Irrigation Volume, Application, and Controlled-release Fertilizers: I. Effect on Plant Growth and Mineral Nutrient Content in Containerized Plant Production[1]

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Abstract

An experiment with four volumes of irrigation and five controlled-release fertilizers (CRFs) was conducted to evaluate effects on plant growth and mineral nutrient content. Rooted cuttings of *Cotoneaster dammeri* 'Skogholm' and seedlings of *Rudbeckia fulgida* 'Goldsturm' were grown in 3.8 liter (4 qt) containers in a pine bark:sand substrate (8:1, by vol) incorporated with 3.5 g (0.12 oz) N per container with one of the following five CRFs: Meister 21N–3.5P–11.1K (21–7–14), Osmocote 24N–2.0P–5.6K (24–4–7), Scotts 23N–2.0P–6.4K (23–4–8), Sustane 5N–0.9P–3.3K (5–2–4) or Woodace 21N–3.0P–9.5K (21–6–12). Irrigation volumes of 200 ml (0.3 in), 400 ml (0.6 in), 800 ml (1.1 in), or 1200 ml (1.7 in) were applied once daily (single) or in two equal applications with a two hr interval between irrigation allotments (cyclic). All measured variables were unaffected by irrigation application (cyclic or single). Top dry weight of cotoneaster increased quadratically with increasing irrigation volume for all CRFs. Maximum top dry weight was obtained with 612 ml (0.8 in), 921 ml (1.3 in), 928 ml (1.3 in), 300 ml (0.6 in), or 909 ml (1.3 in) for plants fertilized with Meister, Osmocote, Scotts, Sustane, and Woodace, respectively. Osmocote, Scotts, and Woodace produced 90% of maximum top weight over a wide range of irrigation volumes [≈ 550 ml (0.8 in) to 1200 ml (1.5 in)]. Stomatal conductance of cotoneaster fertilized with Osmocote 24–4–7 increased linearly with increasing volume of irrigation, whereas net photosynthetic rate increased quadratically and was highest at 800 ml (1.1 in). All CRFs, excluding Sustane, had similar dry weights when irrigated with 200 ml (0.3 in). At 800 ml (1.1 in) and 1200 ml (1.7 in), cotoneaster fertilized with Osmocote 24–4–7 and Scotts 23–4–8 produced greater top dry weight compared to Meister, Sustane, and Woodace. Top dry weight of rudbeckia increased quadratically with increasing irrigation volume regardless of CRFs. Maximum dry weight was produced with 1160 ml, 931 ml, 959 ml, 1091 ml, or 1009 ml for plants grown with Meister, Osmocote, Scotts, Sustane, or Woodace, respectively. Ninety percent of the maximum top dry weight of both species within each CRF could be obtained with a 40% reduction in irrigation volume. Nitrogen content of cotoneaster and rudbeckia were unaffected by irrigation volume, whereas P and K content, depending upon CRF and plant, was reduced at low irrigation volumes.

Index words: cyclic irrigation, water, *Cotoneaster dammeri* 'Skogholm', *Rudbeckia fulgida* 'Goldsturm'.

Significance to the Nursery Industry

The goal of irrigation and fertilization practices is to increase plant growth and promote salability in an efficient manner. Improved understanding of these two factors could help growers better define their growing regimes. Volume of irrigation required to maximize growth of cotoneaster and rudbeckia varied with controlled release fertilizer (CRF), however, daily volume of irrigation greater than 900 ml (1.1 in) was required to maximize growth of both species for most CRFs used in this study. Data herein, however, suggest that 90% of maximum growth could be achieved with a 40% reduction in water applied. Remarkably, Osmocote, Scotts, and Woodace produced 90% of maximum top weight over a wide range of irrigation volumes [≈ 550 ml (0.8 in) to 1200 ml (1.5 in)]. This wide range of irrigation volumes provides the grower much flexibility and should encourage reducing irrigation volumes. Low irrigation volume [200 ml (0.3 in)] reduced plant growth from 24% to 35% probably due to reduced photosynthesis. The nursery industry should strive to increase water efficiency and this study suggests that growers can maintain acceptable rates of growth while reducing irrigation volume.

