Container-grown Shrubs Respond Differently to Controlled-release Fertilizer Rates in a Temperate Climate

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Abstract

To determine the response of container-grown shrubs to controlled-release fertilizer (CRF) rate when grown in a temperate climate, Polyon® 19–04–10 + Minors, an 8–9 month CRF, was incorporated into growing substrates for ‘Gro-Low’ fragrant sumac (Rhus aromatica Aiton), ‘Goldmound’ spirea (Spiraea × bumalis Burv.) and ‘Bloomerang®’ purple lilac (Syringa × ‘Penda’) transplants. Also, a 15–06–11 + Micros, a 10–12 month CRF, was incorporated into growing substrates for ‘Green Mound’ boxwood (Buxus × ‘Green Mound’), ‘Runyan’ yew (Taxus × media) and ‘Emerald’ white-cedar (arborvitae) (Thuja occidentalis L.) transplants, at six rates (0.15, 0.45, 0.75, 1.05, 1.35 and 1.65 kg m⁻³ N; 0.25, 0.76, 1.26, 1.77, 2.28 and 2.78 lb·yd⁻³ N). We observed greater growth index, leaf area, and shoot dry weight at high vs. low CRF rates for the majority of species. Nutrient deficiency symptoms such as light green leaves were observed at low CRF rates for some species, including fragrant sumac, lilac and white-cedar. Optimal species-specific CRF application rates were 1.05 kg m⁻³ N (1.77 lb·yd⁻³ N) for lilac and yew and 0.45 kg m⁻³ N (0.76 lb·yd⁻³ N) for boxwood and white-cedar, while the optimal CRF ranges were 0.75 to 1.35 kg m⁻³ N (1.26 to 2.28 lb·yd⁻³ N) for fragrant sumac and 0.75 to 1.05 kg m⁻³ N (1.26 to 1.77 lb·yd⁻³ N) for spirea. Adjusting CRF application rates based on plant response may provide nursery growers with an efficient tool for managing nursery crop growth and production timing in the temperate climate.

Index words: mineral nutrition, nitrogen, optimal fertilizer rate, nursery crop.

Species used in this study: ‘Green Mound’ boxwood (Buxus × ‘Green Mound’); ‘Gro-Low’ fragrant sumac (Rhus aromatica Aiton); ‘Goldmound’ spirea (Spiraea × bumalis Burv.); ‘Bloomerang®’ purple lilac (Syringa × ‘Penda’); ‘Runyan’ yew (Taxus × media); ‘Emerald’ white-cedar (arborvitae) (Thuja occidentalis L.).

Significance to the Horticulture Industry

Most container nursery production uses controlled-release fertilizer (CRF) to promote vigorous plant growth; however, CRF types and rates are species- and region-specific. Climatic conditions of the growing region influence nutrient release from CRFs. Therefore, region-specific recommendations are needed for CRF application rates during container nursery crop production. Species-specific growth resulted in high, moderate, or low response to CRF with either one (i.e., for ‘Gro-Low’ fragrant sumac, ‘Goldmound’ spirea and ‘Bloomerang®’ purple lilac) or multiple (i.e., for ‘Green Mound’ boxwood, ‘Runyan’ yew and ‘Emerald’ white-cedar) production seasons required for crops to reach a marketable size. Applying species-specific CRF at the optimal rate or range in nursery crop production may save production time, reduce fertilizer costs, prevent nutrient disorders, and protect from negative environmental impacts of nutrient leaching. Therefore, CRF can be used by nursery growers as a tool to manage crop growth and production timing. Future investigation should evaluate additional species to determine responses of commonly-grown nursery crops to CRF rates in the temperate climate.

Introduction

Nursery crop production often occurs in containers on high-density, intensified outdoor farms, and is a $694 million industry in Canada alone (Statistics Canada 2013a). Highly-intensified nursery crop production has been a growing trend and nursery growers ensure crop quality and efficient crop growth in part by fertilization practices (Cabrera 1996, Statistics Canada 2013b, USDA 2006). Controlled-release fertilizer (CRF), rather than fertigation, has been used recently in container nursery crop production to successfully increase fertilizer efficiency and nutrient availability, while minimizing salt buildup (Cabrera 1996, Shaviv 2001, Yeager et al. 1993). In contrast to plant production in controlled environments (Zheng et al. 2010), root-zone fertility requirements for nursery crop production are greatly influenced by fluctuating environmental conditions (Cabrera 1996). Currently, CRF application rate recommendations are developed from studies in constant environmental conditions in the greenhouse or laboratory (Birrenkott et al. 2005, Cabrera 1997, Oliet et al. 2004). As new CRF products are being commercially developed and offered to nursery growers, some short-term outdoor CRF rate research studies have occurred in warm climates with some nursery crops and select CRF products (Chen et al. 2001, Rutger 1992, Yeager and Cashion 1993). However, optimal CRF application rate recommendations are rare in the scientific literature for specific climate regions. Therefore, additional research is needed to build upon past research studies which have suggested CRF application rates for nurseries in temperate climates, typical of Canada and the Northeastern USA, in order to best serve the nursery industry (Agro 2014, Alam et al. 2009, Hicklent and Cairns 1992).

