nutrients released from the CRF prills do not usually match the requirements of the plant and nutrients accumulate in the substrate solution. With intense rain, the nutrients accumulated in the substrate are washed into the environment (Million *et al.*, 2010). Most studies on the use of CRF have been carried out under laboratory conditions and/or without interaction with plants, or in greenhouses, where there is no interference from precipitation (Hershey & Paul, 1982; Niemiera & Leda, 1993; Cabrera, 1997; Huett & Gogel, 2000; Oliet *et al.*, 2004; Merhaut *et al.*, 2006). The variety of results in the literature on the composition

of nursery runoff can also be attributed to geographic differences (Marfà *et al.*, 2002; Garber *et al.*, 2002), species-dependent nutritional requirements, the origin of the substrate used (Guérin *et al.*, 2001) and the variety of irrigation and fertilizer strategies used (Fare *et al.*, 1996; Bilderback, 2002). Headley *et al.* (2001) reported a total N concentration from nursery runoff ranging from 1.35 to 18 mg L<sup>-1</sup> and the majority of the N (> 70%) occurred as NO<sub>3</sub><sup>-</sup>. In a study that monitored nutrient concentrations in runoff water from a nursery, the mean annual NO<sub>3</sub><sup>-</sup>-N concentration was 9 mg L<sup>-1</sup> (Huett, 1999). In a study to quantify the nutrient-release patterns of four types of CRF, Merhaut *et al.* (2006) reported that NO<sub>3</sub><sup>-</sup>-N concentrations in leachates were often higher than 10 mg L<sup>-1</sup> during most of the experiment. Moreover, the experimental results obtained on the relationships between percolate composition and fertigation strategy using *Viburnum tinus* L., showed that a steady-state nutrient level in the root zone can be achieved when a modulated (by dilution) and relatively low concentration of NS is applied in fertigation. The release of nutrients, especially nitrates, can also be considerably reduced (Marfà *et al.*, 2002).

Outdoor nurseries in the Mediterranean region are exposed to irregular distribution of rainfall throughout the year and an increasing trend of extreme climate events (increase of high-intensity precipitation extremes separated by long dry periods) may cause high runoff rates (Ramos & Martínez-Casanovas, 2010). The T regime in the container must also be considered, particularly if CRF are used (Raviv *et al.*, 1986; Handreck, 1992). Further studies in nursery conditions are needed to measure the effects of fertigation compared to the use of CRF on leachate composition and productivity in ornamental plant nurseries on the Mediterranean coast. More data would provide relevant information on the contribution of these leachates to nitrate contamination of the subsoil. It would also be helpful to have additional information to predict climate-related nitrate concentrations in leachates in outdoor potted crops. The aims of this experiment were: i) to determine the effect of different fertilization strategies and doses on the composition of the leachates generated and crop productivity, ii) to establish a N balance for the different fertilization strategies and doses used, and iii) to establish a linear regression model to predict N concentration in leachates as a function of the variables related to substrate temperature and precipitation.

## Material and methods

An experiment was carried out using the two standard fertilization strategies of nurseries on the Mediterranean coast of Catalonia (fertigation and incorporated CRF) (Marfà *et al.*, 2010) for a container crop of *V. tinus* 'Eve Price'. The experiment was arranged in a random design with four treatments. Two different concentrations of NS were applied using fertigation (NSA and NSB), and two different doses of CRF were also applied (CRFC and CRFD).

### Plant material and growing conditions

The experiment was carried out in an outdoor plot at the IRTA research station in Cabrils, Catalonia (Spain) (41°25'N, 2°23'E, altitude of 85 m). The experiment lasted for seven months (15 May to 12 Dec. 2007). Homogeneous rooted cuttings of *Viburnum tinus* L., 'Eve Price' were planted in 5-L pots placed at a distance of 40 cm from the other pots in all directions, thus resulting in a density of 6 plants m<sup>-2</sup>. The growing medium was prepared by mixing three parts composted pine bark (*Pinus pinea* L.) with one part Floragard TKS 1 Instant sphagnum peat (Vertriebs GmbH für Gartenbau, Oldenburg) (by volume) (Cáceres *et al.*, 2007). An automatic irrigation system, MCU Ferti (Multi Computer Unit; FEMCO, Damazan, France), and a drip irrigation system (one drip emitter per pot, 2 L h<sup>-1</sup>) were used. The irrigation was started automatically in each treatment when a threshold of cumulative global solar radiation (300 watts m<sup>-2</sup>), measured by means of solarimeters, was reached. The volume of irrigation water applied was periodically modified to provide a leaching fraction (LF: volume leached/volume applied \* 100) of between 20% and 40%. The same volume of irrigation water was applied in all treatments. The pH of the irrigation water was 7.2, electrical conductivity (EC) was 1.3 dS m<sup>-1</sup> and the NO<sub>3</sub><sup>-</sup> concentration was 24 mg L<sup>-1</sup>.

