HortScience 44(7):1833–1837. 2009.

Evaluating Fertilization and Water Practices to Minimize NO_3-N Leachate from Container-grown Forsythia

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Additional index words. container culture, dibbling, irrigation strategies, leachate nitrogen, CRF

Abstract*. To minimize fertilizer and water use, and NO_3-N runoff from container culture, growth, and nutrient status of forsythia (*Forsythia* ×*intermedia* Zab. 'Spring Glory') in No. 2 containers were compared in response to a controlled-release fertilizer (CRF; Nutricote 18-6-8 100-day at rates of 2, 4, and 6 kg·m^{-3}) and placements (incorporation and topdress) under three irrigation strategies [drip-irrigated low (25% or less) leaching fraction (DrLoLF), hand-sprinkled low leaching fraction (HsLoLF), and hand-sprinkled high (50% or less) leaching fraction (HsHiLF)]. In a coexperiment under drip irrigation only, forsythia response was also examined under incorporation, topdress, and dibble fertilizer placements with the same CRF rates applied as single or split dose. Dibble fertilizer placement was superior to both incorporation and topdress in this order. Maximum growth of forsythia occurred at rates of 4.7 kg·m^{-3} with dibble. With incorporation and topdress, maximum growth was not achieved even at the 6 kg·m^{-3} maximum rate tested. Forsythia grew better with incorporated than with topdressed CRF with the DrLoLF treatment. The response was reverse with HsHiLF or showed no differences with HsLoLF. Under drip irrigation, greater concentrations of NO_3-N generally leached from incorporation and dibbled containers in this order than from topdress. Less nitrate was leached from the topdressed containers because less was released from the CRF prills. At the 6 kg·m^{-3} CRF rate, total cumulative NO_3-N leachings were 76, 85, and 22 kg·ha^{-1} (45 × 45-cm container spacing) for dibbling, incorporation, and topdress, respectively, under drip irrigation. Split application of CRF greatly reduced NO_3-N in leachate, although plant growth also was reduced as a result of less availability of and uptake of nutrients under this strategy.

In agriculture throughout North America, including Maryland (Lea-Cox et al., 2001), California (U.S. National Water Commission, 1977), and Ontario (Alam and Chong, 2006; Nutrient Management Act, 2002), nutrient management and conservation of water have resulted in greater scrutiny of nursery production practices related to fertility and watering. Container production in particular involves use of porous media, which require frequent irrigation and high fertility levels for optimum production. However, the leachate or runoff from containers, especially NO_3-N, the most mobile of all nutrients, poses a potential threat to both surface and groundwater pollution (Colangelo and Brand, 2001; Davidson et al., 2000; Million et al., 2007). In a 140-d study in Connecticut using Sierrablen 17-6-10 as topdress at a rate of 4 kg·m^{-3} (i.e., 10 g per 2.6-L container), spaced 22 × 22 cm, nitrogen leaching from a nursery growing rhododendron was as high as 52 and 61 kg·ha^{-1} under overhead [20% leaching fraction (LF)] and trickle irrigation (14% LF), respectively (Colangelo and Brand, 2001).

The Ornamental Nursery Research Program at the University of Guelph has been re-examining cultural management practices to reduce fertilizer and water use and runoff from container growing. In Ontario, controlled-release fertilizers (CRFs) are most commonly used to fertilize container-grown plants. CRF is commonly incorporated into the medium before potting or topdressed on the surface of the medium after potting or during the season. Dibbling is an effective method of application used in some jurisdictions but has received little or no attention in Ontario. The CRF is placed into the planting hole and the liner is transplanted directly above it (Altland et al., 2004, Bir and Zondag, 1986; Fain et al., 2003; Roberts, 2002). The dibble method usually requires less fertilizer than topdressing or incorporation (Bir and Zondag, 1986; Chong et al., 2006). The objective of this study was to minimize NO_3-N leachate concentrations from container-grown forsythia in response to different CRF rates and placements of a CRF under different irrigation strategies.