Plant growth response to increasing CRF rate typically occurs as a classic curve with increasing growth resulting from increasing CRF rate, to the point of adequate fertilization, followed by a plateau of growth within a range of sufficient fertility, and finishing with reduced growth due to

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toxicity from over-fertilization. This classic growth-response curve occurs at different fertilizer rate ranges for individual plant species and cultivars, thus species-specific optimal fertilization recommendations differ for many agricultural and greenhouse crops (Reed 1996, Resh 1995). Currently, nursery growers often apply generalized CRF rates rather than species-specific rates because specific rates are currently unknown for the majority of nursery crops. The numerous nursery crop species and cultivars, the diverse nursery practices and the wide range of CRF products used in nursery production (Chen et al. 2001) has limited the availability of comprehensive species-specific CRF application rate recommendations. In response, generalized rates of CRF are applied based on production factors such as time and cost, while maintaining industry-standard plant quality. Consequently, some ‘high-feeder’ species may be under-fertilized, resulting in slow growth and potential nutrient deficiencies, while ‘low-feeder’ species may be over-fertilized, causing nutrient loss (i.e., leaching) to the environment, plant injury leading to pest and disease problems, and excessive production cost (Majsztrik et al. 2011, Yeager et al. 1993). By applying species-specific CRF rates, growers can achieve successful transplant establishment, plant growth and performance, production efficiency (e.g., yield), and minimize nutrient deficiencies and leaching (Britton et al. 1998, Cabrera 2003, Chen et al. 2001, Chen et al. 2011).

To expand upon previous research, this study evaluated additional CRF types and species-specific CRF application rates for some economically-important nursery crops in a temperate climate. Specifically, the objective of this study was to identify the response of six container-grown shrub species to a range of CRF application rates when grown under commercial nursery conditions in a temperate climate.

Materials and Methods

Plant material and fertilization. At a Halton region wholesale nursery in Ontario, Canada (43.68° N lat., 79.91° W long.), the following six shrub cultivars were selected for study by the nursery operator, based on cultivar priorities and economic value to the nursery: ‘Green Mound’ boxwood, ‘Gro-Low’ fragrant sumac, ‘Goldmound’ spirea, ‘Bloomerang® purple lilac, ‘Runyan’ yew and ‘Emerald’ white-cedar. Following standard production practices, ten liners for each species grown in 10 cm wide (4 in wide) containers, or 12.5 cm diameter (5 in diameter) round containers for lilac, per CRF rate (n = 10) were planted into approximately 6.4 L (1.69 gal) of growing substrate in #2 black plastic containers (22 cm diameter by 21.5 cm height; 8.8 in diameter by 8.6 in height) on May 30, 2013. This container size was selected based on industry demand, since the highest demand is for #2 containers for ornamental shrubs grown in Ontario. A standard growing substrate was used, consisting of 35% composted pine bark, 30% aged bark, 10% bark nuggets, 15% compost and 10% sphagnum peat moss [Gro-Bark (Ontario) Ltd., Milton, ON]. At planting, the substrate pH was 6.0 and electrical conductivity (EC) was 1.18 mS·cm–1. Nutrient levels in the growing substrate were as follows: 0.29 mmol·L–1 (1.10 mmol·gal–1) nitrate-N (NO3–N), 0.08 mmol·L–1 (0.30 mmol·gal–1) ammonium-N (NH4+), 0.32 mmol·L–1 (1.21 mmol·gal–1) phosphorus (P), 6.52 mmol·L–1 (24.68 mmol·gal–1) potassium (K), 1.45 mmol·L–1 (5.49 mmol·gal–1) magnesium (Mg), and 1.60 mmol·L–1 (6.06 mmol·gal–1) calcium (Ca), as analyzed using a saturated paste extraction method (SGS Agri-Food Laboratories, Guelph, ON). Polygon® 1904–10 + Minors (i.e., 19.0N–1.7P–8.3K, 8–9 month release) and Polygon® 15–06–11 + Micros (i.e., 15.0N–2.6P–9.1K, 10–12 month release) (Agrium Advanced Technologies Inc., Brampton, ON) were applied to deciduous (fragrant sumac, spirea and lilac) and evergreen species (boxwood, yew and white-cedar), respectively. CRF was incorporated into the total volume of growing substrate for each container by hand at 0.15, 0.45, 0.75, 1.05, 1.35 or 1.65 kg·m–1 (0.25, 0.76, 1.26, 1.77, 2.28 or 2.78 lb·yd–3) N. Fertilizer rates were selected based on recommendations made by Agrium Advanced Technologies Inc. and previous studies (Agro 2014, Agro and Zheng 2014, Alam et al. 2009). Irrigation water pH ranged from 8.2 to 8.5 in May and August 2013, respectively, while EC was the lowest in May and highest in June 2013 (0.5 and 0.6 mS·cm–1, respectively), and was sampled from an on-site catchment pond. Plants were weeded as needed and production practices and overhead sprinkler irrigation scheduling both followed standard production practices for the nursery. However, no plants were pruned during the study. Monthly mean minimum and maximum air temperature ranges in May, June, July, August and September 2013 were 7.3 to 23.0, 10.8 to 21.6, 16.5 to 29.3, 12.7 to 26.6 and 7.5 to 21.8°C (45.1 to 73.4, 51.4 to 70.9, 61.7 to 84.7, 54.9 to 79.9 and 45.5 to 71.2°F), respectively (Environment Canada 2013).

Experimental design. Shrub species were placed outside on a black weed barrier fabric in a completely randomized design, arranged by species. Ten replications of each CRF rate treatment were randomly arranged with equal spacing among containers within species sections, to reduce shading. Individuals within species sections were re-randomized monthly to reduce location error. The production area was bordered with at least one row of plants to reduce perimeter effects.

