Fertilization of Two Container-grown Woody Ornamentals Based on Their Specific Nitrogen Accumulation Patterns

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Abstract. Nitrogen accumulation patterns were established for *Weigela florida* (Bunge.) A. DC. ‘Red Prince’ (fast growth rate) and *Euonymus alatus* (Thunb.) Sieb. ‘Compactus’ (slow growth rate). From these, daily and biweekly N delivery schedules were designed to match N supply with N accumulation patterns of each taxon. Delivery schedules were sliding scales in that total N applied was controlled by independent increases (or decreases) of N concentration and solution volume. Daily and biweekly N delivery schedules were tested against a constant N rate (200 mg·L⁻¹) and Osmocote 18N–2.6P–9.9K (The Scotts Co., Marysville, Ohio). Plants were grown in 3.8-L containers in 7 douglas fir bark : 2 sphagnum peatmoss : 1 silica sand (0.65 mm; by volume) outdoors in full sun on a gravel pad for 142 d. Within each taxon, *Weigela* and *Euonymus* grown with sliding-scale N fertilization schedules had similar total dry weights, leaf areas, and total plant N contents to plants grown with a constant N rate (200 mg·L⁻¹) or Osmocote 18N–2.6P–9.9K. Sliding-scale liquid fertilization based on plant N requirements introduced less total N to the production cycle and resulted in higher N uptake efficiency than fertilization with a constant N rate of 200 mg·L⁻¹. In general, liquid N fertilizer treatments resulted in plants with higher shoot to root ratios than plants treated with Osmocote 18N–2.6P–9.9K. *Weigela* and *Euonymus* treated with biweekly schedules were similar to plants treated with daily schedules (same total amount of N delivered with each treatment).

Nitrogen (N) is commonly applied to container nursery crops as controlled-release fertilizer (CRF) or soluble N delivered through irrigation. A recent survey in the southeastern United States reported that 100% of nurseries polled applied CRFs as their primary source of plant nutrients while 75%, 25%, and 25% of small, medium, and large nurseries, respectively, used liquid fertilization to meet the nutrient requirements of their liners (Fain et al., 2000). In theory, single or infrequent applications of a CRF can meet the nutrient requirements of plants thereby requiring less labor to apply and manage than other fertilization methods (Yeager and Cashion, 1993). In addition, CRFs may reduce N leaching and buildup of soluble salts (Bunt, 1988; Maynard and Lorenz, 1980). Soluble nutrients are delivered through irrigation to fertilize small liner material (Fain et al., 2000), high value greenhouse crops (Cabrera et al., 1993) and containers with depleted CRFs. Similar growth and quality of container-grown plants can be achieved with CRF or soluble N fertilizers (Hershey and Paul, 1982; Johnson et al., 1981; Wright and Niemiera, 1987), yet both exhibit inherent inefficiencies.

Nitrogen fertilization with CRFs may be

inefficient because N release patterns often do not match the N requirements of plants and can vary with environmental conditions (Cabrera, 1997; Huett, 1997; Meadows and Fuller, 1983; Wright and Niemiera, 1987). High N release rates may occur early in the growing season when plants are small, N requirements are relatively low, and limited root systems are unable to take up available N (Wright and Niemiera, 1987). Later in the season, depleted CRFs may not release enough N for large, actively growing plants with fully developed root systems and relatively high N requirements. Furthermore, a CRF applied at a generalized rate will not match the N requirements of the various species and cultivars commonly grown at commercial container nurseries (Hinklen and Cairns, 1992; Whitcomb, 1986). A single application rate may provide excess N to dwarf, slow growing, or low N requiring taxa while simultaneously failing to meet the N requirements of large, vigorous, or high N requiring taxa.

Delivery of soluble N through overhead irrigation is inefficient because much of the water applied and dissolved N never reaches the plant roots, falling instead between containers or in roadways (Beeson and Knox, 1991; Yeager et al., 1986). When overhead irrigation was used to fertilize 0.405 ha of 3.8 L containers (10,839 plants), 81% of the fertilizer fell outside of containers (Yeager et al., 1986). Plants at close and 7.6 cm spacing resulted in 37% and 25% irrigation application efficiencies, respectively

(Beeson and Knox, 1991). Container spacing, shedding of water by the plant canopy, and evaporation of water retained on the plant canopy are the main factors associated with low efficiencies in overhead irrigation systems (Beeson and Knox, 1991).