Introduction

Maintaining adequate water and nutrients are key components to maximizing production of containerized nursery crops. To maximize plant growth, growers in the southeastern United States commonly utilize high volumes of irrigation and rates of controlled-released fertilizer (CRF) in pine bark substrates. Frequent high volume irrigations are deemed necessary due to the porous nature and low water holding properties of pine bark. A survey of Alabama nurseries reported the average daily volume of water applied via overhead irrigation ranged from 0.8 cm (0.3 in) to 3.3 cm (1.2 in) (4). With increasing demands to reduce irrigation volume, quantity of water required to produce containerized crops is a concern of the nursery industry. Little research, however, has examined the volume of irrigation required to maximize growth of containerized nursery crops. Simply reducing irrigation volume without regards to the plant's needs can lead to stomatal closure, reduced photosynthesis, and subsequent loss of plant growth (9). Previous studies examining the

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growth response of plants to reduced irrigation volume have reported results varying from decreased (8, 13, 25), increased (7), to no difference (16). Growth response to irrigation volume might be expected to vary with substrate (20), irrigation management (18), plant species (7), and rate of fertilization (28).

Research has shown that cyclic irrigation, where the daily water allotment is applied in a series of cycles comprised of an irrigation and a resting interval, improves irrigation application efficiency 24% to 38% compared to a single irrigation event (5, 11, 24). Although, cyclic irrigation does not necessarily reduce the volume of water applied in an irrigation cycle, it may be possible to reduce irrigation volume since more water is retained in the substrate.

There are other factors to consider when reducing irrigation volume. The liquid fraction of a substrate is the major avenue of nutrient movement to the root surface. Whether by mass flow or diffusion, maintaining adequate substrate moisture is necessary for nutrient movement (15). Thus, a reduction in irrigation volume could impede plant nutrient absorption. There have been few studies that have investigated the effect of irrigation volume on plant nutrient absorption (27).

Irrigation volume has a profound influence on nutrient concentrations in the substrate solution. The quantity of nutrients leached from the substrate usually increases with increasing irrigation volume, thereby decreasing the nutrient concentration of the substrate solution (14). Whether this impacts or limits nutrient adsorption and subsequent plant growth is not well documented.

Irrigation volume, mineral nutrient sources, and fertilizer rates have been examined in production of greenhouse crops. These studies, however, have focused on liquid fertilization (2, 10), whereas resin-, polymer-, and sulfur-coated nutrients along with urea and isobutylidene-diurea comprise the majority of CRFs used by the nursery industry (23). Limited research has been conducted on the response of CRFs to irrigation volume (8, 17). Therefore, the objective of this study was to determine effects of irrigation volume, application (cyclic versus single), and CRFs on plant growth and mineral nutrient content in a simulated nursery.

Materials and Methods

The experiment, a split-plot design with three replications and two cultivars, *Rudbeckia fulgida* Ait. 'Goldsturm' and *Cotoneaster dammeri* Schneid. 'Skogholm', was conducted on a gravel pad at the North Carolina State University Horticulture Field Laboratory, Raleigh, during May to September 1994. Both species were classified by the authors as having high water requirements and medium nutrient requirements. Main plots were four volumes of irrigation and two methods of irrigation application. Irrigation volumes were chosen based on available water (AW = 783 ml) at container capacity held in a 3.8 liter (4 qt) container filled with a pine bark:sand (8:1, by vol) substrate amended per m^3 (yd^3) with 1.8 kg (4 lb) dolomitic limestone and 0.9 kg (1.5 lb) micronutrient fertilizer (MicroMax, The Scotts Co., Marysville, OH). Physical properties of the substrate are reported in Groves et al. (6). Irrigation volumes of 0.25AW [200 ml (0.3 in)], 0.5AW [400 ml (0.6 in)], 1.0AW [800 ml (1.1 in)], or 1.5AW [1200 ml (1.7 in)] were applied once daily (single, 7:00 AM) or in two equal applications with a two hr interval between irrigation allotments (cyclic, 5:00 AM and and 7:00 AM). Irrigation was applied using pressure compensated spray stakes (Acu-Spray Stick, Wade Mfg. Co., Fresno, CA) at a rate of 200 ml/min (0.3 in/min). Within each main plot were five subplots consisting of two plants fertilized with one of five CRFs (two plants per replicate for a total of 6 plants per treatment).