Measurements. Plant growth was evaluated by measuring plant height and width, in two perpendicular directions, for five plants per species per CRF rate treatment one week after transplanting (May 30, 2013) and monthly thereafter until the end of the study (September 11, 2013). Above-ground plant growth index was calculated as ((height × width1 × width2) / 300), as outlined by Rutger (1992). Growing substrate pH and EC were measured for five plants per species per CRF rate treatment one week after transplanting and monthly thereafter until September 2013 using the pour-through method (Wright 1986). On August 12 and September 11, 2013, leaf chlorophyll content index (CCI) was measured for five plants per species per CRF rate treatment, before cool fall air temperatures and leaf senescence began. CCI was measured for three representative mid-canopy leaves for short-stemmed species (spirea and lilac); while three of the last fully-expanded upper leaves and three lower leaves were measured for the tall-stemmed fragrant sumac plants, using an Opti-Sciences CCM-200 meter (Opti-Sciences, Inc., Hudson, NH). Leaves of the evergreen species were too small for CCI measurements. On September 11, 2013, five plants per species per CRF rate were ranked from 1 (worst) to 5 (best) for overall appearance among all rates, relative to plants of the same species. Overall appearance ranking was evaluated visually based on foliage density, plant symmetry, leaf size and color, number of stems, and amount of branching. In addition, nursery grower and industry representatives

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identified marketable-sized plants for each species in September 2013. Total leaf area per plant was measured for five plants per species per CRF rate treatment using a LI-COR LI-3100 leaf area meter (LI-COR, Lincoln, NE) at the end of the study. Stems and leaves from individual plants were dried at 70 °C (158 °F) until a constant weight was achieved. Shoot dry weight was calculated from the sum of stem and leaf tissue dry weight values per plant. Dried leaves were analyzed for tissue N, P, K, Mg, and Ca concentration (% dry weight) using AOAC methods 990.03 and 985.01 (SGS Agrifood Laboratories, Guelph, ON).

Statistical analysis. All data sets were analyzed using GraphPad Prism version 5.03 software (GraphPad Software Inc., La Jolla, CA), following outlier removal. A two-way repeated measures ANOVA with a Bonferroni post-test was used to evaluate differences among CRF rates and time points for growth index, CCI, EC, and pH among CRF rates per species. Regression analyses with extra sum-of-squares F tests were used to relate growth index, plant height, leaf area, shoot dry weight, tissue nutrient concentration, overall appearance, CCI, EC, and pH to CRF rate. Pearson correlation coefficients were calculated to compare leaf dry weight with leaf tissue nutrient concentration. All data were evaluated using a significance level of P < 0.05.

Results and Discussion

Growth index. At the end of the 111 day growing season (May 23 to September 11, 2013), growth index, plant height, leaf area, and shoot dry weight values were greater at high vs. low CRF rates for fragrant sumac and spirea, and for all lilac characteristics except height (Table 1). Leaf area and shoot dry weight for white-cedar and only leaf area for yew were greater at high vs. low CRF rates. Conversely, growth index was greater at low vs. high CRF rates for boxwood. Over time, growth index showed a quadratic or linear increase for fragrant sumac, spirea, lilac, and white-cedar grown at all CRF rates, and yew grown at the majority of CRF rates (Fig. 1; Table 2). Change in boxwood growth index over time was not significant at any CRF rate, likely due in part to the determinate growth pattern of boxwood. Although growth response to CRF rate in the current study was not the expected ‘classic curve’ (Chen et al. 2001), we observed

| Fertilizer rate (kg·m⁻³ N) | Growth index | Height (cm) | Leaf area (cm²) | Shoot dry weight (g) |
|----------------------------|--------------|-------------|-----------------|----------------------|

| ‘Gro-Low’ fragrant sumac      |
|-------------------------------|
| 0.15                          |
| 0.45                          |
| 0.75                          |
| 1.05                          |
| 1.35                          |
| 1.65                          |

| ‘Green Mound’ boxwood         |
|-------------------------------|
| 0.15                          |
| 0.45                          |
| 0.75                          |
| 1.05                          |
| 1.35                          |
| 1.65                          |

| ‘Goldmound’ spirea            |
|-------------------------------|
| 0.15                          |
| 0.45                          |
| 0.75                          |
| 1.05                          |
| 1.35                          |
| 1.65                          |

| ‘Runyan’ yew                  |
|-------------------------------|
| 0.15                          |
| 0.45                          |
| 0.75                          |
| 1.05                          |
| 1.35                          |
| 1.65                          |

| ‘Emerald’ white-cedar         |
|-------------------------------|
| 0.15                          |
| 0.45                          |
| 0.75                          |
| 1.05                          |
| 1.35                          |
| 1.65                          |

| Significance                  |
|-------------------------------|
| Linear                        |
| Quadratic                     |
| Regression response to fertilizer rate is nonsignificant (NS) at P < 0.05 or (*, **, ***) significant at P < 0.05, 0.001 and 0.0001, respectively.

0.25, 0.76, 1.26, 1.77, 2.28 and 2.78 lb·yd⁻³ N. Polygon® 19–04–10, 8–9 month was applied to fragrant sumac, spirea, and lilac, while Polygon® 15–06–11, 10–12 month was applied to boxwood, yew, and white-cedar.

3Regression response to fertilizer rate is nonsignificant (NS) at P < 0.05 or (*, **, ***).
a distinct CRF-influenced growth response for some species (e.g., fragrant sumac), and a minimal response for others (e.g., boxwood).