Materials and Methods

Expt. 1

Single controlled-release fertilizer application: different rates of incorporation versus topdress and irrigation strategies. On 23 May 2007, 20-cm tall plug-rooted liners of forsythia (*Forsythia* ×*intermedia* Zab. 'Spring Glory', a flowering shrub) were potted in No. 2 (6 L, 21 cm diam. × 21 cm deep) nursery containers filled with a medium consisting of 65% by volume of pine bark:25% peatmoss: 10% compost [Grow-Bark (Ontario) Ltd., Milton, Ontario, Canada]. Nutricote 18-6-8 (18N–6P–8K) T100 CRF with micronutrients (Plants Products Co. Ltd., Brampton, Ontario, Canada) was incorporated (before potting) or topdressed (just after potting) once at rates of 2, 4, and 6 kg·m^{-3} product or 12, 24 and 36 g/container, respectively (166 pots could be filled with 1 m^3 of the medium). Plants were hand sprinkled lightly each day with water to avoid any leaching from the containers until they were transferred to experimental plots on 27 May. On this date, containers were spaced 45 × 45 cm apart on a crushed stone base and subjected to three irrigation strategies: 1) 5 min of drip irrigation through one 2.25-L (0.5-gal) turbulent flow drip emitter per container (NIBCO Irrigation Systems, Elkhart, IN), once a day in the morning during the first month of growth and twice per day (0900 HR and 1600 HR) thereafter; 2) hand sprinkling lightly once in the morning throughout the experiment for ≈6 to 7 s with water from a fine nozzle that delivered ≈300 mL of water each time (Wonder Waterer; Waldo and Associates, Inc., Perrysburg, OH); and 3) hand sprinkling like in Treatment 2 but twice as long that delivered ≈600 mL of water each time. Throughout the experiment, drip-irrigated (Dr) Treatment 1 yielded a low leaching fraction of 25% or less and is hereafter abbreviated as DrLoLF. The hand sprinkled (Hs) Treatments 2 and 3 yielded low (25% or less) and high (50% or

Received for publication 2 July 2009. Accepted for publication 19 Aug. 2009.
Support for this research was provided by the Canada-Ontario Research and Development Program (CORD IV) and the Landscape Ontario Horticultural Trades Foundation.
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less) LFs and are hereafter abbreviated as HsLoLF and HsHiLF, respectively. The lower half portion of each container selected for leachate collection was placed within an inverted, half-cone-shaped plastic collar (15 cm small diameter, 30 cm wide diameter) to act as a shelter to prevent contamination from hand sprinkling and rain. Plants were irrigated mostly by the same person throughout the season. The experiment was a split-plot design with the three irrigation strategies as main plots and the three CRF rates and two CRF placements as subplots. There were three replications of each main plot and three plants per subplot unit.

Sampling and analysis. Before using, duplicate samples of the medium were collected and analyzed for pH, electrical conductivity (EC, a measure of total soluble salts concentration), and selected nutrients (Table 1; Agri-Food Laboratories, Guelph, Ontario, Canada) and physical properties (Ontario Ministry of Agriculture, Food and Rural Affairs, 2003). At the start, the pH and EC in the medium were 6.1 ± 0 and 0.72 ± 0 $dS \cdot m^{-1}$, respectively. The concentrations of nutrients ($mg \cdot L^{-1}$) as measured in saturated paste extracts are shown in Table 1. The physical properties of the medium were: total porosity, 72% ± 1.3%; aeration porosity, 23% ± 0.1%; water retention porosity, 48% ± 1.6%; and bulk density, 0.34 ± 0.01 $g \cdot cm^{-3}$.

At the end of May, one leachate collection pot (18 cm diam. and 9 cm height) was placed under one randomly selected container per treatment and replicate. Between 28 May and 20 Aug., inclusive, each collection pot with irrigation leachates accumulated over 3-d intervals (Monday to Wednesday and Thursday to Saturday) were collected. The collection pots were washed and repositioned for further collections. For each collection interval, the leachate volume was measured as also its pH and EC; NO_3-N concentration was also measured using a nitrate ion sensor connected to Accumet XL25 (Fisher Scientific, Pittsburgh, PA). Nitrate–nitrogen standard solutions of 0.1, 0.01, 0.001, and 0.0001 M were prepared using $NaNO_3$. To each 100 mL NO_3-N standard or leachate sample, 2 mL of 2M $(NH_4)_2SO_4$ solution was added as an ionic strength adjuster. The concentration of NO_3-N was calculated using the following formula: $Y = 10^{-6} \times [i + (s \times r)] \times 62000 \times 0.23$ in which Y = concentration of NO_3-N in $mg \cdot L^{-1}$, i and s are the intercept and slope of the standard curve, respectively, and r is the NO_3 sensor reading. Data for concentrations of NO_3-N in the leachate were expressed as amounts collected per day.