Each plant was fertilized at potting (May 23) with 3.5 g N from one of the following fertilizers: Meister 21N–3.5P–11.1K (21–7–14, Helena Chemical Co., Tampa, FL) composed of 0.5% NO_3, 0.7% NH_4, 19.8% polymer-coated urea (referred to as polymer-coated urea), sulfur-coated ammonium phosphate and triple superphosphate (referred to as sulfur-coated P), and potassium nitrate and polymer-coated potassium sulfate (referred to as polymer-coated KS); Osmocote 24N–2.0P–5.6K (24–4–7, The Scotts Co.) consisting of resin-coated 6.6% NH_4, 5.9% NO_3, 11.5% urea (referred to as resin-coated NH_4NO_3), resin-coated ammonium phosphate and calcium phosphate (referred to as resin-coated P), and resin-coated potassium sulfate (referred to as resin-coated K); Scotts 23N–2.0P–6.4K (23–4–8, Southern formulation, The Scotts Co.) containing polymer-coated urea and ammonium nitrate (referred to as polymer-coated N), polymer-coated ammonium phosphate and calcium phosphate (referred to as polymer-coated P), and polymer-coated potassium sulfate (referred to as polymer-coated K); Sustane 5N–0.9P–3.3K (5–2–4, Sustane Corp., Cannon Falls, MN) containing 0.8% NH_4, 4.2% organic N, organic P, and organic K (referred to as composted turkey litter); or Woodace 21N–3.0P–9.5K (21–6–12, Vigoro Industry, Inc., Fairview Heights, IL) composed of 1% NO_3, 16.5% urea, 3.5% water insoluble N (referred to as urea), noncoated magnesium potassium phosphate (referred to as MgKP), and sulfur-coated potassium sulfate and potassium nitrate (referred to as sulfur-coated K). Rates of P and K resulting from 3.5 N were: Meister 0.58 g P and 1.84 g K, Osmocote 0.29 g P and 0.82 g K, Scotts 0.29 g P and 0.97 g K, Sustane 0.63 g P and 2.30 g K, and Woodace 0.50 g P and 1.59 K. Fertilizers were weighed for each container and incorporated into the substrate before transplanting. A container received 400 ml (0.6 in) water daily until experiment initiation on day 0 (May 30). The study was terminated 120 days after initiation (DAI).

Leaf gas exchange was measured for cotoneaster 72 and 95 DAI with a LI-COR LI-6200 closed portable infrared gas exchange system (LI-COR, Lincoln, NE) between 1100 HR and 1500 HR. Photosynthetically active radiation (PAR), air and leaf temperature, and relative humidity (RH) inside the leaf chamber were measured concurrently with gas exchange. Environmental conditions during measurements were > 1400 $umol \cdot s \cdot m^{-2}$ PAR, leaf temperature in the chamber ranged from 33.7 to 36.1C (92.7 to 97.9F), and RH ranged from 30.3% to 35.0%. Net photosynthetic rate and stomatal conductance were calculated using the LI-COR 6200 measurements. An attached shoot (stem and leaves), 7 cm (2.8 in) in length, of cotoneaster fertilized with Osmocote 24–4–7 was placed in a 0.25 liter (165.4 cm^3) chamber for 30 sec. Measurements commenced immediately after CO_2 concentration decreased. Ambient CO_2 concentration ranged from 320 to 350 $mg \cdot liter^{-1}$.