### Fertilizer treatments

Four different fertilization treatments were used in the experiment, with 48 plants each. In two of them, the fertilizer was applied in a nutrient solution (NS) by continuous fertigation, *i.e.* whenever the plants were irrigated, they were fertilized with the NS corresponding to each treatment. The NS was applied to the plants

at two different doses (A and B). In the NSA treatment a relatively low-concentration NS was applied that had been previously assayed for *V. tinus* (Marfà *et al.*, 2002). The NSB treatment dose had about 25% less N, P and K than dose A (Table 1). In the growing media used in the other two treatments, a resin-coated Osmocote Exact Standard (CRF) 15N (7.1 N-NO<sub>3</sub><sup>-</sup> + 7.9 N-NH<sub>4</sub><sup>+</sup>)-3.9P-7.5K with an 8- to 9-month release period at 21°C was applied (Scotts O.M. España S.A.) at two different doses: 7 g L<sup>-1</sup> and 5 g L<sup>-1</sup> for treatments CRFC and CRFD, respectively. These doses are commonly used by nurseries in Catalonia growing native woody shrubs such as *V. tinus* (Marfà *et al.*, 2010). In accordance with local practice, before the containers were filled with the growing medium, the CRF was homogeneously mixed with the substrate. It is not common for nurseries growing potted ornamental plants in Catalonia to use dibble or topdress placements of CRF, as occurs in other extensive areas where potted ornamental plants are grown (Alam *et al.*, 2009). The total amount of N supplied by the fertilizer and irrigation water was 3.2 g pot<sup>-1</sup> for the NSA treatment, 2.4 g pot<sup>-1</sup> for the NSB treatment, 5.5 g pot<sup>-1</sup> for the CRFC treatment and 4.0 g pot<sup>-1</sup> for the CRFD treatment.

### Runoff, N balance and plant data collection

Physicochemical and hydrological characterization of the substrate was conducted before and after the experiment. Substrate samples from the CRFC and CRFD treatments were analysed at the end of the experiment after manually removing the CRF prills (de Kreijl, 2004). The nitrate concentration in the extract (1 substrate: 1.5 deionized water, by volume) was measured with a Dionex ion chromatography system (model DX 120, Dionex Corporation, Sunnyvale, CA, USA). The total N concentration was determined using the Kjeldahl method. At the beginning of the experiment, the NO<sub>3</sub><sup>-</sup>-N concentration was 5.1 mg L<sup>-1</sup>, the pH was 5.7, EC was 0.2 dS m<sup>-1</sup> and the total Kjeldahl N content was 0.23%. Substrate T was recorded continuously throughout the experiment using a Testo data logger (model 177, Testo AG, Lenzkirch, Germany). One sensor per treatment was placed through the pot. Substrate T data were used to define the variable H<sub>T21</sub>, *i.e.* the accumulated degree hours per week in which the substrate T was over 21°C. Rainfall data were obtained from a meteorological station belonging to the Catalan Meteorological Network (METEOCAT) lo-

**Table 1.** Average composition of nutrient solution formulations used in the fertigation treatments (NSA and NSB)

Treatments	NO <sub>3</sub> <sup>-</sup> -N	NH <sub>4</sub> <sup>+</sup> -N	H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	pH	EC (dS m <sup>-1</sup> )
	(mg L <sup>-1</sup> )								
NSA	57.4	5.6	68.6	480	97.5	300	67.2	6.3	1.8
NSB	43.4	4.2	49.0	336	74.1	300	67.2	6.3	1.7

cated at the IRTA experimental station. Precipitation (PR) has been used as a variable in several studies that model nitrate leaching (van der Laan *et al.*, 2010).