On 24 Aug. (harvest), samples of youngest fully-matured leaves were collected from each plot, dried at 60 °C for 1 week, weighed, ground, and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, manganese, copper, iron, and boron (Agri-Food Laboratories). The shoots (stems and remaining leaves) were removed at substrate level, dried, and weighed. Dry weight of the leaf samples was added to the final dry weight of the shoot.

Expt. 2

Single versus split controlled-release fertilization application at different rates and placement. In this coexperiment, plants of the same species were potted on 4 June, transferred to experimental plots on 10 June, and harvested on 10 Sept. 2007. The growing medium, sampling and data collection, and other cultural factors were as described in Expt. 1, except where noted. Each of the same rates of CRF was dibbled, incorporated, or topdressed as a one-time dose at the start or as a split dose (one-third at start, and two-thirds as topdress 1 month later). This split application was used to investigate if this strategy would be better for plant growth and for reduction of early-season nitrate leaching from initial one-time application. In this experiment, method of irrigation was provided and was applied as per Treatment 1 in Expt. 1. The experimental design was a three factorial with three CRF rates, three CRF placements, and two application timings. All treatments were arranged in a randomized complete block design. There were three replications and three plants per plot.

Statistical analysis. Data for shoot dry weight (SDW) and foliar nutrient responses over CRF rates were subjected to analysis of variance using SAS (SAS Institute, Inc., Cary, NC) and expressed as linear or curvilinear regressions ($P < 0.05$). Contrast analysis ($P < 0.05$) was used to test the similarity of regression responses. Correlation analyses were conducted between 1) SDW and foliar nutrient concentrations; and 2) SDW and NO_3-N concentrations in the leachate.

Results

Growth. In Expt. 1, growth of forsythia increased linearly with increasing rates of CRF under each of the three irrigation strategies (DrLoLF, HsLoLF, and HsHiLF) (Fig. 1). Among irrigation strategies (Fig. 1), growth was better with incorporated than with

Table 1. The concentrations of nutrients in the growth medium as measured in saturated paste extracts.

Nutrient element	$mg \cdot L^{-1}$	SE
NH_4-N	<0.05	
NO_3-N	3.3	± 0
Phosphorus	5.14	± 0.56
Potassium	142.00	± 21
Calcium	25.00	± 4
Magnesium	12.00	± 0.35
Sodium	17.00	± 2.7
Chlorine	122.00	± 28
SO_4	2.50	± 0.4
Iron	1.07	± 0.13
Manganese	0.42	± 0.3
Zinc	0.09	± 0
Copper	0.04	± 0.002
Boron	0.31	± 0
Molybdenum	<0.01	
Aluminum	1.76	± 0.08