At harvest, tops of both species were removed. Roots of cotoneaster were placed over a screen and washed with a high pressure water stream to remove substrate. It was not possible to separate roots of rudbeckia from the substrate accurately. Plant tissues of each species were dried at 62C (144F) for 5 days and weighed. After drying, tops of each species were ground in a Wiley mill to pass a 40 mesh (0.425 mm) screen. Each tissue sample (1.25 g) was combusted at 490C (914F) for 6 hr. The resulting ash was dissolved in 10 ml (0.03 oz) 6 N HCl and diluted to 50 ml (1.5 oz) with deionized water. Phosphorus and K concentrations were determined by inductively coupled plasma emissions spectrophotometer (P-2000 Perkin-Elmer, Norwalk, CT). Nitrogen was determined using 10 mg (0.03 oz) samples in a CHN elemental analyzer (PE 2400, Perkin-Elmer). At Day 0, 10 plants of each species were harvested, dried, weighed, and ground for N, P, and K analysis as described previously. Average initial weight and mineral nutrient content were subtracted from the final dry weight and nutrient content of each species prior to statistical analysis.

Data were subjected to analysis of variance procedures (ANOVA) and regression analysis where appropriate (21). Simple linear or polynomial curves were fitted to the data when significant trends were identified in the regression analysis. Irrigation volume for maximum top and root dry weights were estimated by calculating the irrigation volume at which the first order derivation of the irrigation volume response of dry weight was equal to 0. Mean separations were performed via least significant difference (LSD) procedure at P = 0.05. Dry weight (g) data were used to calculate root:top ratio (RTR = root dry weight ÷ top dry weight) for cotoneaster only. Top mineral nutrient content was determined by multiplying top dry weight by nutrient concentration expressing each nutrient in grams. The fertilizer × irrigation volume interaction was significant for all measured variables except N and P content of cotoneaster and N, P, and K content of rudbeckia. All other interactions were nonsignificant.

Results and Discussion

Plant growth. Plant growth was unaffected by irrigation application (cyclic or single) nor were there any significant interactions. Tyler et al. (24) and Fare et al. (4) also reported that plant growth was unaffected by method of irrigation application. Thus, data were averaged over irrigation application and reanalyzed.

To simplify and shorten the results and discussion, CRFs will be referred to by company names. Top dry weight of cotoneaster increased quadratically with increasing irrigation volume for all CRFs (Fig. 1). Maximum top dry weight was obtained with 612 ml, 921 ml, 928 ml, 300 ml, and 909 ml for cotoneaster fertilized with Meister, Osmocote, Scotts, Sustane, and Woodace, respectively. Obviously, growers could increase irrigation efficiency by reducing irrigation volume early in the season when the plants are small. However, these values probably represent irrigation volumes required to maximize growth during peak water demands. Within the range of irrigation volumes included in this study, percentage loss of plant growth ranged from 0% to 7% depending upon CRF with high volumes of irrigation [1200 ml (1.7 in)] whereas, low volumes [200 ml (0.3 in)] reduced plant growth 24% to 45%. This may explain why growers are hesitant to reduce irrigation volume without adequate recommendations.

Ninety percent of maximum top dry weight of cotoneaster grown with Osmocote, Scotts, or Woodace could be produced with 553 ml (0.8 in), 580 ml (0.9 in), or 515 ml (0.8 in), respectively which represents ≈ 40% reduction in irrigation volume. Tyler et al. (25) reported that irrigation volume was reduced by 44% with only an 8% loss in top dry weight. Osmocote, Scotts, and Woodace produced 90% of maximum top weight within each CRF over a wide range of irrigation volumes [≈ 550 ml (0.8 in) to 1200 ml (1.7 in)]. This wide range of irrigation volume provides the grower much flexibility and should encourage reducing irrigation volume.

All CRFs, excluding Sustane, had similar top dry weights of cotoneaster when irrigated with 200 ml suggesting that water was limiting growth (Fig. 1a). At 800 ml and 1200 ml, cotoneaster fertilized with Osmocote 24–4–7 and Scotts 23–4–8 produced greater top dry weight compared to Meister, Sustane, and Woodace. It appears as irrigation volume increased, mineral nutrient source and control-release mechanisms played a critical role in determining plant growth.