During the growing period the volume of input water was measured daily in the CRF treatments and, as well as in the NSA and NSB treatments. The corresponding leachate volume and N concentration were also measured for each treatment. Lysimetric boxes were used to gather the leachates (Fare *et al.*, 1994; Cáceres *et al.*, 2007), with three boxes per treatment (n = 3). Each box had four containers, considering the leachate produced by four pots as a repetition. The following variables were measured on a weekly basis in triplicate in the irrigation water, input NS and leachates: the pH was determined with a selective ion analyser (model EA 920, Orion Research, Inc., Beverly, MA, USA), EC was measured using a Crison conductivity meter (model GLP 31, Crison Instruments, S.A., Barcelona), NO<sub>3</sub><sup>-</sup> concentration with a Metrohm chromatograph model 761 Compact IC (Metrohm AG, Herisau, Switzerland), and NH<sub>4</sub><sup>+</sup> concentration with an Orion selective electrode (model 95-12, Orion Research, Inc., Beverly, MA, USA). Total N of the plant was determined using the Kjeldahl method and the dry weight of the plant was measured by drying the sample at 60°C for 48 h at the beginning (in 6 plants) and end of the experiment (in 12 plants). The information gathered was used to calculate the N balance using the following equation:

$$N_T - \Delta N_P - N_S - N_L - N_O = N_{ND}$$

where  $N_T$  = N applied as fertilizer and in irrigation water and N in the growing medium at planting;  $\Delta N_P$  = N change in plant;  $N_S$  = N in the growing medium at the end of the experiment;  $N_L$  = N recovered in leachate;  $N_O$  = N remaining in the CRF prills;  $N_{ND}$  = N not detected.

The N remaining in the CRF prills at the end of the experiment (CRFC and CRFD treatments) was measured by taking a substrate sample for gravimetric analysis and removing any CRF prills. These prills were passed through a Filter-Lab paper filter (Filtros Anioia, S.A., Barcelona) placed inside a glass funnel. The prills inside the paper filter were ground manually with a glass rod

and then the entire contents were placed in a 250-mL beaker. The ground prills were rinsed with distilled water to a volume of 100 mL in the beaker. Total N in the solution obtained was determined using the Kjeldahl method and the NO<sub>3</sub><sup>-</sup> content was measured using the ion chromatography system described above.

### Statistical analysis

All statistical analyses were performed using SAS v.9.1 (SAS Institute, Cary, NC, USA). All the sample data were analysed using one-way analysis of variance and mean separation among treatments was obtained by Tukey's test. Data on precipitation and substrate T (independent variables) from each fertilization strategy (NS or CRF) were analysed using multiple linear regression models (MLRM, REG procedure in SAS software) for predicting the N concentration in leachates (dependent variable). For the MLRM, it was assumed that independent and dependent variables were random variables with a normal distribution. The general form of the MLRM was:

$$Y = A + \beta_1 \cdot PR + \beta_2 \cdot H_{T21}$$

where Y = nitrogen concentration in leachates (NO<sub>3</sub><sup>-</sup>-N + NH<sub>4</sub><sup>+</sup>-N, in mg L<sup>-1</sup>); A = intercept or independent term coefficient; PR = precipitation (L m<sup>-2</sup> week<sup>-1</sup>);  $H_{T21}$  = accumulated degree hours per week in which the substrate T was greater than 21°C (°C h week<sup>-1</sup>);  $\beta_1$  = regression parameter for PR variable;  $\beta_2$  = regression parameter for  $H_{T21}$  variable.

## Results

### Leachates: N content, EC and pH

Nitrate was the predominant form of N in the leachates from all treatments. It represented 100% in both NS treatments, 98% in the CRFC treatment and 99% in the CRFD treatment.