**Root-zone EC and pH.** Nursery crop growth and above-ground attributes (e.g., tissue nutrient concentration, visual observations and CCI values) are influenced by growing substrate EC and pH values. From transplanting to day 56 (July 8, 2013), the substrate EC for the majority of CRF rates was within the recommended range for plant growth (i.e., 0.6 to 2.0 mS·cm⁻¹; Wright 1986) for both CRF types in the current study (Table 3). In addition, for most crops grown with high rates of the 10–12 month CRF, substrate EC was within the recommended range for plant growth throughout the study. However, for low rates of the 10–12 month CRF and for all rates of the 8–9 month CRF, from day 82 to the end of the trial (i.e., August 13 to September 11, 2013), substrate EC was below this recommended range, and similar to the average irrigation water EC (i.e., 0.55 ± 0.03 mS·cm⁻¹). For both CRF types, no significant change in substrate EC occurred from August to September 2013, suggesting no additional nutrient release from the CRF during this time. Air temperatures, ranged from 7.5 to 21.8 °C (45.5 to 71.2 °F) in September 2013 and, therefore, would not have hindered nutrient release. These data suggest that during the 3.5 months of the current study, the majority of nutrients had been released from the 8–9 month CRF at all rates, as well as the 10–12 month CRF at low rates, despite different release durations. Since CRF nutrient release durations are based on observations in controlled laboratory conditions, temperatures and moisture conditions outdoors in the nursery may have caused faster nutrient release than the expected 8–9 or 10–12 months. An additional CRF application would have been needed if the nursery crops remained in production for a second year. Thus, applying CRF during the first year of production may not eliminate the need for an additional CRF application the following year, even following application of some CRFs which are expected to be long-duration.

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**Fig. 1.** Index of above-ground growth measured over time for six nursery crops grown in #2 containers following transplant and fertilization on May 23, 2013, with six rates (0.15, 0.45, 0.75, 1.05, 1.35 kg·m⁻³ N; 0.25, 0.76, 1.26, 1.77, 2.28 and 2.78 lb·yd⁻³ N) of either Polyon® 19–04–10, 8–9 month (‘Gro-Low’ fragrant sumac, ‘Goldmound’ spirea, ‘Bloomerang® purple lilac) or 15–06–11, 10–12 month (‘Green Mound’ boxwood, ‘Runyan’ yew, ‘Emerald’ white-cedar) controlled-release fertilizer. Data are means ± SE (n = 5). Where effect of time was significant (P < 0.05), lines indicate the calculated regression; otherwise no lines are shown.
Table 2. Regression equation and $R^2$ of the growth index response to time (days after fertilization on May 23, 2013) for six container-grown nursery crops grown until September 11, 2013 (111 days) following application of a controlled-release fertilizer.

| Fertilizer rate (kg m$^{-3}$ N) | Regression equation | $R^2$ |
|-------------------------------|---------------------|------|
| **'Gro-Low' fragrant sumac** |
| 0.15 | $Y = -8.7 + 0.79X$ | 0.82 |
| 0.45 | $Y = -37.4 + 3.0X$ | 0.63 |
| 0.75 | $Y = -52.7 + 3.9X$ | 0.74 |
| 1.05 | $Y = -91.2 + 5.5X$ | 0.49 |
| 1.35 | $Y = -23.1 + 0.84X + 0.06X^2$ | 0.81 |
| 1.65 | $Y = -22.7 + 0.62X + 0.07X^2$ | 0.91 |
| **'Goldmound' spirea** |
| 0.15 | $Y = 8.9 + 0.14X$ | 0.22 |
| 0.45 | $Y = 5.6 + 0.40X$ | 0.83 |
| 0.75 | $Y = -0.78 + 0.64X$ | 0.75 |
| 1.05 | $Y = -1.3 + 0.73X$ | 0.82 |
| 1.35 | $Y = -0.64 + 0.55X$ | 0.73 |
| 1.65 | $Y = -5.3 + 0.75X$ | 0.86 |
| **'Bloomerang'® purple lilac** |
| 0.15 | $Y = 68.4 + 1.2X$ | 0.30 |
| 0.45 | $Y = 76.9 + 1.6X$ | 0.41 |
| 0.75 | $Y = -32.8 + 8.9X - 0.05X^2$ | 0.52 |
| 1.05 | $Y = 25.9 + 6.2X$ | 0.65 |
| 1.35 | $Y = 51.6 + 5.5X$ | 0.49 |
| 1.65 | $Y = 60.3 + 5.3X$ | 0.65 |
| **'Runyan' yew** |
| 0.75 | $Y = 12.5 + 0.06X$ | 0.23 |
| 1.05 | $Y = 17.2 + 0.21X$ | 0.35 |
| 1.35 | $Y = 11.8 + 0.12X$ | 0.27 |
| 1.65 | $Y = 10.7 + 0.09X$ | 0.50 |
| **'Emerald' white-cedar** |
| 0.15 | $Y = 31.3 + 0.22X$ | 0.62 |
| 0.45 | $Y = 46.1 + 0.30X$ | 0.38 |
| 0.75 | $Y = 28.6 + 0.42X$ | 0.47 |
| 1.05 | $Y = 37.3 + 0.34X$ | 0.36 |
| 1.35 | $Y = 17.9 + 0.50X$ | 0.77 |
| 1.65 | $Y = 18.0 + 0.45X$ | 0.79 |

$0.25, 0.76, 1.26, 1.77, 2.28$ and $2.78$ lb·yd$^{-3}$ N. Polyon® 19–04–10, 8–9 month was applied to fragrant sumac, spirea, and lilac, while Polyon® 15–06–11, 10–12 month was applied to boxwood, yew, and white-cedar.

Regression equations and $R^2$ values indicated for CRF rates when the effect of time was significant ($P < 0.05$). Y, growth index; X, days after fertilization.