Regardless of form, applying excess N to container production systems promotes N leaching (Cabrera et al., 1993; Hershey and Paul, 1982; van der Boon and Niers, 1983; Yeager et al., 1993) and may depress plant growth (Barnett and Ormrod, 1985; Cabrera, 2003; Cabrera and Devereaux, 1998). In contrast, supplying insufficient N reduces plant size and quality (Marschner, 1995; Mengel and Kirkby, 1987). Therefore, designing fertilization strategies to maximize plant growth and quality while minimizing N input is essential to maintaining nursery profits and reducing N leaching.

Several studies have observed plant growth and plant N status across a range of N concentrations in the potting substrate (Barnett and Ormrod, 1985; Cabrera, 2003; Cabrera and Devereaux, 1998; Dubois et al., 2000; Griffin et al., 1999; Henry et al., 1992; Jull et al., 1994; Niemiera and Wright, 1982). These studies often result in recommendations of constant N concentrations in the substrate for optimum growth of specific plant taxa. However, these recommendations do not take into account that plants may take up N at different rates during the growing season. Furthermore, plant growth is not a direct response to N concentration but to total nutrient availability (Wright and Niemiera, 1987). While plants are actively growing, N absorption increases with increasing dry weight gain. Therefore, N supply must be simultaneously increased (Ingstad, 1982).

Sliding-scale fertilization matches N supply to plant N requirements and is based on plant N accumulation patterns and plant N uptake efficiency over time. It allows for the uncoupled increase (or decrease) of N concentration and irrigation volume, making it possible to match N and water supply to changing N and water requirements of a growing plant. During implementation of a sliding-scale fertilization schedule, total N supply (amount) can be increased by applying the same concentration at increasing volumes, applying the same concentration more frequently, or by increasing the N concentration of the solution applied (Ingstad, 1982).

To design a sliding-scale fertilization schedule for a plant taxon, its seasonal N accumulation pattern must first be defined. The N accumulation patterns for several woody species have been determined (Craig et al., 2003; Hanson and Howell, 1995; Hilen and Good, 1985; Munoz et al., 1993; Rose and Biernacka, 1999; Wienbaum et al., 1978), but few attempts have been made to develop or test N delivery programs based directly on N accumulation patterns. For an herbaceous crop, poinsettias (*Euphorbia pulcherrima* Willd. ex. Klotzsch), sliding-scale N fertilization based on established N accumulation patterns was developed and tested (Rose et al., 1994). At initiation, plants were fertilized with N at a rate of 75 mg·L⁻¹.

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Nitrogen rate was increased by 25 mg·L⁻¹ about every 14 d, reaching a maximum of 150 mg·L⁻¹, and was then decreased to a final N concentration of 100 mg·L⁻¹. Poinsettias fertilized with the sliding-scale N fertilization regime exhibited higher N recovery efficiency (58%) than those fertilized at a constant N rate of 200 mg·L⁻¹ (38%). Furthermore, the sliding-scale treatment introduced 41% less N to the production system than the constant rate treatment.

We propose that sliding-scale N fertilization programs can be developed for container-grown woody plants based on their N accumulation patterns. Furthermore, plants comparable to those grown with constant rate liquid fertilization or CRFs can be produced. The first objective of this work was to determine the dry matter increase and N accumulation patterns for *Weigela florida* 'Red Prince', (fast growth rate) and *Euonymus alatus* 'Compactus', (slow growth rate). The second objective was to design sliding-scale liquid N fertilization schedules specific to *Weigela* and *Euonymus* based on their established N accumulation patterns. The third objective was to compare plants grown under the sliding-scale liquid N fertilization program to plants fertilized with constant rate liquid fertilization or a CRF.