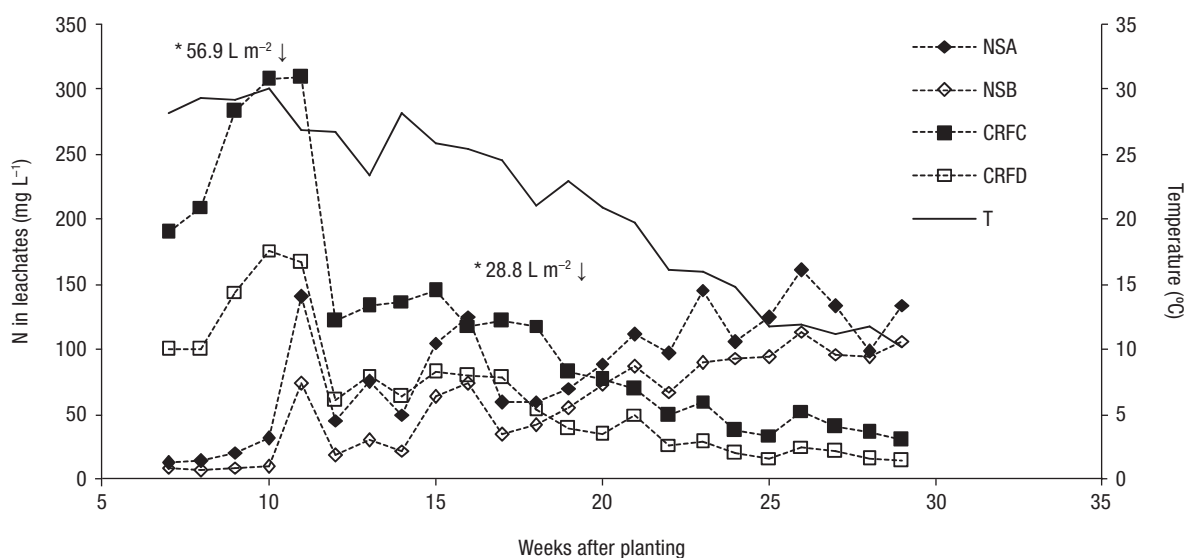


In the first 10 weeks of the growing period, a high release rate of  $\text{NO}_3^-$ -N was detected in the treatments in which the CRF was used that reached concentrations of between 100 and 300  $\text{mg L}^{-1}$ . However, in the treatments in which NS were applied, the  $\text{NO}_3^-$ -N concentration did not exceed 50  $\text{mg L}^{-1}$  (Fig. 1). The N leaching process in each treatment showed the effect of an intense rainfall event that took place at the end of week 10 of the growing period, which resulted in a considerable increase in N leaching (Fig. 2). After week 11, the  $\text{NO}_3^-$ -N concentration dropped drastically in the CRF treatments (Fig. 1). Starting in week 19 of the growing period, the  $\text{NO}_3^-$ -N concentration of the leachates from both NS treatments was higher than the  $\text{NO}_3^-$ -N concentration of the NS (Table 1). Starting in week 20 of the growing period, the  $\text{NO}_3^-$ -N concentration was lower in the CRF treatments than in the NS treatments (Fig. 1). The average substrate T remained above 25°C during the first 19 weeks of growing in all treatments. The maximum T was recorded in week 10 (Fig. 1). There was a significant linear relationship between the EC of the leachates and their N concentration when all treatments were considered [ $\text{EC (dS m}^{-1}) = 0.009 \text{ N leachate (mg L}^{-1}) + 0.794$ ;  $R^2 = 0.866$ ;  $n = 92$ ]. With regard to N, the EC of the leachates from the CRF treatments was especially high during the 11 weeks of the growing period (average EC: 2.8  $\text{dS m}^{-1}$ ) compared to the EC of the NS treatments (average EC: 1.4  $\text{dS m}^{-1}$ ) (data

not shown). This situation reversed starting in week 21 of the growing period until the end of the experiment, *i.e.* the EC of the leachates from the CRF treatments began to drop (average EC: 1.2  $\text{dS m}^{-1}$ ) compared to the EC of the NS treatments (average EC: 1.8  $\text{dS m}^{-1}$ ), as had occurred with the  $\text{NO}_3^-$ -N concentration (Fig. 1). The pH of the leachates from NS treatments remained basic during the entire growing period (average pH: 8.2) and was significantly higher than the pH of the NS applied (data not shown). However, the pH of the leachates from the CRFC treatment was moderately acidic (average pH: 5.8) or remained slightly acidic in the leachates from the CRFD treatment (average pH: 6.7) (data not shown).

### Nitrogen leaching and its relation to $H_{T21}$ and PR

The MLRM showed that N concentration in leachates from NS treatments could be estimated using the  $H_{T21}$  variable in an inverse and moderate relationship ( $R^2 = 0.65$ ), however there was no relation between N concentration and PR (Table 2). A highly significant coefficient of multiple determination for the multiple regression analysis indicated that N concentration in leachates from CRF treatments ( $R^2 = 0.89$ ) could be estimated in terms of the variables  $H_{T21}$  and PR (Table 2).



**Figure 1.** Daily  $\text{NO}_3^-$  concentration in leachates, averaged weekly, of outdoor growing *Viburnum tinus* 'Eve Price' in 5-L containers, fertilized with either nutrient solution (NS,  $\blacklozenge$  or  $\diamond$ ) or incorporated controlled-release fertilizer (CRF,  $\blacksquare$  or  $\square$ ). On the secondary axis, substrate temperature over time (—). \* Rainfall events ( $> 20 \text{ L m}^{-2}$ ).