Chlorophyll content index and overall appearance. Portable chlorophyll meters have been used in tissue nutrient disorder identification, especially to identify N deficiencies, for numerous woody plant species (Chang and Robison 2003, van den Berg and Perkins 2004). Nursery crop production may also benefit from using portable chlorophyll meters and considering CCI values, in addition to visual evaluations and tissue nutrient analysis, to identify nutrient disorders. For example, Minotta and Pinzauti (1996) found higher leaf chlorophyll in tree seedlings grown in soils with high vs. low nutrient concentration. In September 2013 in the current study, mid-canopy spirea and lower leaf fragrant sumac CCI values were greater at high vs. low CRF rates (Table 4) suggesting a foliar N deficiency at low (0.15 and 0.45 kg m$^{-3}$ N; 0.25 and 0.76 lb·yd$^{-3}$ N) CRF rates (Wang et al. 2012). Specifically, leaf CCI values ≤ 7.6 and ≤ 17.8 corresponded to visual nutrient deficiencies for spirea and fragrant sumac, respectively. Additionally, in September 2013, mid-canopy lilac leaf CCI values were greater at high vs. low (0.15 kg m$^{-3}$ N; 0.25 lb·yd$^{-3}$ N) CRF rates, suggesting N deficiencies corresponded to visual nutrient deficiencies at CCI values ≥ 16.0 for lilac. Therefore, to prevent nutrient deficiency symptoms the desired CCI values would be > 7.6, 17.8, and 16.0 for spirea mid-canopy leaves, fragrant sumac lower leaves, and lilac mid-canopy leaves, respectively.

The CRF rate influenced overall appearance of all nursery crops at harvest. For all species, high CRF rates produced the best overall appearance (Fig. 2). Increased flowering was observed for spirea and lilac at increasing CRF rates, which contributed to the overall appearance of these species (data not shown). Overall appearance did not differ for any species grown with 1.35 vs. 1.65 kg·m$^{-3}$ N (2.28 vs. 2.78 lb·yd$^{-3}$ N) and the worst overall appearance occurred at 0.15 kg·m$^{-3}$ N (0.25 lb·yd$^{-3}$ N) for fragrant sumac, lilac, and white-cedar.

**Chlorophyll content index.** Production of high-quality nursery crops involves ensuring healthy plant nutrient status and preventing nutrient disorders (i.e., deficiencies or toxicities). Leaf tissue N, K and Ca, but not P or Mg concentration was influenced by CRF rate for the majority of nursery crops (Table 5). Similarly, Oliet et al. (2004) observed no influence of P application rate on leaf (needle) concentration in *Pinus halepensis* seedlings. However, *P. halepensis* stem and root P concentrations increased with increasing application rate. Therefore, further study should identify stem, root, and leaf P concentrations in nursery crops when identifying appropriate P application rates.

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**Tissue nutrient concentration.** Production of high-quality nursery crops involves ensuring healthy plant nutrient status and preventing nutrient disorders (i.e., deficiencies or toxicities). Leaf tissue N, K and Ca, but not P or Mg concentration was influenced by CRF rate for the majority of nursery crops (Table 5). Similarly, Oliet et al. (2004) observed no influence of P application rate on leaf (needle) concentration in *Pinus halepensis* seedlings. However, *P. halepensis* stem and root P concentrations increased with increasing application rate. Therefore, further study should identify stem, root, and leaf P concentrations in nursery crops when identifying appropriate P application rates.

As a point of reference for tissue nutrient concentration levels, sufficiency ranges have been published for select nursery crop species (Bryson et al. 2014, Plank and Kissel 2006). Although the published nutrient sufficiency ranges may assist in nutrient disorder identification, other factors

(i.e., 10–12 months). Further on-farm research is needed in temperate climates to determine nutrient release rates for a variety of CRF types outdoors.

Root-zone pH influences nutrient availability, thereby affecting the response of plants to fertilization. In the current study, initial growing substrate pH for all species in May 2013 was above or near the upper limit of the ideal range for plant growth (i.e., 5.5 to 6.25; Reed 1996; Table 3). Substrate pH increased for all species at low CRF rates from May to September 2013, and remained high or above the ideal pH range throughout the study for the majority of species and CRF rates. The high substrate pH was likely due to the high irrigation water pH (i.e., ranging from 8.18 to 8.45, with an average of 8.29, from May to August 2013), which is typical of high-alkalinity water in Ontario (Zheng et al. 2011). Since some fertilizers can acidify the substrate pH during plant production (Zheng et al. 2013), the lower substrate pH observed in the current study, for high vs. low CRF rates, suggested the applied CRF influenced substrate pH levels. Despite the high substrate pH level in the current study, pH-induced nutrient disorder symptoms (e.g., interveinal leaf chlorosis) were not observed. Therefore, further research is needed to identify preferred substrate pH ranges for commonly-grown nursery crops.
(i.e., plant growth) may cause these published sufficiency ranges to be imprecise due to dilution or concentration effects (Jarrell and Beverly 1981). Therefore, compared to published sufficiency levels, tissue nutrient analysis for some species may not identify nutrient deficiencies during nursery crop production, potentially due to nutrient dilution or concentration effects. Therefore, plant growth may play a key role in diagnosing nursery crop tissue nutrient deficiencies. Using multiple approaches (e.g., nutrient deficiency concentrations and CCI in addition to visual observations) when determining nutrient disorders may be beneficial for nursery growers, especially for species like spirea for which cultivar leaf color impacted visual nutrient disorder identification. We recommend additional research to confirm nutrient deficiency ranges based on plant growth and identify leaf tissue nutrient disorder levels for many commonly-grown and newly-introduced nursery crops in the temperate climate. Overall, by using a combination of nutrient disorder identification strategies, growers can have increased confidence in diagnosing plant nutrient status, compared to relying on a single diagnostic strategy.

Yew grown at all CRF rates had some yellow and white leaves, indicating undesirable environmental conditions for this species. Although yew shoot tips were light green-yellow in August 2013 for all CRF rates, shoot tips at all CRF rates were green in September 2013, suggesting nutrient disorder or environmental stress conditions were corrected with time.

Despite low growing substrate EC values after day 56 in the current study (i.e., less than the recommended range for plant growth), some species did not exhibit nutrient deficiency symptoms, or if EC recommendations should be adjusted for some nursery crops.