Materials and Methods

The purpose of the 2001 trial was to determine the optimal N concentration, dry weight increase and N accumulation patterns for *Weigela* and *Euonymus*. On 1 Apr. 2001, uniform rooted stem cuttings of *Euonymus* and *Weigela* were potted into 3.8-L containers filled with 7 fresh douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco.] bark (initial pH of 3.6) : 2 sphagnum peatmoss : 1 silica sand (0.65 mm) by volume. The substrate was amended with 0.883 kg Micromax (The Scotts Co., Marysville, Ohio), 1.77 kg calcitic lime (CaCO₃), 1.77 kg dolomitic lime (CaCO₃ + MgCO₃), 1.05 kg 8 to 9 month slow release phosphorous (2.6P; The Scotts Co.), and 1.18 kg 8 to 9 month slow release potassium (9.9K; The Scotts Co.) all per m³. Substrate pH at transplanting (after all amendments were added) was 5.6. Trials were conducted in full sun at the Lewis Brown Horticulture Farm in Corvallis, Ore (latitude: 44.5 north, longitude: 123.2 west).

Optimal N concentration (2001). To con-

firm the optimal N concentration for growth of *Weigela* and *Euonymus*, 50 plants of each taxon were arranged in a completely randomized design and supplied with N concentrations of 25, 50, 100, 200, or 300 mg·L⁻¹. Nitrogen was supplied as ammonium nitrate (NH₄NO₃; Western Farm Services, Tangent, Ore.) on alternate days beginning on 1. Apr. Applied solution volume was 150 mL/container at initiation and was increased to maintain a 25% leaching fraction, as monitored every two weeks, reaching a final volume of 300 mL/container. After 16 June, supplemental irrigation was delivered on alternate days when plants did not receive N applications. On 7 July, five randomly selected plants from each taxon and each N concentration were partitioned into leaves, roots, and shoots. Leaf area was determined with the LI-COR 3100 Leaf Area Meter (Lincoln, Neb.). All tissues were dried at 65 °C for at least 96 h, weighed, ground (Wiley Mini-mill; Thomas Scientific, Swedeboro, N.J.) to pass a 0.85-mm sieve, and analyzed for total N by the Kjeldahl procedure (Horneck et al., 1989).

Dry weight and N accumulation patterns (2001). To determine the dry weight gain and N accumulation pattern of *Weigela* and *Euonymus*, 60 plants of each taxon were arranged in a completely randomized design and supplied N as ammonium nitrate (NH₄NO₃; Western Farm Services) at a concentration of 200 mg·L⁻¹. Solutions were applied on alternate days beginning on 9. Apr. Solution volume and irrigation were the same as applied for the previously described experiment. Plants were harvested on 14 May, 11 June, 9 July, and 6 Aug. At each harvest, four randomly selected plants of each taxon were partitioned into leaves, roots, and shoots. All tissues were dried at 65 °C for at least 96 h, weighed, ground (Wiley Mini-mill; Thomas Scientific, Swedeboro, N.J.) to pass a 0.85-mm sieve, and analyzed for total N by the Kjeldahl procedure (Horneck et al., 1989).

Calculation of a sliding-scale liquid fertilization regime. Sliding-scale fertilizer N treatments applied in 2002 were designed from total plant N, periodic N uptake, and percent N uptake values from plants grown at an N concentration of 200 mg·L⁻¹ during 2001. Five sequential N delivery periods were designed for 2002: 35, 14, 28, 28, and 35 d periods, respectively. Nitrogen requirements

for *Weigela* and *Euonymus* were estimated with regression equations established in year 1. Nitrogen required by each taxon for each period was determined by subtracting total plant N of previous periods from total plant N of the period being calculated. The amount of N applied for each period was calculated by dividing the amount of N required per period by the percent N uptake during that period.

Comparison of plants grown with a sliding-scale N fertilization schedule, constant N rate, and a CRF (2002). On 1 Apr. 2002, uniform rooted cuttings of *Weigela* and *Euonymus* were transplanted into 3.8-L containers. Forty plants of each taxon were arranged in a completely randomized design in full sun on a gravel pad at Oregon State University's Lewis Brown Horticulture Farm (Corvallis, Ore.).

Treatments included 8 to 9 month release Osmocote 18N-2.6P-9.9K (The Scotts Co.) incorporated or top dressed at the manufacturer's recommended high and medium rate (INC-HI, TOP-HI, TOP-HI(30), INC-MED, and TOP-MED), one constant N rate treatment (CONST), and two sliding-scale N treatments (WG-DLY and WG-BIWK for *Weigela*; EU-DLY and EU-BIWK for *Euonymus*; Table 1). Osmocote treatments and the constant N rate liquid treatment were applied to both taxa. Sliding-scale treatments were applied only to the taxon for which they were designed. A detailed description of the sliding-scale treatments is provided (Table 2).