**Table 2.** Multiple linear regression equations for the prediction of the N concentration in leachates (Y nitrogen leaching; mg L<sup>-1</sup>) related to the weekly cumulative degree hour up to 21°C (H<sub>T21</sub>; °C h week<sup>-1</sup>) and precipitation (PR; L m<sup>-2</sup> week<sup>-1</sup>) for a potted crop of *Viburnum tinus* L. 'Eve Price' ( $Y = A + \beta_1 \times PR + \beta_2 \times H_{T21}$ ) receiving different doses of either a fertigation nutrient solution (NSA or NSB) or controlled-release fertilizer (CRFC or CRFD)

Treatments	Regression parameters	Value	p-value	R <sup>2</sup>	F-value	p-value
NSA	A	124.3	< 0.0001	0.65	69.8	< 0.0001
	β <sub>1</sub>	-0.2	0.6963			
	β <sub>2</sub>	-0.1	< 0.0001			
NSB	A	93.8	< 0.0001			
	β <sub>1</sub>	-0.1	0.7755			
	β <sub>2</sub>	-0.1	< 0.0001			
CRFC	A	35.1	< 0.0001	0.89	105.6	< 0.0001
	β <sub>1</sub>	1.8	< 0.0001			
	β <sub>2</sub>	0.9	< 0.0001			
CRFD	A	18.3	0.0286			
	β <sub>1</sub>	1.1	0.0067			
	β <sub>2</sub>	0.1	< 0.0001			

## Nitrogen balance

The amount of N accumulated by the plants expressed as % of the total available N ( $N_T = N$  applied as fertilizer + N in irrigation water + N in the growing medium at planting) reached a maximum of 13% in the NSA treatment and this value was significantly higher than those of the other treatments. There were no significant differences in the amount of N accumulated in the substrate between the four treatments. The amount of organic N in the growing media at the end of the experiment increased by 26% compared to the amount of organic N at planting in the NSA, CRFC and CRFD treatments. However, the organic N content in the SNB growing media at the end of the experiment diminished by 15% compared to the amount at planting (data not shown). The relative N leachate (%) corresponding to the CRFC treatment was significantly greater than that of the other treatments (Table 3). The N remaining in the CRF prills at the end of the experiment was low and similar in both CRF treatments (5% of the  $N_T$ ). Between 2% and 26% of the  $N_T$  was not accounted for in the treatments at the end of the experiment (Table 3).

## Nitrogen efficiency

The efficiency of use of N supplied by the fertilizer and irrigation water was 9.2 g g<sup>-1</sup> for the NSA treat-

ment, 6.1 g g<sup>-1</sup> for the NSB treatment, 4.4 g g<sup>-1</sup> for the CRFC treatment and 5.7 g g<sup>-1</sup> for the CRFD treatment (Table 3). Of all the treatments, the NSA treatment was significantly the most efficient treatment in terms of the use of N for dry-weight production (g dry matter produced / g N supplied). Nitrogen efficiency was not significantly different between the NSB, CRFC and CRFD treatments ( $p < 0.01$ ).

## Discussion

Other authors have reported that NO<sub>3</sub><sup>-</sup> was the predominant form of N detected in the leachates due to nitrification processes in the growing media, even when different fertilization strategies were applied, given that nitrification processes are usually very active in pot growing conditions (Cabrera, 1997; Fernández-Escobar *et al.*, 2004; Oliet *et al.*, 2004; Merhaut *et al.*, 2006; Medina *et al.*, 2008). When different kinds of CRF are used, NO<sub>3</sub><sup>-</sup> leaching seems to be related to the irrigation strategy (drip, sprinkler), how the CRF is applied (incorporated, topdressed or dibbled) (Alam *et al.*, 2009) and substrate T, which affects the speed of NO<sub>3</sub><sup>-</sup> release from prills and the nitrification rate of NH<sub>4</sub><sup>+</sup>-N (Cabrera, 1997).

Some authors observed a similar NO<sub>3</sub><sup>-</sup>-N leaching pattern when a CRF was applied that consisted of a very high NO<sub>3</sub><sup>-</sup>-N concentration in the leachates in the

first weeks of growing (Alam *et al.*, 2009). Cabrera (1997) and Merhaut *et al.* (2006) also observed a high EC in leachates at the beginning of their tests using different kinds of CRF and attributed these high EC values to the release of the soluble salts contained in the CRF due to the high T, as occurred in our experiment. In the CRF treatments, because of the massive release of nutrients from inside the prills due to high T and the subsequent washout effect from intense rain (Fig. 1 and 2), the phenomena of washout and the runoff of soluble nitrogenous compounds and other macronutrients probably predominated over fixation in the exchange complex and other phenomena (*e.g.* nitrification/denitrification). Regarding the leachate pH, Merhaut *et al.* (2006) obtained similar results when different CRF were applied to a substrate, though it was irrigated with water with a pH of 7.5. Several authors indicate that the type of substrate, the formulation and dose of N applied to a crop, the T regime and the presence of plants all affect nitrification processes, which cause the pH of the soil solution to drop to less than 5 (Niemiera & Wright, 1986; Lang & Elliott, 1991). The N-NH<sub>4</sub><sup>+</sup>:N-NO<sub>3</sub><sup>-</sup> ratio of the fertilizer applied was 1:0.9 in the CRF treatments and 1:10.3 in the NS treatments. The nitrification rate was therefore probably higher in the CRF treatments than in the NS treatments (Lang & Elliot, 1991), which would result in greater acidification of the substrate in the CRF treatments, as observed in our experiment. Moreover, the high substrate T during the first weeks of the growing period favoured nitrification (Niemiera & Wright, 1987).