**Optimal fertilization rates.** The differences among CRF rates in growth and appearance contributed to identifying the optimal CRF rate for each species in the current study. Specifically, to determine the optimal CRF rate or range for the six container-grown shrubs, we defined the highest

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### Table 3. Influence of fertilizer rate on potted mix EC and pH over time for six container-grown nursery crops following application of a controlled-release fertilizer.

| Fertilizer rate (kg·m–3 N) | EC (mS·cm–1) | pH | Significance |
|----------------------------|--------------|----|--------------|
|                            | May July Sept. | May July Sept. | Linear Quadratic |
| **'Gro-Low' fragrant sumac** | | | |
| 0.15 | 0.70 0.53 0.37 | 6.63 7.08 7.19 | NS NS |
| 0.45 | 0.68 0.53 0.29 | 6.69 6.89 7.11 | NS NS |
| 0.75 | 0.81 0.52 0.32 | 6.64 6.81 7.02 | NS NS |
| 1.05 | 0.96 0.67 0.31 | 6.66 6.70 6.93 | NS NS |
| 1.35 | 1.54 0.56 0.37 | 6.51 6.66 6.83 | NS NS |
| 1.65 | 1.54 0.88 0.42 | 6.60 6.42 6.83 | NS NS |

| **'Goldmound' spirea** | | | |
|------------------------|--------------|----|--------------|
| 0.15 | 0.84 0.37 0.31 | 6.61 6.99 7.14 | NS NS |
| 0.45 | 0.98 0.43 0.32 | 6.54 6.86 7.09 | NS NS |
| 0.75 | 1.15 0.57 0.37 | 6.56 6.89 7.00 | NS NS |
| 1.05 | 1.52 0.65 0.32 | 6.55 6.72 6.91 | NS NS |
| 1.35 | 2.17 0.91 0.39 | 6.48 6.46 6.68 | NS NS |
| 1.65 | 1.88 1.16 0.36 | 6.54 6.57 6.65 | NS NS |

| **'Bloomerang'® purple lilac** | | | |
|--------------------------------|--------------|----|--------------|
| 0.15 | 1.16 0.40 0.37 | 6.57 7.00 7.12 | NS NS |
| 0.45 | 1.25 0.53 0.42 | 6.65 6.97 7.11 | NS NS |
| 0.75 | 1.45 0.54 0.42 | 6.61 6.87 6.95 | NS NS |
| 1.05 | 1.63 0.82 0.39 | 6.58 6.82 6.94 | NS NS |
| 1.35 | 1.80 0.85 0.35 | 6.53 6.35 6.74 | NS NS |
| 1.65 | 1.88 1.03 0.40 | 6.45 6.42 6.67 | NS NS |

| **'Green Mound' boxwood** | | | |
|---------------------------|--------------|----|--------------|
| 0.15 | 0.70 0.56 0.36 | 6.63 6.96 7.15 | NS NS |
| 0.45 | 1.01 0.59 0.45 | 6.71 6.79 6.91 | NS NS |
| 0.75 | 1.12 0.78 0.54 | 6.60 6.63 6.77 | NS NS |
| 1.05 | 1.00 0.80 0.60 | 6.66 6.75 6.80 | NS NS |
| 1.35 | 1.28 0.91 0.69 | 6.63 6.58 6.69 | NS NS |
| 1.65 | 1.10 0.98 0.67 | 6.61 6.44 6.19 | NS NS |

| **'Runyan' yew** | | | |
|-------------------|--------------|----|--------------|
| 0.15 | 1.04 0.50 0.32 | 6.55 7.41 7.25 | NS NS |
| 0.45 | 1.00 0.63 0.49 | 6.54 6.95 6.93 | NS NS |
| 0.75 | 1.11 0.79 0.62 | 6.61 6.80 6.82 | NS NS |
| 1.05 | 1.59 0.94 0.53 | 6.57 6.69 6.87 | NS NS |
| 1.35 | 1.15 0.94 0.74 | 6.59 6.59 6.59 | NS NS |
| 1.65 | 1.38 1.27 0.74 | 6.62 6.54 6.56 | NS NS |

| **'Emerald' white-cedar** | | | |
|---------------------------|--------------|----|--------------|
| 0.15 | 0.82 0.42 0.38 | 6.52 7.39 7.14 | NS NS |
| 0.45 | 1.11 0.42 0.37 | 6.49 7.15 7.16 | NS NS |
| 0.75 | 1.28 0.82 0.46 | 6.58 6.56 6.85 | NS NS |
| 1.05 | 1.31 0.49 0.44 | 6.54 6.89 7.01 | NS NS |
| 1.35 | 1.49 0.84 0.64 | 6.58 6.61 6.70 | NS NS |
| 1.65 | 1.79 0.54 0.67 | 6.65 6.75 6.76 | NS NS |

*aRegression response to fertilizer rate is nonsignificant (NS) at P < 0.05 or (*, **, ****) significant at P < 0.05, 0.001 and 0.0001, respectively.

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CRF rate in the optimal range to be the rate above which no increase in growth characteristics, i.e., growth index, shoot dry weight, leaf area and overall appearance, or no nutrient disorder symptoms were observed. The lowest CRF rate in the optimal range was the rate below which plants were showing nutrient disorder symptoms. If no difference was identified between the highest and lowest optimal CRF application rates, a single optimal CRF rate rather than an optimal range was specified. Comparing mean values, no growth characteristic increased for fragrant sumac above 1.35 kg·m⁻³ N (2.28 lb·yd⁻³ N), while nutrient disorder symptoms were observed below 0.75 kg·m⁻³ N (1.26 lb·yd⁻³ N), leaf area decreased for both lilac and yew, the overall appearance and shoot dry weight decreased for lilac and yew, respectively, and no growth characteristic increased above this rate for these species, when means were compared. For both boxwood and white-cedar, mean overall appearance did not increase above 0.45 kg·m⁻³ N (0.76 lb·yd⁻³ N), while leaves of boxwood were lighter green and white-cedar leaf area and shoot dry weight values were lower at 0.15 vs. 0.45 kg·m⁻³ N (0.25 vs. 0.76 lb·yd⁻³ N). Given these results and the optimal CRF rate and range criteria, the species-specific optimal CRF ranges were 0.75 to 1.35 kg·m⁻³ N (1.26 to 2.28 lb·yd⁻³ N) for fragrant sumac and 0.75 to 1.05 kg·m⁻³ N (1.26 to 1.77 lb·yd⁻³ N) for spirea, while the optimal CRF rates were 1.05 kg·m⁻³ N (1.77 lb·yd⁻³ N) for lilac and yew and 0.45 kg·m⁻³ N (0.76 lb·yd⁻³ N) for white-cedar.