Substrate and amendments for plants receiving sliding-scale and constant rate liquid N treatments were the same as for the previous year (2001). The substrate for plants receiving Osmocote treatments was amended with 0.883 kg Micromax (The Scotts Co.), 1.77 kg calcitic lime (CaCO₃), 1.77 kg dolomitic lime (CaCO₃ + MgCO₃) all per cubic meter. The pH of both substrates, after all amendments were added, was 5.8 to 6.0.

Plants were harvested on 20 Aug. Potting substrate was washed from the roots and plants were partitioned into leaves, roots, and shoots. All tissues were dried, weighed, ground (Wiley Mini-mill; Thomas Scientific, Swedeboro, N.J.) to pass a 0.85 mm sieve, and analyzed for total N by the Kjeldahl procedure (Horneck et al., 1989).

Leachate was collected on 3 May and 2 July using the pour-through extraction method

Table 1. Summary of treatments applied to *Weigela florida* 'Red Prince' and *Euonymus alatus* 'Compactus' grown in 3.8-L containers for 140 d (1 Apr.–18 Aug.) during 2002.

Treatment	Abbreviation	Application	Total N applied (mg/plant)	Total irrigation applied (L/plant)
Osmocote 18-6-12				
Incorporated at a high rate	INC-HI	at planting	2994	33.5
Top-dressed at a high rate	TOP-HI	at planting	3240	33.5
Top-dressed at a high rate (30-d delay)	TOP-HI(30)	30 d after planting	3240	33.5
Incorporated at a medium rate	INC-MED	at planting	2230	33.5
Top-dressed at a medium rate	TOP-MED	at planting	2520	33.5
Liquid ²				
Constant N concentration (200 mg·L ⁻¹)	CONST	M,W,F ³	2900	33.5
Daily sliding-scale for <i>Weigela</i>	WG-DLY	daily	1837.5	33.5
Biweekly sliding-scale for <i>Weigela</i>	WG-BIWK	M and F	1837.5	33.5
Daily sliding-scale for <i>Euonymus</i>	EU-DLY	daily	1015	24.2
Biweekly sliding-scale for <i>Euonymus</i>	EU-BIWK	M and F	1015	24.2

²Liquid N treatments were supplied in irrigation water.

³M = Monday, W = Wednesday, F = Friday.

Table 2. Sliding-scale liquid N treatments applied to *Weigela florida* 'Red Prince' and *Euonymus alatus* 'Compactus' grown in 3.8-L containers for 140 d during 2002.

Treatment	Period					Total
	1 Apr.– 5 May	6 May– 19 May	20 May– 16 June	17 June– 14 July	15 July– 18 Aug.	
WG-DLY (delivered daily)						
[N] (mg·L ⁻¹)	0	50	75	75	56.25	---
Number of N applications	0	14	28	28	34	104
WG-BIWK (delivered twice a week)						
[N] (mg·L ⁻¹)	0	50	262.5	262.5	196.8	---
Number of N applications	0	4	8	8	10	30
Both <i>Weigela</i> treatments						
Irrigation volume (mL·d ⁻¹)	150	150	200	250	400	---
Total irrigation (L)	5.25	2.1	5.4	6.75	14.0	33.5
Total N (mg)	0	105	420	525	787.5	1837.5
EU-DLY (delivered daily)						
[N] (mg·L ⁻¹)	0	0	50	50	75	---
Number of N applications	0	0	28	28	34	90
EU-BIWK (delivered twice a week)						
[N] (mg·L ⁻¹) applied M and F	0	0	175	175	262.5	---
Number of N applications	0	0	8	8	10	26
Both <i>Euonymus</i> treatments						
Irrigation volume (mL·d ⁻¹)	150	150	150	200	200	---
Total irrigation (L)	5.25	2.1	4.2	5.6	7.0	24.2
Total N (mg)	0	0	210	280	525	1015

(Wright, 1984), and pH and electrical conductivity (EC) were determined with a pH-conductivity meter (Accumet AR20; Fisher Scientific). Air temperature and rainfall data were collected with a weather station (WS-100; Rain Bird International Inc., Glendora, Calif.).