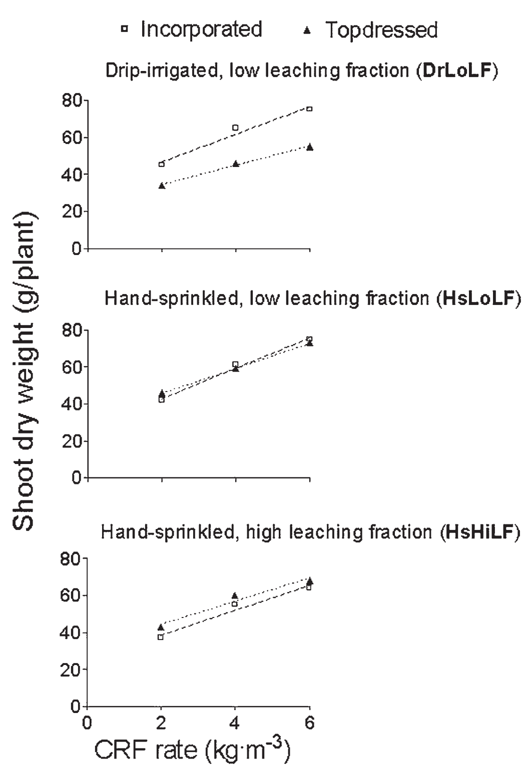

Fig. 1. Shoot dry weight response of container-grown forsythia to various controlled-release fertilization (CRF) rates (2, 4, and 6 $kg \cdot m^{-3}$), placement methods [incorporated (I) and topdressed (T)], and irrigation strategies [drip low-leaching fraction (DrLoLF), hand-sprinkled low-leaching fraction (HsLoLF), and hand-sprinkled high-leaching fraction (HsHiLF)] (Expt. 1). Responses were plotted over rates of CRF. Equations: DrLoLF, $Y_I = 31 + 7.6x$, $r^2 = 0.964$; $Y_T = 23 + 5.5x$, $r^2 = 0.993$; HsLoLF, $Y_{I/T} = 28 + 7.5x$, $r^2 = 0.999$; HsHiLF, $Y_I = 32 + 6.3x$, $r^2 = 0.964$; $Y_T = 25 + 6.8x$, $r^2 = 0.959$.

topdressed CRF when plants were drip-irrigated with low leaching fraction (DrLoLF); reversed when plants were hand sprinkled with high leaching fraction (HsHiLF); or showed no difference when plants were hand sprinkled with low leaching fraction (HsLoLF) (Fig. 1).

Among the three fertilizer placements (dibbled, incorporated, and topdressed) (Fig. 2), dibble was superior to both incorporation and topdress, in this order, with single or split dose. With dibble single placement, maximum SDW of forsythia (70 g/plant) occurred at a rate of 4.7 kg·m^{-3} (calculated) (Fig. 2). With incorporation and topdress, maximum SDW (67 and 60 g/plant, respectively) was not achieved even at the 6 kg·m^{-3} highest rate tested (Fig. 2).

NO_3-N concentrations in leachate. The concentrations of NO_3-N in the container leachates varied directly with CRF rates and irrigation strategies (Fig. 3). As exemplified by data in Expt. 1, with all three irrigation strategies (Fig. 3), the concentrations of leachate NO_3-N increased rapidly and reached their peaks within 3 weeks for incorporated CRF. At the 6 kg·m^{-3} CRF rate, values were highest with the hand sprinkled high leaching fraction (HsHiLF) (116 mg·L^{-1}/d on 14 June) but were less sustained (i.e., decreased sharply throughout the remainder of the experiment) compared with the HsLoLF (highest value 103 mg·L^{-1}/d on 21 June) and DrLoLF (highest value 80 mg·L^{-1}/d on 21 June). At the 4 and 2 kg·m^{-3} CRF rates, similar patterns were observed but with lesser amounts of NO_3-N in the leachate.

With topdressed CRF at the 6 kg·m^{-3} rate, corresponding rise and peaking of NO_3-N leachate concentrations occurred later and also in lesser quantities (Fig. 3): 5 weeks from the start under hand sprinkled high leaching fraction (HsHiLF, highest value 85 mg·L^{-1}/d on 5 July) and 7 weeks under both hand sprinkled low leaching fraction (HsLoLF, highest value 68 mg·L^{-1}/d on 16 July) and drip-irrigated low leaching fraction (DrLoLF, highest value 20 mg·L^{-1}/d on 19 July). At the 4 and 2 kg·m^{-3} rates, trends were generally similar with HsLoLF and HsHiLF, however, with lesser amounts of NO_3-N in the leachate. In contrast with DrLoLF, NO_3-N concentration in the leachates were 5 mg·L^{-1}/d or less throughout the experimental period.

In Expt. 2, NO_3-N leachate concentrations in incorporation and topdressed treatments (both single and split doses of CRF; Fig. 4) trended similarly to those in Expt. 1 (Fig. 3). With single dose at the 6 kg·m^{-3} rate (Fig. 4), NO_3-N concentrations from dibbled CRF increased up to 1 month (maximum 75 mg·L^{-1}/d, 12 July) and decreased slowly thereafter. Under split dose, values remained minimal (10 mg·L^{-1}/d or less), increasing up to 22 mg·L^{-1}/d (at the highest CRF rate) between 23 July and 13 Aug. and decreasing thereafter. At the 4 and 2 kg·m^{-3} CRF rates, similar patterns were observed, however, with lesser amounts of NO_3-N in the leachate, with the split dose in particular (10 mg·L^{-1}/d or less) (Fig. 4).