Table 4. Influence of fertilizer rate on chlorophyll content index on upper, lower, or mid-canopy leaves of three nursery crops following application of a controlled-release fertilizer.

| Fertilizer rate (kg·m⁻³ N) | Leaf chlorophyll content index |
|-----------------------------|--------------------------------|
|                             | August 12, 2013 | September 11, 2013 |
| 'Gro-Low' fragrant sumac, upper leaves |
| 0.15                        | 15.3            | 22.3            |
| 0.45                        | 17.6            | 24.2            |
| 0.75                        | 20.0            | 26.3            |
| 1.05                        | 19.1            | 25.4            |
| 1.35                        | 19.0            | 27.2            |
| 1.65                        | 18.5            | 26.4            |
| Regression equation         | Y = –4.78 + 10.45X + 13.96X² | Y = 22.84 + 2.74X |
| Significance                | **              | **              |
| 'Gro-Low' fragrant sumac, lower leaves |
| 0.15                        | 13.3            | 13.0            |
| 0.45                        | 20.4            | 17.8            |
| 0.75                        | 21.3            | 19.0            |
| 1.05                        | 26.4            | 26.6            |
| 1.35                        | 27.6            | 35.0            |
| 1.65                        | 31.4            | 41.4            |
| Regression equation         | Y = 13.35 + 11.15X | Y = 7.33 + 5.96X + 12.23X² |
| Significance                | ***             | *               |
| 'Goldmound' spirea, mid-canopy leaves |
| 0.15                        | 6.6             | 6.8             |
| 0.45                        | 7.5             | 7.6             |
| 0.75                        | 9.0             | 8.5             |
| 1.05                        | 9.6             | 12.7            |
| 1.35                        | 8.7             | 10.8            |
| 1.65                        | 9.0             | 14.2            |
| Regression equation         | Y = –2.50 + 6.01X + 5.67X² | Y = 5.78 + 4.80X |
| Significance                | *               | ***             |
| 'Bloomerang'® purple lilac, mid-canopy leaves |
| 0.15                        | 28.5            | 16.0            |
| 0.45                        | 47.9            | 44.1            |
| 0.75                        | 57.2            | 44.9            |
| 1.05                        | 50.7            | 55.4            |
| 1.35                        | 52.0            | 63.7            |
| 1.65                        | 47.8            | 70.0            |
| Regression equation         | Y = –29.88 + 63.51X + 22.22X² | Y = –15.60 + 60.40X + 11.39X² |
| Significance                | ***             | *               |

*0.25, 0.76, 1.26, 1.77, 2.28 and 2.78 lb·yd⁻³ N. Polyon® 19–04–10, 8–9 month was applied to fragrant sumac, spirea, and lilac. *Regression response to fertilizer rate is significant at P < 0.05, 0.001 or 0.0001, respectively.
During production. Nursery crops based on CRF rate and growing environment were assessed for individual crop preferences, and evaluate benefits of species-specific CRF rates, determine optimal species-specific CRF rates, identify optimal species-specific CRF rates, and evergreen nursery crops, the growing environment (e.g., irrigation) was the same. Thus, further research is needed in high, moderate, or low response to CRF with either one (i.e., for fragrant sumac, spirea and lilac) or multiple (i.e., for boxwood, yew and white-cedar) production seasons required for crops to reach a marketable size. In the current study, we calculated the potential CRF-influenced reduction in crop production period by extrapolating the September 2013 growth index value for the lowest CRF rate which produced the value of conducting on-farm evaluations and validate the need to identify optimal CRF rates or ranges, nutritional requirements and environmental preferences for individual nursery crop species, as indicated by previous studies on additional crops (Agro 2014, Chong et al. 2014, Saska and Kuzovkina 2014, Ruter 1992, Worrall et al. 1987). Further on-farm research is needed with additional crops, in collaboration with nursery growers, to identify optimal species-specific CRF rates, determine individual crop preferences, and evaluate benefits from grouping nursery crops based on CRF rate and growing environment during production.

Fertilizer-influenced production period. An important benefit of applying an appropriate CRF rate during nursery crop production is the potential to save production time (Clark and Zheng 2014). Species-specific growth resulted in high, moderate, or low response to CRF with either one (i.e., for fragrant sumac, spirea and lilac) or multiple (i.e., for boxwood, yew and white-cedar) production seasons required for crops to reach a marketable size. In the current study, we calculated the potential CRF-influenced reduction in crop production period by extrapolating the September 2013 growth index value for the lowest CRF rate which produced marketable-sized plants, with the regression calculation of growth index value for the lowest CRF rate which produced the value of conducting on-farm evaluations and validate the need to identify optimal CRF rates or ranges, nutritional requirements and environmental preferences for individual nursery crop species, as indicated by previous studies on additional crops (Agro 2014, Chong et al. 2014, Saska and Kuzovkina 2014, Ruter 1992, Worrall et al. 1987). Further on-farm research is needed with additional crops, in collaboration with nursery growers, to identify optimal species-specific CRF rates, determine individual crop preferences, and evaluate benefits from grouping nursery crops based on CRF rate and growing environment during production.