Because sliding-scale N treatments were applied specifically to the taxon they were designed for, only comparisons within a taxon were analyzed. No comparisons were made across taxa. Regression analysis, analysis of variance (ANOVA), mean separations, and orthogonal contrasts were performed using SAS v. 8.02 (SAS Institute, Cary, N.C.).

Results and Discussion

Optimal N concentration (2001). Leaf area, total plant dry weight, and total plant N content were similar for both taxa at an N concentration of 25 mg·L⁻¹ (Fig. 1 A–C). As N concentration increased from 25 to 200 mg·L⁻¹, leaf area, total plant dry weight, and total plant N content of *Weigela* and *Euonymus* exhibited quadratic saturation response curves, but *Weigela* reached higher values than *Euonymus*. For both taxa, leaf area, total plant dry weight, and total plant N content declined slightly at an N concentration of 300 mg·L⁻¹. Leaf area of *Weigela* and *Euonymus* reached maximum values of 2373 and 189 cm², respectively, at an N concentration of 200 mg·L⁻¹. Maximum total plant dry weight values occurred at an N concentration of 200 mg·L⁻¹ for both taxa, 31.5 and 5.8 g for *Weigela* and *Euonymus*, respectively. Similarly, maximum total plant N values occurred for both taxa at an N concentration of 200 mg·L⁻¹, 523 and 130 mg for *Weigela* and *Euonymus*, respectively. These data indicate that an N concentration of 200 mg·L⁻¹ is optimum for growth of *Weigela* and *Euonymus*. For other container-grown taxa, optimum N concentration values between 50 and 150 mg·L⁻¹ have been reported (Barnett and Ormrod, 1985; Cabrera, 2003; Cabrera and Devereaux, 1998; Griffin et al., 1999; Niemiera

and Wright, 1982). Some studies have reported negative effects on growth at N concentrations beyond 50 or 60 mg·L⁻¹ (Barnett and Ormrod, 1985; Cabrera, 2003; Cabrera and Devereaux, 1998), and the growth reduction has been attributed to high growing substrate salinity

(Cabrera and Devereaux, 1998). In this study, negative effects on growth were not observed across N concentrations of 25 to 300 mg·L⁻¹, possibly because the experimental period of 98 d did not provide enough time for salinity to build to detrimental levels.

Fig. 1. Leaf area (A), total plant dry weight (B), and total plant N content (C) of *Weigela florida* 'Red Prince' (●) and *Euonymus alatus* 'Compactus' (○). Plants were grown from rooted cuttings in 3.8 L containers for 98 d (1 Apr.–7 July, 2001) and supplied N at concentrations of 25, 50, 100, 200, and 300 mg·L⁻¹ on alternating days. Error bars indicate ±SE.

Fig 2. Total plant dry weight (A), total plant N content (B), and plant N uptake efficiency (plant N/applied N × 100) (C) for *Weigela florida* 'Red Prince' (●) and *Euonymus alatus* 'Compactus' (○). Plants were grown from rooted cuttings in 3.8-L containers for 128 d (1 Apr–6 Aug., 2001) and supplied N at a concentration of 200 mg·L⁻¹ on alternating days. Error bars indicate ± SE.

Dry weight increase and N accumulation (2001). At an N concentration of 200 mg·L⁻¹, total plant dry weight, total plant N content, and plant N uptake efficiency differed dramatically over time for *Weigela* and *Euonymus* (Fig. 2 A–C). At the first harvest (35 d after N applications began), total plant dry weight, total plant N content, and plant N uptake efficiency were similar and relatively low for both taxa. Thereafter, each attribute was higher for *Weigela* than *Euonymus*. Total plant dry weight accumulation for both taxa was best defined by quadratic equations. Dry weight accumulation patterns for container-grown *Thuja occidentalis* L. 'Smaragd', *Cotoneaster dammeri* C.K. Schneid. 'Coral Beauty', and *Aronia arbutifolia* (L.) Pers. 'Brilliantissima' were also best defined by quadratic equations (Craig et al., 2003). Total plant N of *Weigela* and *Euonymus* increased from 44.9 and 29.4 mg/plant, respectively, at 35 d after treatments began to 958.5 and 242.2 mg/plant, respectively, at 120 d after treatments began. These results agree with other studies that indicated plant N requirements change with dry matter accumulation and growth stage (Argo and Biernbaum, 1991; Craig et al., 2003; Hanson and Howell, 1995; Hilén and Good,

1985; King and Stimart, 1990; Munoz et al., 1993; Rose and Biernacka, 1999; Wienbaum et al., 1978). When both taxa are grown at an N concentration of 200 mg·L⁻¹, *Weigela* exhibits greater dry weight gain, N uptake, and N uptake efficiency than *Euonymus*. Knowledge of plant N accumulation patterns will allow for the design of CRF or sliding-

scale liquid programs that better match plant N requirements.