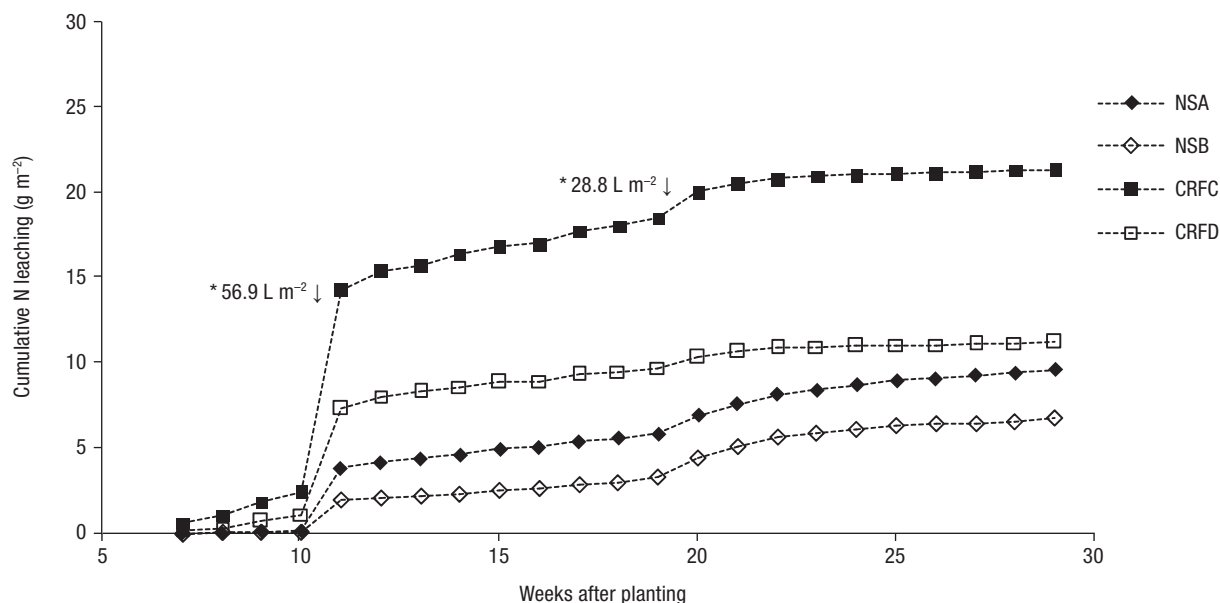
In the NS treatments, N concentration in leachates did not correlate significantly to PR, probably because in these treatments a relatively low N concentration was applied periodically by fertigation and the N concentration in the growing medium solution was not usually high, as has been observed in previous experiments using analogous relatively low-concentration NS and monitoring N content in the substrate solution using the induced percolate method (Marfà *et al.*, 2002). Thus, the leaching effect of PR in the NS treatments was not significantly correlated with the N concentration in leachates. Results obtained previously on rates of N leached from a *Viburnum tinus* L. container crop using relatively low-concentration NS (Marfà *et al.*, 2002) agree with the results obtained in this experiment and are coherent with the correlations presented. However, when H<sub>T21</sub> increased, the N leaching rate showed a linear drop. Relatively high H<sub>T21</sub> values in the growing media favoured high absorption of nitrates by the roots. The fact that N correlated significantly and positively with the two independent variables H<sub>T21</sub> y PR in the CRF treatments may be because temperatures over 21°C actually determined the release rate of N in the CRF prills and that, due to the massive release of this N in the first weeks of the experiment (Fig. 2), the concentration of nitrates in the substrate solution was high and the washout effect of the intense rain also produced a significant and positive correlation of N to PR (Table 2).