### Table 5. Influence of fertilizer rate on tissue nutrient concentrations evaluated in September 2013 for six container-grown nursery crops following application of a controlled-release fertilizer.

| Fertilizer rate (kg·m⁻³ N) | % N | % P | % K | % Mg | % Ca |
|---------------------------|-----|-----|-----|------|------|
| 'Gro-Low' fragrant sumac |     |     |     |      |      |
| 0.15                      |     |     |     |      |      |
| 0.45                      |     |     |     |      |      |
| 0.75                      |     |     |     |      |      |
| 1.05                      |     |     |     |      |      |
| 1.35                      |     |     |     |      |      |
| 1.65                      |     |     |     |      |      |
| 'Goldmound' spirea         |     |     |     |      |      |
| 0.15                      |     |     |     |      |      |
| 0.45                      |     |     |     |      |      |
| 0.75                      |     |     |     |      |      |
| 1.05                      |     |     |     |      |      |
| 1.35                      |     |     |     |      |      |
| 1.65                      |     |     |     |      |      |
| 'Bloomerang'® purple lilac |     |     |     |      |      |
| 0.15                      |     |     |     |      |      |
| 0.45                      |     |     |     |      |      |
| 0.75                      |     |     |     |      |      |
| 1.05                      |     |     |     |      |      |
| 1.35                      |     |     |     |      |      |
| 1.65                      |     |     |     |      |      |
| 'Green Mound' boxwood     |     |     |     |      |      |
| 0.15                      |     |     |     |      |      |
| 0.45                      |     |     |     |      |      |
| 0.75                      |     |     |     |      |      |
| 1.05                      |     |     |     |      |      |
| 1.35                      |     |     |     |      |      |
| 1.65                      |     |     |     |      |      |
| 'Emerald' white-cedar     |     |     |     |      |      |
| 0.15                      |     |     |     |      |      |
| 0.45                      |     |     |     |      |      |
| 0.75                      |     |     |     |      |      |
| 1.05                      |     |     |     |      |      |
| 1.35                      |     |     |     |      |      |
| 1.65                      |     |     |     |      |      |

0.25, 0.76, 1.26, 1.77, 2.28 and 2.78 lb·yd⁻³ N. Polyon® 19–04–10, 8–9 month was applied to fragrant sumac, spirea, and lilac, while Polyon® 15–06–11, 10–12 month was applied to boxwood, yew, and white-cedar.

Regression response to fertilizer rate is nonsignificant (NS) at or (*) significant at P < 0.05.
By implementing species-specific production preferences (e.g., CRF application rate), crop production schedules can be coordinated with industry demand (Clark and Zheng 2014, Scagel et al. 2012). For example, excess shoot growth, as seen for fragrant sumac at high CRF rates, may be eliminated by adjusting the CRF rate to meet production and shipping schedules. Once planted in the landscape, root growth will be favored over shoot growth, thus preventing excess shoot growth in the nursery and avoiding the nursery-incurred labor costs of pruning (Burdett et al. 1984). Therefore, identifying optimal species-specific fertilizer rates may save production costs (e.g., irrigation water, fertilizer and pruning costs) for species such as fragrant sumac. Further research is needed to clearly identify species-specific differences in production schedules for additional shrubs grown at a range of CRF rates in the temperate climate.

Despite the current practice of applying CRF to nursery crops based on expected crop needs or estimations, we determined species-specific optimal CRF application rates or ranges for individual nursery crops. Overall, the results of the current study indicate nursery crops respond in a species-specific manner to CRF rate when grown in a temperate climate. In addition, we determined CRF may be used as a nursery crop management tool to regulate plant growth, time of production, nutrient disorders and the root-zone environment. By identifying and applying optimal species-specific fertilizer rates, nursery crop production efficiency can be maximized and CRF application can be optimized. We observed greater growth index at high vs. low CRF rates for fragrant sumac, spirea, lilac and yew, and greater leaf area and shoot dry weight values at high vs. low CRF rates for all species except boxwood. The optimal species-specific CRF application rates were 1.05 kg·m⁻³ N (1.77 lb·yd⁻³ N) for lilac and yew and 0.45 kg·m⁻³ N (0.76 lb·yd⁻³ N) for white-cedar and boxwood, while the optimal CRF ranges were 0.75 to 1.35 kg·m⁻³ N (1.26 to 2.28 lb·yd⁻³ N) for fragrant sumac, and 0.75 to 1.05 kg·m⁻³ N (1.26 to 1.77 lb·yd⁻³ N) for boxwood.

Fig. 2. Overall appearance measured in September 2013 for six nursery crops grown in #2 containers following transplant and fertilization on May 23, 2013, with six rates (0.15, 0.45, 0.75, 1.05, 1.35 kg·m⁻³ N; 0.25, 0.76, 1.26, 1.77, 2.28 and 2.78 lb·yd⁻³ N) of either Polyon® 19–04–10, 8–9 month (‘Gro-Low’ fragrant sumac, ‘Goldmound’ spirea, ‘Bloomerang® purple lilac) or 15–06–11, 10–12 month (‘Green Mound’ boxwood, ‘Runyan’ yew, ‘Emerald’ white-cedar) controlled-release fertilizer. Regression equations and lines of best fit are presented when significant, data are means ± SE (n = 5).
(1.26 1.77 lb·yd–3 N) for spirea. Although no boxwood, yew or white-cedar plants reached marketable size during the first year of growth, CRF application at the optimal rate was sufficient for growth during the first year of production. Building upon the current study and previous work, additional research is needed to determine the response of additional temperate climate nursery crops to CRF rate.

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