Comparison of plants grown with a sliding-scale N fertilization schedule, constant N rate, and a CRF (2002). For *Weigela*, all treatments produced plants with similar dry weights (Table 3). Leaf area of the WG–DLY and WG–BIWK treatments was similar to CONST, TOP–HI (30), and INC–HI, the treatment with the greatest leaf area. Likewise, total plant N content of the WG–DLY and WG–BIWK treatments was similar to the CONST and INC–HI (Table 3). The shoot to root ratio of CONST (8.3) was significantly higher than all other treatments. In addition to Duncan's mean separation (Table 3), WG–DLY and WG–BIWK were compared to all CRF treatments using orthogonal contrasts. Dry weight and leaf area of WG–DLY and WG–BIWK were not significantly different from the CRF treatments. However total plant N ($F = 13.41, P = 0.0009$) and shoot to root ratio ($F = 4.25, P = 0.0475$) were significantly higher for WG–DLY and WG–BIWK than for all CRF treatments. *Weigela* plants grown with sliding-scale treatments (WG–DLY and WG–BIWK) had similar total dry weight and leaf area to plants grown with CRFs but higher total N content and shoot to root ratios.

For *Euonymus*, the highest total plant dry weight, leaf area, and total plant N was achieved with the TOP–HI treatment, and the highest shoot to root ratio (4.8) resulted from CONST (Table 4). Total plant dry weight and leaf area of the EU–DLY and EU–BIWK were not significantly different from the other treatments (Table 4). Total plant N content of the EU–BIWK treatment was not significantly different from all other treatments. Total plant N content of EU–DLY was less than TOP–HI but similar to all other CRF treatments. In addition to Duncan's mean separation (Table 4), EU–DLY and EU–BIWK were compared to all CRF treatments using orthogonal contrasts. Dry weight, leaf area, and total plant N of EU–DLY and EU–BIWK were not significantly different from the CRF treatments. However, shoot to root ratio was significantly higher for EU–DLY and EU–BIWK than for the CRF treatments ($F = 10.10, P = 0.0033$). Dry weight, leaf area, and total plant N content of *Euonymus* plants grown with the sliding-scale

Table 3. Total dry weight, leaf area, total plant N content, and shoot:root ratio of *Weigela florida* 'Red Prince' grown in 3.8-L containers with controlled-release, constant N rate, and sliding-scale liquid N fertilizer treatments (2002).

Treatment ^a	Total dry wt (g)	Leaf area (cm ²)	Total plant N (mg)	Shoot to root ratio
INC–HI	58.7 a ^b	2967.4 a	914.4 a	6.2 b
TOP–HI	51.5 a	2463.5 c	554.2 cd	4.7 b
TOP–HI(30)	55.0 a	2656.0 abc	503.5 d	4.8 b
INC–MED	54.2 a	2533.0 bc	672.8 bc	4.9 b
TOP–MED	52.3 a	2560.0 bc	597.4 cd	5.2 b
CONST	51.3 a	2818.6 ab	913.7 a	8.3 a
WG–DLY	51.9 a	2854.6 ab	784.4 ab	6.4 b
WG–BIWK	53.4 a	2664.1 abc	803.1 ab	5.8 b

^aINC–HI = incorporate at the high rate (7.12 kg·m⁻³), TOP–HI = top-dress at the high rate (18 g/container), TOP–HI(30) = top-dress at the high rate 30 d after planting, INC–MED = incorporate at the medium rate (5.34 kg·m⁻³), TOP–MED = topdress at the medium rate (14 g/container), CONST = 200 mg·L⁻¹ N delivered Monday, Wednesday, and Friday, WG–DLY = daily sliding-scale treatments to *Weigela florida* 'Red Prince', WG–BIWK = biweekly sliding-scale treatments to *Weigela florida* 'Red Prince'.