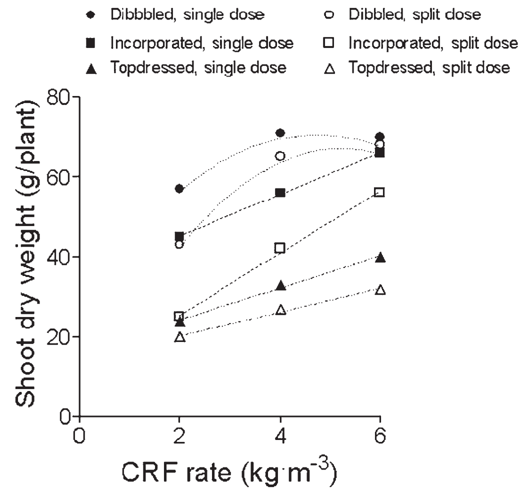

Fig. 2. Shoot dry weight response of container-grown forsythia to various controlled-release fertilizer (CRF) rates (2, 4, and 6 kg·m^{-3}), placement methods [dibbled (D), incorporated (I), and topdressed (T)] with single (one time dose at start) or split dose (one-third at start and two-thirds as topdress 1 month later) (Expt. 2). Responses were plotted over rates of CRF. Equations: Single dose, $Y_D = 28 + 18x - 1.9x^2$, $r^2 = 0.694$; split dose, $Y_D = 2 + 25x - 2.4x^2$, $r^2 = 0.839$; single dose, $Y_I = 35 + 5.3x$, $r^2 = 0.999$; split dose, $Y_I = 10 + 7.8x$, $r^2 = 0.997$; single dose, $Y_T = 16 + 4.0x$, $r^2 = 0.995$; split dose, $Y_T = 14 + 3.0x$, $r^2 = 0.991$.

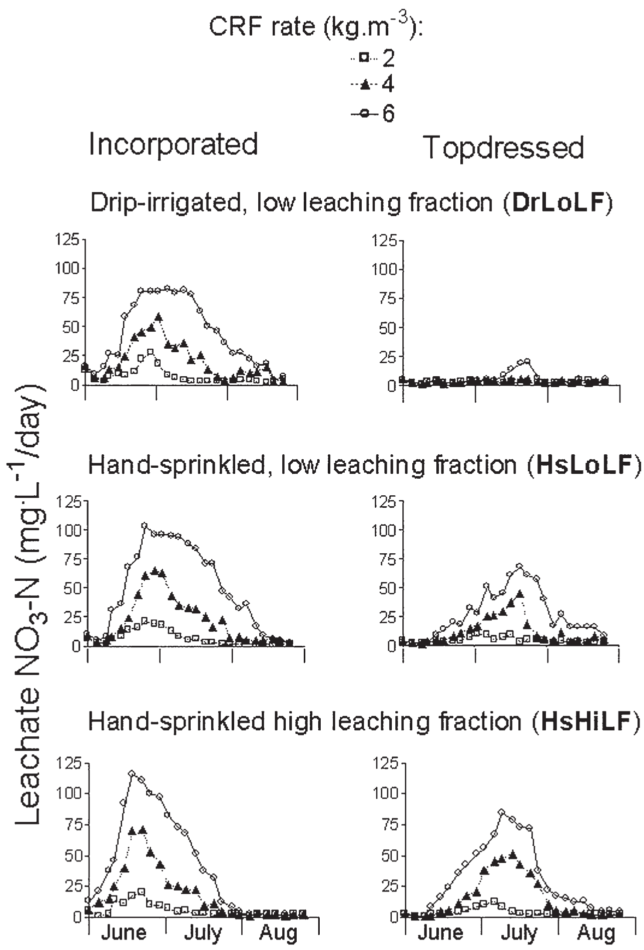

Fig. 3. Concentrations of leachate NO_3-N from container-grown forsythia under various controlled-release fertilizer rates (2, 4, and 6 kg·m^{-3}), irrigation strategies [drip low-leaching fraction (DrLoLF), hand-sprinkled low-leaching fraction (HsLoLF), and hand-sprinkled high-leaching fraction (HsHiLF) (Expt. 1)].