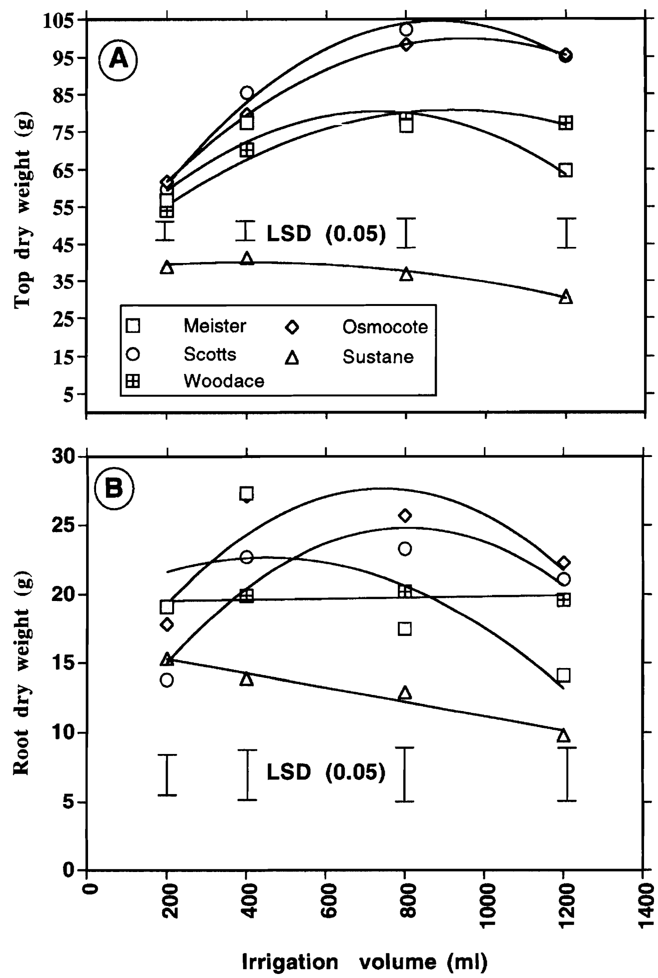

Fig. 1. Effect of irrigation volume and controlled-released fertilizer on top (A) and root (B) dry weights of *Cotoneaster dammeri* 'Skogholm'. Regression equations for top dry weight are: Meister $y = 40.50 + 0.1102x - 0.00009x^2$ ($r^2 = 0.85$); Osmocote $y = 38.64 + 0.1289x - 0.00007x^2$ ($r^2 = 0.99$); Scotts $y = 31.37 + 0.1670x - 0.00009x^2$ ($r^2 = 0.99$); Sustane $y = 37.64 + 0.0120x - 0.00002x^2$ ($r^2 = 0.96$); and Woodace $y = 39.20 + 0.0909x - 0.00005x^2$ ($r^2 = 0.97$). Regression equations for root dry weight are: Meister $y = 19.20 + 0.0156x - 0.00002x^2$ ($r^2 = 0.60$); Osmocote $y = 12.00 + 0.0420x - 0.00003x^2$ ($r^2 = 0.73$); Scotts $y = 7.46 + 0.0428x - 0.00003x^2$ ($r^2 = 0.84$); Sustane $y = 16.32 - 0.0051x$ ($r^2 = 0.96$); and Woodace which was not affected by irrigation volume. Means within irrigation volume are separated by LSD, P = 0.05

Sustane produced the lowest top dry weight at all volumes, probably due to reduced substrate NH_4 and NO_3 levels (6). Most N in Sustane was organic N, which is available only after being mineralized. Therefore, total N released was less for Sustane compared to the other fertilizers (6) which could have reduced plant growth.

Effect of irrigation volume on root dry weight of cotoneaster varied with CRF (Fig. 1b). Root dry weight decreased linearly with increasing irrigation volume when grown with Sustane, whereas plants fertilized with Woodace had similar root dry weights across all volumes. Meister, Osmocote, and Scotts produced a quadratic response with increasing volume of water, with greatest root weight at 390 ml, 700 ml, and 713 ml, respectively. From this data, response of root dry weight to reduced irrigation volume would be dependent upon CRF. The CRF producing maximum root dry weight varied with irrigation volume. Similar to top dry weight, however, plants fertilized with Sustane had the lowest root dry weight of all CRFs at all volumes except 200 ml.