^bMeans within columns followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.

Table 4. Total dry weight, leaf area, total plant N content, and shoot:root ratio of *Euonymus alatus* 'Compactus' grown in 3.8-L containers with controlled-release, constant N rate, and sliding-scale liquid fertilizer treatments (2002).

Treatment ^a	Total dry wt (g)	Leaf area (cm ²)	Total plant N (mg)	Shoot to root ratio
INC-HI	5.6 b ^y	141.2 b	137.1 b	2.6 c
TOP-HI	11.1 a	273.6 a	239.5 a	3.7 abc
TOP-HI(30)	8.2 ab	182.9 ab	166.1 ab	3.1 bc
INC-MED	9.4 ab	261.1 ab	217.7 ab	3.7 abc
TOP-MED	7.0 ab	181.3 ab	156.1 ab	3.1 bc
CONST	5.4 b	147.7 b	143.3 b	4.8 a
EU-DLY	8.1 ab	250.5 ab	150.9 b	4.5 ab
EU-BIWK	8.8 ab	242.4 ab	202.4 ab	4.4 ab

^aINC-HI = incorporate at the high rate (7.12 kg·m⁻³), TOP-HI = top-dress at the high rate (18 g/container), TOP-HI(30) = top-dress at the high rate 30 d after planting, INC-MED = incorporate at the medium rate (5.34 kg·m⁻³), TOP-MED = topdress at the medium rate (14 g/container), CONST = 200 mg·L⁻¹ N delivered Mon., Wed. and Fri., EU-DLY = daily sliding-scale treatments to *Euonymus alatus* 'Compactus', EU-BIWK = biweekly sliding-scale treatments to *Euonymus alatus* 'Compactus'.

^yMeans within columns followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.

liquid treatments (EU-DLY and EU-BIWK) were similar to plants grown with the CRF treatments, but the shoot to root ratio of plants grown with the sliding-scale liquid treatments was higher than that of the CRF treatments.

Nitrogen uptake efficiency (total plant N/total N applied) was calculated for WG-DLY, WG-BIWK, EU-DLY, EU-BIWK, and CONST, and comparisons were made within each taxon (Table 5). For both taxa, the sliding-scale liquid N treatments resulted in higher N uptake efficiency than the CONST treatment. Nitrogen uptake efficiency, though dependent on many factors, is a function of the amount of N applied. If total plant N remains constant while the amount of N applied decreases, N uptake efficiency will increase. In this experiment, less N was applied with the sliding-scale liquid treatments (1837.5 and 1015 mg for *Weigela* and *Euonymus*, respectively) than with the CONST treatment (2900 mg; Table 1), but total plant N was similar across all liquid N treatments (Table 3 and 4). Therefore, higher N uptake efficiency values were realized with the sliding-scale liquid treatments than with the CONST treatment. Comparisons of N

uptake efficiency did not include CRF treatments because the amount of N released and retained in the prills at the time of harvest was not determined. However, several studies have suggested that the effective N release of Osmocote 18N-2.6P-9.9K under nursery conditions is about 120 to 150 d depending on temperature and moisture levels during the season (Huett and Gojell, 2000; Meadows and Fuller, 1983). Considering air temperature, rainfall data (Fig. 3), and irrigation volumes (Table 1), if all of the N was released from the

CRF treatments during the 142-d experimental period, higher N uptake efficiencies may have been realized with the sliding-scale liquid N treatments because they introduced less N to each container.

Shoot to root ratios of both taxa were higher with liquid fertilization than with CRF treatments (Table 3 and 4). The highest shoot to root ratios occurred with the CONST treatment. Previous studies have reported increased shoot to root ratios with increased N amounts for several woody landscape plants (Cabrera, 2003; Cabrera and Devereaux, 1998; Henry et al., 1992; Hummel et al., 1990; Yeager and Wright, 1981). This response is attributed to plants' inherent tendency toward homeostasis by compensating for carbon or N imbalances (Cabrera and Devereaux, 1998). Under ample N supply, carbon may become the limiting factor to plant growth. Plants respond by allocating resources to shoots and leaves for the acquisition of carbon (Cabrera and Devereaux, 1998). Container-grown plants with high shoot to root ratios may be predisposed to slow establishment and greater mortality rates when planted into a landscape environment that is less intensively managed (Cabrera and Devereaux, 1998).

