Fertilization Methods for Organic and Conventional Potted Blueberry Plants

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Abstract. This study determined optimal fertilization for each of three production methods (i.e., two organic and one conventional) of potted *Vaccinium corymbosum* ‘Duke’ northern highbush blueberry plants. The three production methods were as follows: 1) organic granular [(OG) organic coir substrate fertilized with Bio-Fert General Purpose + bloodmeal applied at 4.4, 7.3, 10.2, 13.1, and 16.0 g/pot nitrogen (N)], 2) organic liquid [(OL) organic coir substrate fertilized with Bio-Fert General-Purpose Liquid + calcium oxide (CaO) applied at 12.2, 14.7, 18.6, 25.3, and 39.5 mmol·L⁻¹ N], and 3) conventional (C; pine bark, coir, and peat substrate fertilized with Osmocote Plus 15N–3.9P–9.9K, 5- to 6-month-duration controlled-release fertilizer applied at 4.4, 7.3, 10.2, 13.1, and 16.0 g/pot N). Blueberry plants were grown in #5 black, squat nursery containers outdoors in the Niagara peninsula, ON, Canada for two (2015–16) growing seasons. Both of the organic and the conventional production systems produced healthy blueberry plants when fertilizer was applied appropriately. With fertilizer application at 4.4 and 7.3 g/pot N for C, 12.2 and 14.7 mmol·L⁻¹ N for the OL, and 8.50 to 13.95 g/pot N for the OG treatments, healthy plant growth was observed in combination with low nutrient leaching. High fertilizer rates resulted in excessive root zone electrical conductivity (EC), poor plant growth, and interveinal chlorosis, which affected fruit production negatively. For C and OL treatments, fertilization at rates of 4.4, 7.3 and 10.2 g/pot N, and 12.2, 14.7, and 18.6 mmol·L⁻¹ N, respectively, produced the greatest total fresh weight of fruit. For OG, a large total fruit fresh weight was produced by all plants with no difference among fertilizer rates. This study suggests optimal fertilizer rates from 4.4 to 7.3 g/pot N for C, 12.2 to 14.7 mmol·L⁻¹ N for the OL treatment, and from 8.50 to 13.95 g/pot N for the OG treatment can be applied based on the methods described in this study during potted blueberry production in nurseries and home gardens.

Blueberry production is currently of great interest as a result of the known health benefits of the fruit. Highbush blueberry hectareage has been increasing steadily, with the 2010 hectareage totaling 9100, 46,300, and 77,300 ha in Canada, North America, and worldwide, respectively (Brazelton, 2011). The increase in plantedighbush blueberry hectareage requires healthy nursery stock,

some of which is produced in containers. In addition to potted nursery stock for commercial field production, potted blueberry plants are also in demand by consumers for home gardens. Recent interest in urban agriculture and the local food movement has increased consumer appeal for growing edible crops, especially using organic methods; however, blueberry production is challenging because of specific soil pH requirements [i.e., pH 4.2–5.5 (Puls, 1999)]. For home gardeners, in-ground cultivation of blueberry plants is often not possible given these soil requirements; therefore, containerized blueberry production is a promising alternative for home gardeners to reap the health benefits of blueberry fruit grown in their own backyard.

Despite the detailed recommendations available for field production of blueberries and the need for similar recommendations for container production, very few scientific studies have been conducted on the production of northernighbush blueberry plants in containers (Heiberg and Lunde, 2006; Miller et al., 2006; Smolarz, 1985). In addition, limited research has been conducted on the response of northernighbush blueberry

plants to organic growing substrates and fertilizers (Miller et al., 2006; Strik et al., 2017). Some successful growing substrates for potted blueberries have included such components as coir, perlite, turf, peat, bark, wood fiber, sphagnum moss, and sand (Heiberg and Lunde, 2006; Hortidaily, 2015; Kingston et al., 2017; Miller et al., 2006; Smolarz, 1985); however, an industry-standard growing substrate for containerized blueberry production has not been identified. An appropriate growing substrate for containerized blueberry production must ensure appropriate physical properties and drainage because of the susceptibility of fine blueberry roots to root rot in poorly drained soils (de Silva et al., 1999). Physical properties for a typical nursery growing substrate include a total porosity of 50% to 85% (Agriculture and Agri-Food Canada, 2003), with appropriate levels for potted blueberries at the high end of this range [e.g., 76% to 86% (Kingston et al., 2017)]. In addition, appropriate chemical properties of the growing substrate need to be maintained during containerized blueberry production, including pH (4.2–5.5), EC (<2.0 mS·cm⁻¹), and nutrient concentrations (Kingston et al., 2017; Machado et al., 2014; Puls, 1999; Retamales and Hancock, 2012). Despite the great influence of fertilization strategies on the root-zone environment, limited research has evaluated nutrient management strategies using conventional and organic fertilizers for containerized northernighbush blueberry production (Miller et al., 2006; Smolarz, 1985). Therefore, further research is needed to develop nutrient management strategies for potted blueberry plant production in commercial nurseries and also for home gardeners to grow and maintain healthy, high-yielding potted blueberry plants.