Root:top ratio (RTR) of cotoneaster decreased with increasing irrigation volume when fertilized with Meister, Osmocote, and Woodace (data not presented). Increasing water supply can increase top growth relative to root growth (3, 22). Effect of RTR on future landscape performance has not been investigated. Nevertheless, a decreasing RTR could affect landscape performance as top growth will be dependent upon the existing root system when initially planted in the landscape. Root:top ratio of cotoneaster grown with Scotts and Sustane was unaffected by irrigation volume (data not presented).

Top dry weight of rudbeckia increased quadratically with increasing irrigation volume regardless of CRFs (Fig. 2). Maximum dry weight was produced with 1160 ml, 931 ml, 959 ml, 1091 ml, and 1009 ml for plants grown with Meister, Osmocote, Scotts, Sustane, and Woodace, respectively. Irrigation volumes producing maximum dry weight were similar for cotoneaster grown with Osmocote, Scotts, and Woodace. Similar to cotoneaster, dramatic reductions in volume of irrigation could be obtained if the grower's goal was 90% of maximum top dry weight. Except for Sustane, all CRFs produced similar top dry weights at 200 ml and 400 ml suggesting that at 0.25AW and 0.5AW, water was the main factor affecting plant growth rather than CRF. *Ilex cornuta* 'Burfordii' and *Ilex* x 'Nellie R. Stevens' grown with several CRFs had similar top growth when irrigated with 1.2 cm (0.5 in) per day (19) which is similar to lower volumes of irrigation used in the present study. Even though they were not significantly greater than all other CRFs, Rudbeckia fertilized with Meister 21–6–12 and Osmocote 24–4–7 had the greatest dry weight at 800 ml and 1200 ml. This is in contrast to cotoneaster where plants grown with Meister were smaller compared to most of the other CRFs. This could be in response to differences in sources of mineral nutrients, rate of release, or differences in root morphology and rate of growth between cotoneaster and rudbeckia. Roots of rudbeckia were fibrous and rapidly filled the container volume (personal observation). In contrast, roots of cotoneaster were less fibrous and did not fill the container volume for many weeks.

At 75 and 95 DAI, stomatal conductance of cotoneaster fertilized with Osmocote 24–4–7 increased linearly with increasing volume of irrigation (data not presented), whereas net photosynthetic rate increased quadratically and was highest at 800 ml (data not presented). Photosynthetic rate was lowest at 200 ml implying a water deficit compared to other volumes of irrigation. Photosynthetic rate reportedly decreases with increasing water stress (as irrigation decreases) due to partial or complete stomatal closure (12). This supports the hypothesis that at lower irrigation volumes water was limiting plant growth, whereas water was not limiting at 800 ml and 1200 ml.

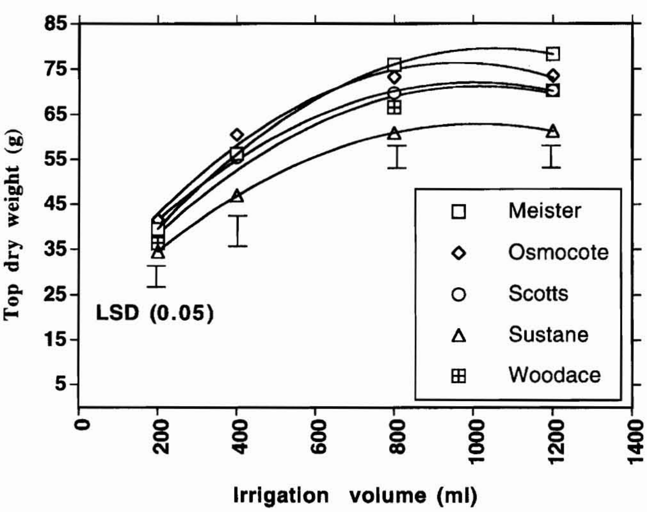

Fig. 2. Effect of irrigation volume and controlled-release fertilizer on top dry weight of *Rudbeckia fulgida* 'Goldsturm'. Regression equations for top dry weight are: Meister $y = 18.58 + 0.1160x - 0.00005x^2$ ($r^2 = 0.94$); Osmocote $y = 22.74 + 0.1117x - 0.00006x^2$ ($r^2 = 0.82$); Scotts $y = 24.12 + 0.0959x - 0.00005x^2$ ($r^2 = 0.82$); Sustane $y = 18.86 + 0.0873x - 0.00004x^2$ ($r^2 = 0.80$); and Woodace $y = 20.14 + 0.1009x - 0.00005x^2$ ($r^2 = 0.83$). Means within irrigation volumes are separated by LSD, P = 0.05.