The WG-DLY and WG-BIWK treatments delivered the same total amount of N with 104 and 30 N applications, respectively (Table 2). The WG-DLY treatment supplied solutions with relatively low N concentrations daily, and the WG-BIWK treatment supplied solutions with higher N concentrations but less frequently (biweekly). Total plant dry weight, leaf area, total plant N, and shoot to root ratios were similar for *Weigela* regardless of whether

Fig. 3. Daily maximum and minimum air temperatures (A) and rainfall (B) at the experimental site (Lewis Brown Horticulture Farm, Corvallis, Ore.) from planting (1 Apr. 2002) to harvest (20 Aug. 2002).

Table 5. Nitrogen uptake efficiency of *Weigela florida* 'Red Prince' and *Euonymus alatus* 'Compactus' grown in 3.8-L containers with constant N rate and sliding-scale liquid fertilizer treatments (2002).

Treatment ^a	N uptake efficiency (total plant N/total N applied)
<i>Weigela florida</i> 'Red Prince'	
WG-DLY	42.7 a ^y
WG-BIWK	43.7 a
CONST	31.5 b
<i>Euonymus alatus</i> 'Compactus'	
EU-DLY	14.9 a
EU-BIWK	19.9 a
CONST	4.9 b

^aWG-DLY = daily sliding-scale treatments to *Weigela florida* 'Red Prince', WG-BIWK = biweekly sliding-scale treatments to *Weigela florida* 'Red Prince', CONST = 200 mg·L⁻¹ N delivered Mon., Wed. and Fri. to both taxa, EU-DLY = daily sliding-scale treatments to *Euonymus alatus* 'Compactus', EU-BIWK = biweekly sliding-scale treatments to *Euonymus alatus* 'Compactus'.

^yMeans within a taxon and column followed by the same letter are not significantly different ($\alpha = 0.05$) by Duncan's multiple range test.

the applied N was delivered daily (WG-DLY) or biweekly (WG-BIWK). The EU-DLY and EU-BIWK treatments were delivered with 90 and 26 N applications, respectively (Table 2). Like *Weigela*, total plant dry weight, leaf area, total plant N, and shoot to root ratios for *Euonymus* plants were similar regardless of daily or biweekly supply. According to this data, biweekly applications are adequate for the growth of *Weigela* and *Euonymus*. Greater precision, accomplished by more frequent applications at lower N concentrations, may not be necessary. A fertilizer program designed with fewer applications requires less solution preparation and allows for more flexible scheduling of applications to multiple crops.

At 93 d after planting, the pH of the substrate for all treatments ranged from 6.1 to 6.6, and the electrical conductivity (EC) ranged from 0.19 to 0.84 dS·m⁻¹. In *Euonymus*, liquid treatments yielded lower pHs and higher ECs in the substrate than the CRF treatments (data not shown). However, all values were within the recommended range for container-grown woody nursery crops (Wright, 1984; Yeager et al., 1997).

To implement a sliding-scale liquid fertilization program on a commercial scale, researchers and commercial nurseries will have to determine seasonal N accumulation patterns for each taxon produced. Existing drip irrigation and fertigation technology (Daughtry, 1990; Qcom, 2003; Whiteside, 1989) will have to be employed to avoid water and nutrient losses associated with overhead irrigation (Beeson and Knox, 1991). In addition, plants should be organized into groups with similar N requirements so that single applications can be made to large groups. Such a fertilization regime may be best suited for high value crops grown in large containers. As an example of a nursery that has reorganized production, El Modeno Gardens, a 95-acre container nursery in California, divided their plants into 64 groups according to water needs and used trickle irrigation to replenish specific crop evapotranspiration (Whiteside, 1989).

Sliding-scale liquid N fertilizer treatments resulted in plants with similar total dry weights, leaf areas, and total plant N contents, but higher shoot to root ratios than plants treated with Osmocote 18N-2.6P-9.9K. Sliding-scale liquid fertilization based on plant N requirements introduced less total N to the production cycle and resulted in higher N uptake efficiency than fertilization with a constant N rate of 200 mg·L⁻¹. Finally, a sliding-scale fertilization program based on biweekly N delivery is an appropriate level of precision when matching N applications to established N accumulation patterns of *Weigela* and *Euonymus*.

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