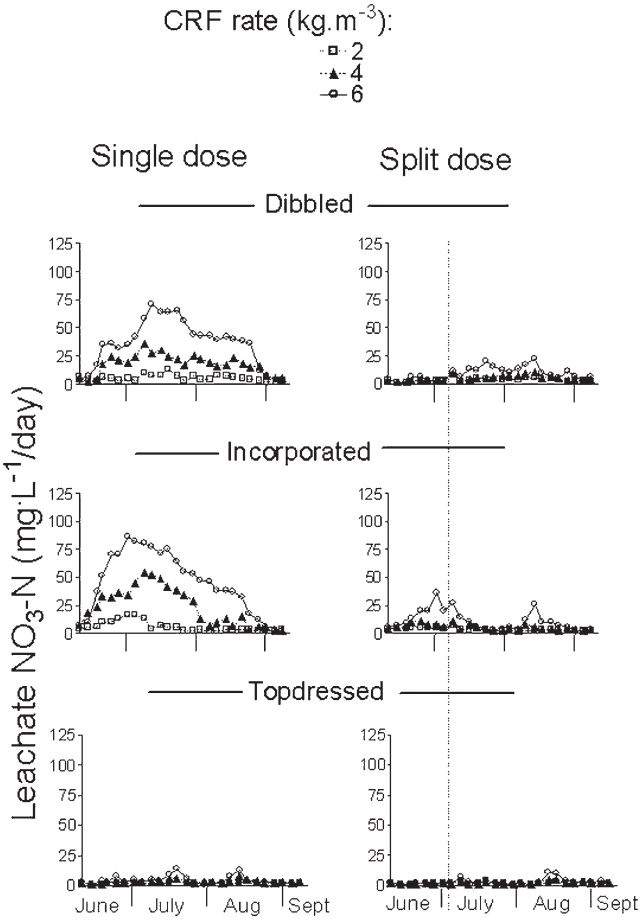

Fig. 4. Concentrations of leachate NO_3-N from drip-irrigated container-grown forsythia under various controlled-release fertilizer rates (2, 4, and 6 kg·m^{-3}), placements (dibbled, incorporated, and topdressed) with single or split doses. The vertical dotted line indicates date (4 July) of second (split) application (Expt. 2).

Table 2. Correlation of shoot dry weight (SDW) with foliar nutrient and NO_3-N leachate concentrations.

	Correlation coefficients (r)^z	
Nutrients	Expt. 1	Expt. 2
Foliage		
Nitrogen	0.74**	0.49**
Phosphorus	0.71**	0.70**
Potassium	–0.15	0.10
Calcium	0.68**	0.47**
Magnesium	0.54**	0.60**
Iron	0.65**	0.64**
Manganese	0.60**	0.46**
Zinc	0.27	0.51**
Copper	0.02	0.57**
Boron	0.33*	0.32*
Leachate		
NO_3-N	0.84**	0.82**

^{z}n = 54 (mean over treatment combinations × three replications).

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

Discussion

This article examines selected uses of CRF and watering practices to reduce leachate from nursery containers. The combined results of the two side-by-side experiments demonstrated that forsythia grew variedly in response to CRF rates and also to application and irrigation strategies as well as irrigation strategies. Similar to results of previous studies (Chong et al., 2006), the results of Expt. 2 confirmed that, under drip irrigation, forsythia grew maximally with dibbled CRF at a rate of 4.7 kg·m^{-3}, surpassing growth obtained from incorporated and topdressed CRF even at 6 kg·m^{-3}, the highest rate tested. This effectively indicated a saving of at least 22% in fertilizer use with the dibbled method, and at these rates, growth was 27% higher compared with incorporated and 115% higher compared with topdress (Fig. 2).

Related data in Expt. 2, drip-irrigated only, showed that among the CRF placement methods, the calculated amounts of NO_3-N leached from dibble containers over the duration of the experiment were intermediate for CRF rates (mean, 252 mg/pot; range, 151 to 367 mg/pot) compared with incorporated (mean, 295 mg/pot; range, 151 to 410 mg/pot) and topdressed (mean, 79 mg/pot; range, 65 to 108 mg/pot). Only a few studies have compared the effectiveness of these three fertilizer placement methods (Altland et al., 2004; Broschat and Klock-Moore, 2003) and no placement methods were pronounced. Responses varied with species, location, and cultural factors (Broschat and Klock-Moore, 2003; Million et al., 2007). Higher plant growth with dibbled CRF also has been reported by Altland et al. (2004) for container-grown azalea (*Rhododendron* sp. cv. Stewartsonian), holly (*Ilex crenata* cv. Compacta), lavender (*Lavandula intermedia* cv. Grosso), and winter creeper euonymus (*Euonymus fortunei* cv. Emerald Gaiety) by Broschat and Klock-Moore (2003) for container-grown tropical ornamental plants and by Chong et al. (2006) for container-grown cotoneaster. It is noteworthy that none of these authors reported effect of CRF placements at different rates. Results in our laboratory at the University of Guelph indicated that at lower rates, the differences between dibble and other placements were higher (Chong et al., 2006).