Mineral nutrient content. Since mineral nutrient content, in lieu of nutrient concentration, reflects more accurately plant nutrient absorption (8), only plant nutrient content will be presented. All interactions were nonsignificant for N and P content of cotoneaster. Nitrogen content of cotoneaster was unaffected by irrigation volume suggesting that even at 200 ml there was sufficient water for N absorption (Table 1). Tyler et al. (25) also reported that top N content of *Cotoneaster dammeri* 'Skogholm' was unaffected by irrigation volume. These data support the hypothesis that growth reductions at the lower irrigation volumes were due primarily to water deficits. Cotoneaster fertilized with polymer-coated N (Scotts) had the highest N content while plants fertilized with composted turkey litter (Sustane) had the lowest (Table 2). Top dry weight and N content of cotoneaster were positively correlated (r = 0.76, P = 0.001) implying that top growth was a reflection of the ability of CRFs to supply adequate substrate N throughout the growing season.

Phosphorus content of tops of cotoneaster decreased with increasing irrigation volume suggesting that P uptake was not impeded by low volumes of irrigation (Table 1). However, this may reflect reduced substrate P concentration with increasing irrigation volume (6). This is supported by a positive correlation (r = 0.48, P = 0.001) between P content of cotoneaster and substrate P concentration (6). Schomaker (22) working with eastern white pine (*Pinus strobus*) and Jarrell

Table 1. Effect of irrigation volume on mineral nutrient content in tops of *Cotoneaster dammeri* 'Skogholm' and *Rudbeckia fulgida* 'Goldsturm' 120 days after treatment initiation.

Irrigation volume (ml)	Cotoneaster		Rudbeckia	
	N	P	P	K
	Nutrient content (g)			
200	0.84	0.08	0.07	0.37
400	0.88	0.07	0.08	0.46
800	0.79	0.06	0.09	0.54
1200	0.80	0.05	0.10	0.55
Significance[z]				
Linear	NS	0.001	0.001	0.001
Quadratic	NS	NS	0.002	0.001

[z]Regression analysis of irrigation volume, NS = $P > 0.05$.

et al. (8) working with *Ligustrum texanum* reported increasing irrigation volume increased P content. In contrast to N content where one CRF (Scotts) appeared to be superior, three P sources (resin-coated P, polymer-coated P, and MgKP) produced the highest P content, whereas cotoneaster grown with sulfur-coated P had the lowest (Table 2). This suggests that the rate of P application was not as critical as the source or control-release mechanism as resin-coated P and polymer-coated P were applied in the smallest quantity.

Response of K uptake to irrigation volume was CRF dependent. Increasing irrigation volume decreased K content of tops of cotoneaster when fertilized with polymer-coated KS and composted turkey litter (Table 3). Potassium content of cotoneaster grown with resin-coated K and polymer-coated K increased with increasing irrigation volume, whereas sulfur-coated K showed no trend. Similar to P, this suggests

Table 2. Effect of nutrient source and control-release mechanism on mineral nutrient content in tops of *Cotoneaster dammeri* 'Skogholm' and *Rudbeckia fulgida* 'Goldsturm' 120 days after treatment initiation.