Regarding N balance, values of N uptake by the plants were low. In a container-grown crop of *Ilex cornuta* × *regosa*, a maximum relative amount of 24%

**Table 3.** Nitrogen balance and total dry matter from an outdoor potted crop of *Viburnum tinus* L. ‘Eve Price’ receiving different doses of either a nutrient solution (NSA or NSB) or controlled-release fertilizer (CRFC or CRFD). Nitrogen is expressed as the relative amount of total N (%) (applied as fertilizer, in irrigation water and in the growing medium at planting), and as absolute N values (g m<sup>-2</sup>)

Nitrogen	NSA		NSB		CRFC		CRFD	
	%	g m <sup>-2</sup>	%	g m <sup>-2</sup>	%	g m <sup>-2</sup>	%	g m <sup>-2</sup>
Total applied	100	30.7	100	25.9	100	44.2	100	35.1
Plant uptake	13 a <sup>(z)</sup> **	3.9	6 b**	1.6	7 b**	2.9	8 b**	2.7
Growing medium	54 <sup>ns</sup>	16.6	42 <sup>ns</sup>	10.9	34 <sup>ns</sup>	15.2	43 <sup>ns</sup>	15.1
Leachate	31 b*	9.6	26 b*	6.7	48 a*	21.3	32 b*	11.2
Remaining in CRF	–	–	–	–	5 <sup>ns</sup>	2.0	5 <sup>ns</sup>	1.8
Not measured <sup>(zz)</sup>	2 <sup>ns</sup>	0.6	26 <sup>ns</sup>	6.7	6 <sup>ns</sup>	2.8	12 <sup>ns</sup>	4.3
Supplied by the fertilizer and irrigation water	–	19.2	–	14.4	–	32.7	–	23.6
Total dry matter	–	177	–	88.2	–	145	–	134

<sup>z</sup> Any two means within a line not followed by the same letter are significantly different according to Tukey’s test at  $p \leq 0.05$  probability level.  $p < 0.001$ \*\*,  $p < 0.01$ \*,  $p > 0.05$ <sup>ns</sup>. <sup>zz</sup> Gaseous N losses and net mineralization.



**Figure 2.** Daily cumulative nitrogen leaching-loss ( $\text{NO}_3^- - \text{N} + \text{NH}_4^+ - \text{N}$ ), averaged weekly, of outdoor growing *Viburnum tinus* 'Eve Price' in 5-L containers, fertilized with either nutrient solution (NS,  $\blacklozenge$  or  $\diamond$ ) or incorporated controlled-release fertilizer (CRF,  $\blacksquare$  or  $\square$ ). \* Rainfall events ( $> 20 \text{ L m}^{-2}$ ).

of the N supplied was measured (Ristvey *et al.*, 2004). In another study on two container-grown woody ornamental species, the relative amount of N accumulated by the plants was 47% (Cabrera, 2003). Values of N accumulated in the substrate were much higher than those observed by other authors in potted woody plant crops. In fact, in an experiment with greenhouse-grown woody ornamental plants, N content in the substrate was 4% to 6% of the total N supplied; this substrate was made of two parts sphagnum peat moss, one part vermiculite and one part sand (by volume) (Cabrera, 2003). In another 3-yr study with woody ornamental plants, using a substrate made of hardwood, the amount of N in the substrate at the end of the experiment was between 1% and 3% of the N supplied (Ristvey *et al.*, 2004). The increase in organic N in the substrate detected at the end of the experiment in treatments NSA, CRFC and CRFD compared to the initial content could indicate a case of immobilization of inorganic N by the bacterial biomass in the substrate and transformation into organic N, as has been observed when pine bark has not been composted properly (Raviv *et al.*, 2002). In previous experiments with *V. tinus* grown in pots in the same location with a Mediterranean climate as in this experiment and in another location with an oceanic climate using several growing media, including a reference substrate consisting of a mixture of sphagnum peat moss and

composted pine bark, losses of N through leaching of up to 50% compared to the amount supplied were recorded with fertigation (Guérin *et al.*, 2000). In different container crops and climate situations, other authors have recorded similar values close to 50% of N lost through leaching into the environment (Cabrera, 2003; Nimiera & Leda, 1993). The amount of leached  $\text{NO}_3^- - \text{N}$  in the CRFD treatment was  $112 \text{ kg ha}^{-1}$ , whereas in the NSA treatment it was  $96.6 \text{ kg ha}^{-1}$ ; these values are relatively similar to the  $85 \text{ kg ha}^{-1}$  found in a potted *Forsythia* crop using incorporated CRF (Nutricote 18N-6K-8P, 3-month release) (Alam *et al.*, 2009). The fraction of the total N remaining in the CRF prills at the end of the experiment was low in comparison with the values reported in other studies. For example, Hershey & Paul (1982) detected that between 20% and 21% of the N remained in the formula prills at the end of the growing period (Osmocote 14N-6.1P-11.6K, 3-4 months at  $21^\circ\text{C}$ ); the CRF was applied to a greenhouse crop growing for three months at  $20^\circ\text{C}$ . In another study carried out under controlled conditions in the laboratory, two formulas of Osmocote (19N-4.8P-8.3K and 18N-2.6P-8.7K; 8-9 months at  $21^\circ\text{C}$ ) were subjected to incubation for 19 weeks at  $45^\circ\text{C}$  and between 20% and 28% of the N remained inside the prills (Lamont *et al.*, 1987). Other authors found 23% of the N inside the Osmocote prills (14N-6.1P-11.6K) after a three-month trial at  $22^\circ\text{C}$  (Niemiera