Higher growth with dibble CRF compared with topdress and incorporation may be the result of the differences in nutrient availability in different areas of the root ball. With dibbling, the CRF prills are confined right close to the root ball; with incorporation, they are found throughout the container volume; and with topdress, they are spread only across the top surface area of the medium. In an 8-week study in Australia, Goodwin et al. (2003) reported that dibbled fertilizer under both capillary and overhead irrigation systems had higher ECs (0.5 to 0.7 dS·m^{-1}) in the middle layer of the pot compared with the top and bottom (0.2 dS·m^{-1} or less). In contrast, under capillary irrigation with topdressed CRF, the EC was highest at the top and was reversed with overhead irrigation.

Although the substrate EC in the containers was not measured in this study, foliar analysis showed that most major and minor nutrients increased with increasing rates of CRF and contents of all nutrients were significantly higher in dibbled treatments compared with incorporated and topdressed treatments (data not shown). In fact, positive correlations (Table 2) were observed between 1) SDW and concentrations of all macronutrients and micronutrients with few exceptions (zinc and copper in Expt. 1; potassium in both experiments) (Table 2) and 2) SDW and NO_3-N leachate concentrations (Table 2). Thus, forsythia growth appears to be related to the differences in availability of nutrients from fertility-irrigation practices.

Nutrient availability and leachate runoff are highly dependent and interrelated with irrigation and fertility practices. Goodwin et al. (2003), Morvant et al. (2001), and Rathier and Frink (1989) observed higher plant growth with drip over overhead irrigation, although other authors reported the reverse (Dole et al., 1994) or no difference (Argo and Biernbaum, 1995; Richards and Reed, 2004). In our study, the reduced performance of topdressed CRF seem to be related to less sustained or less uniform release of nutrients resulting from intermittent wet–dry exposure of the CRF prills at the medium surface in contrast to constantly wet exposure of dibbled and incorporated prills (Fain et al., 2003). Goodwin et al. (2003) reported that there were few roots in the top few centimeters of the pot in pansy (*Viola* *tricolor*), French lavender (*Lavendula dentata*), rose (*Rosa* sp.), and tomato (*Lycopersicon esculentum*), because the medium tends to be drier here and water in this region would presumably only be available before the top of the pot dried out. Thus, plants grown in containers with fertilizer on the surface would have had less access to nutrients (Broschat, 2005; Goyette and Pill, 1992). It is noteworthy that during the experiment, the moisture status in the containers near the center of the containers (8- and 10-cm depths, 13 cm from the rim) was monitored using a garden tensiometer (Chong and Lumis, 2000) and were found to be similar at all times among treatments in both experiments.

Rathier and Frink (1989) reported that CRF could be more efficient if applied in split applications, which could preclude high initial nitrogen (N) release and high N concentrations in leachate. Poor plant growth under split application in our study was also related to fertility-irrigation practices, largely as a result of the surface application effects of the second application. Rathier and Frink (1989) used overhead irrigation; in our case (Expt. 2), we used drip irrigation. Under drip-irrigated topdress (Fig. 3) and drip-irrigated split-dose dibbled, incorporated, and topdressed (Fig. 4), there was reduced NO_3-N leaching but presumably also nutrient availability.

Conclusion

Under drip irrigation, dibble placement of CRF promoted more growth of container-grown forsythia compared with traditional incorporation and topdress. Dibbled placement under drip irrigation with 25% or less LF was best. It provided intermediate leachate and maximum growth at lower rates (4.7 $kg \cdot m^{-3}$) with a savings of at least 22% of CRF compared with topdress and incorporation. The results will assist growers to maximize fertilizer application efficiency while at the same time minimizing nitrate concentrations in the leachate in compliance with nutrient and water management legislation.

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