	Nitrogen			Phosphorous			Potassium	
		Content (g)			Content (g)			Content (g)
Fertilizer	Source	Coton.	Rudbeckia	Source	Coton.	Rudbeckia	Source	Rudbeckia
Meister 21–7–14	Polymer-coated urea	0.96b[z]	0.96a	Sulfur-coated P	0.04c	0.10a	Polymer-coated KS	0.58a
Osmocote 24–4–7	Resin-coated NH_4NO_3	0.98b	0.98a	Resin-coated P	0.08a	0.08b	Resin-coated K	0.45c
Scotts 23–4–8	Polymer-coated N	1.22a	0.94a	Polymer-coated P	0.09a	0.08b	Polymer-coated K	0.47bc
Sustane 5–2–4	Composted turkey litter	0.26d	0.54c	Composted turkey litter	0.06b	0.08b	Composted turkey litter	0.39d
Woodace 21–6–12	Urea	0.69c	0.75b	MgKP	0.09a	0.09a	Sulfur-coated K	0.51b

[z]Means within a column (nutrient source) followed by the same letter or letters are not significantly different as determined by LSD, P = 0.05.

Table 3. Effect of irrigation volume and nutrient source on potassium content in tops of *Cotoneaster dammeri* 'Skogholm' 120 days after treatment initiation.

Irrigation volume (ml)	Potassium source				
	Polymer-[z] coated KS	Resin-coated K	Polymer-coated K	Composted turkey litter	Sulfur-coated K
	Potassium content (g)				
200	0.61a[y]	0.52b	0.52b	0.38c	0.58ab
400	0.67a	0.61a	0.66a	0.38b	0.66a
800	0.58b	0.67a	0.62ab	0.30c	0.61a
1200	0.53b	0.68a	0.70a	0.24c	0.58b
Significance[x]					
Linear	0.030	0.001	0.004	0.001	NS
Quadratic	NS	NS	NS	NS	NS

[z]Polymer-coated KS = Meister 21–7–14; resin-coated K = Osmocote 24–4–7; polymer-coated K = Scotts 23–4–8; composted turkey litter = Sustane 5–2–4; sulfur-coated K = Woodace 21–6–12.

[y]Means within a row (irrigation volume) followed by the same letter or letters are not significantly different as determined by LSD, P = 0.05.

[x]Regression analysis of irrigation volume, NS = $P > 0.05$.

that the rate of K application was not as critical as the source or control-release mechanism as resin-coated K and polymer-coated K were also applied in the smallest quantity. This is further supported by a positive correlation ($r = 0.83$, $p > 0.001$) between top dry weight and K content of cotoneaster. Jarrell et al. (8) also reported that the effect of irrigation volume on top K content was CRF dependent. Bengston and Voigt (1) stated that K uptake decreased with increasing water applications when K was in a readily available form, but uptake increased when K was in a slowly available form. Cotoneaster fertilized with composted turkey litter (Sustane) had the lowest K content at all volumes. Tyler et. al. (26) also reported that composted turkey litter was an inadequate source of K. At 1200 ml, two K sources (resin-coated K and polymer-coated K) produced the highest K content.

Irrigation volume and CRF affected N, P, and K content of tops of rudbeckia independently (irrigation volume × CRF interaction was nonsignificant) (Tables 1 and 2). Similar to cotoneaster, N content was unaffected by irrigation volume (data not presented), whereas K and P content increased with increasing irrigation volume suggesting that low volumes of irrigation might have reduced uptake (Table 1). Rudbeckia fertilized with polymer-coated urea, resin-coated NH_4NO_3, and polymer-coated N had the greatest N content (Table 2). Top P content was greatest for sulfur-coated P and MgKP. Rudbeckia grown with polymer-coated KS had the highest K content. Composted turkey litter produced the lowest N and K content.

Volume of irrigation required to maximize growth of cotoneaster and rudbeckia varied with CRF, however, daily irrigation volume greater than AW capacity [800 ml (1.1 in)] was required to maximize growth of both species for most CRFs in this study. Data herein, however, suggest that 90% of maximum growth could be achieved with » 40% reduction in water applied. Even though irrigation volume did not affect N uptake, there was evidence that P and K absorption, depending upon the CRF and plant, may be impeded by low irrigation volumes. CRFs varied in their respond to irrigation volume. The difference among CRFs can be attributed to differences in mineral nutrient source, ability of the control-release mechanism to maintain adequate substrate solution nutrient concentration, and susceptibility of nutrient sources to leaching losses (6). The nursery industry should strive to increase water efficiency and this study suggests that growers can maintain acceptable rates of growth while reducing irrigation volume.

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