& Leda, 1993). According to the specifications of the CRF used in our experiment, the mean T recorded should have produced a faster release rate than the one expected at 21°C (8-9 months). This is coherent with the evolution of the N leachate recorded during the growing period in the CRF treatments (Fig. 2). This is probably why the relative and absolute N content in the CRF prills at the end of the growing period was low compared to those in other studies. The relative amounts of N not accounted for were small compared to those mentioned by other authors. In N balances carried out in other potted woody plants, N losses through denitrification of between 23% and 41% compared to the amount applied have been reported (Cabrera, 2003). Niemiera & Leda (1993) recorded N losses of up to 51%. In general, the undetected N was probably partly due to the loss of N by NH<sub>3</sub> volatilization and/or denitrification, as well as any possible net mineralization. The pH of the leachates in the NSB treatment, the one with the highest relative undetected N value, was moderately alkaline. Conditions therefore existed for N losses through NH<sub>3</sub> volatilization and denitrification. But the percentage of undetected N in treatment NSB can only be explained by differences in the substrate conditions (*i.e.* moisture and microbiological processes) between the NSB treatment and the other three treatments. Moisture content was higher in the NSB treatment than in the other treatments. Given that the water dose was the same in all treatments and growth was the lowest in the NSB treatment (data not shown), it is clear that the NSB plants consumed the least amount of water (unpublished data). It is understood that the amount of denitrification depends on environmental conditions in the substrate and that anaerobic conditions in particular favour denitrification (Shirivedhin & Gray, 2006).

The results show that N applied using fertigation at a dose 25% lower than the N content of the NSA treatment, as was the case with the NSB treatment, significantly reduced the efficiency of use of N compared to the NSA treatment. Moreover, in the CRF treatments, the application of the smaller dose (CRFD) did not result in significant improvements in the efficiency of N, though N losses through leaching in the CRFD treatment was significantly lower than in the higher dose of CRFC. In a previous experiment in the same location using an analogous peat-bark substrate, continuous fertigation and *V. tinus* as a container-crop, but where a nutrient solution with a higher N concentration was

applied (211 mg NO<sub>3</sub><sup>-</sup>-N L<sup>-1</sup> and 35.0 mg NH<sub>4</sub><sup>+</sup>-N L<sup>-1</sup>) than the one used in the NSA treatment, N efficiency was 3.4 (g dry matter g<sup>-1</sup> N<sub>T</sub>). This value is lower than the ones obtained in the treatments used in this experiment, particularly the NSA treatment. But when a relatively low-concentration NS was used like the one used in the NSA treatment, N efficiency was 8.9 g g<sup>-1</sup>, which was similar to the value obtained for the NSA treatment (Guérin *et al.*, 2000, 2001; Marfà *et al.*, 2002).

The T regime recorded during the experiment is common in the climatic conditions of nurseries in the North-western Mediterranean region. Therefore, when choosing CRF formulas, the mean T regime of the nursery locations in the region should be taken closely into account in relation to the anticipated release rate under these climatic conditions because they will probably not correspond to the conditions of laboratory tests or the manufacturer's recommendations and predictions. In the climatic conditions in this experiment, the use of CRF with an 8-9 month release period did not reduce the NO<sub>3</sub><sup>-</sup>-N content of leachates compared to the NS treatments, and N uptake by plants and the efficiency of use of N supplied were lower than in the NSA treatment. Depending on the fertilization mode, the regression formulas, their sign and the respective coefficients of correlation between the N concentration in the leachates and the variables PR and H<sub>21</sub> were different, which indicates different nitrate leaching patterns. Due to the great influence of T and PR on the release of nutrients from CRF prills, further studies are required to improve CRF coating technology to avoid the rapid release of N into the environment in regions where the abovementioned climate conditions are prevalent. Therefore, subsequent studies should be carried out to modulate NS composition and concentration so it better meets plant requirements during the growing period to improve efficiency of use of N.

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