In addition, current nursery production of blueberry plants is most commonly in a #1 or #2 nursery container size, using conventional growing substrates and fertilizers. However, to reach additional markets, especially consumers favoring long-term organic container production of blueberries, nursery production practices can be adapted to supply a complementary product. To ensure low-maintenance solutions for consumers, finishing nursery-grown blueberry plants in a larger container (i.e., #5 vs. #1 or #2), in combination with organic production, will eliminate the inconvenience of repotting for consumers, at least for the first year. This large, organically grown blueberry plant has the potential to be a value-added product for nursery growers. Therefore, this study aimed to develop fertilization methods for organic and conventional #5 potted northernighbush blueberry plants. Specifically, the objective of this study was to determine the optimal fertilization rates for each of following three methods for #5 potted *Vaccinium corymbosum* ‘Duke’ production: organic substrate with organic granular (OG) fertilizer, organic substrate with organic liquid (OL) fertilizer, and conventional substrate with controlled-release conventional (C) fertilizer.

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Materials and Methods

Plant material and growing substrates.

One-year-old northern highbush blueberry plants (*Vaccinium corymbosum* L. 'Duke'; Willowbrook Nurseries, Fenwick, ON, Canada) grown in a #1 nursery container had the roots washed to remove all growing substrate before planting bare root into a #5 black, squat nursery container (top diameter, 31.5 cm; height, 23.0 cm). Immediately before planting on 30 June 2015, growing substrates were moistened with municipal-sourced tap water (pH, 7.78; EC, 0.2 mS·cm⁻¹; bicarbonate alkalinity, 0.1 mg·L⁻¹). Containers were filled with 14.5 L of either a conventional or organic growing substrate, adjusted to consistent compactness and depth (i.e., 2 cm below the container rim). The conventional growing substrate, consisting of composted pine bark, coir, and peat was mixed by Gro-Bark (Ontario) Ltd. (Milton, ON). The organic substrate was 100% coir supplied by a local company (Milleniumsoils Coir, a division of VGROVE Inc., St. Catharines, ON). At planting, the root-zone pH and EC values were 4.8 and 1.05 mS·cm⁻¹ for the conventional, and 5.7 and 2.5 mS·cm⁻¹ for the organic growing substrates, respectively, as analyzed from leachate obtained using the pour-through procedure (Wright, 1986). Before fertilizer application, plant-available nutrient levels in the growing substrate for the conventional and organic substrates, respectively, were as follows: <0.04 and 0.43 mmol·L⁻¹ nitrate (NO₃), <0.04 and 0.04 mmol·L⁻¹ ammonium (NH₄), 0.12 and 4.46 mmol·L⁻¹ phosphorus (P), 3.50 and 10.65 mmol·L⁻¹ potassium (K), 1.36 and 0.15 mmol·L⁻¹ magnesium (Mg), 0.88 and <0.03 mmol·L⁻¹ calcium (Ca), 2.05 and 0.29 mmol·L⁻¹ sulfate (SO₄), 1.88 and 5.10 mmol·L⁻¹ sodium (Na), and 3.50 and 15.43 mmol·L⁻¹ chloride (Cl), as analyzed using a saturated paste extraction method (SGS Agri-Food Laboratories, Guelph, ON). The conventional and organic substrates, on average, had 85.2% and 85.0% total porosity, 21.6% and 35.9% air-filled porosity, 63.6% and 49.1% water-holding capacity, and 0.19 and 0.097 g·cm⁻³ bulk density, as analyzed using the North

Carolina State University porometer method (Fonteno and Harden, 2014) at the University of Guelph (Guelph, ON).

Three fertilization methods were tested: 1) C, 2) OG fertilizer, and 3) OL fertilizer. For C, a controlled-release fertilizer [(CRF) Osmocote Plus 15N–3.9P–9.9K, 5- to 6-month duration) was applied to the growing substrate surface (top-dressed) at one of five fertilizer rates (i.e., 4.4, 7.3, 10.2, 13.1 or 16.0 g/pot N) right after transplanting on 30 June 2015, and the same rate was reapplied by top-dressing on 8 June 2016. For OG, before planting into the organic substrate on 30 June 2015, one-quarter of the total amount for one of five rates (i.e., 4.4, 7.3, 10.2, 13.1, or 16.0 g/pot N) of fertilizer [1:1.82 general-purpose 4N–1.3P–7.5K (BioFert Manufacturing Inc., Chilliwack, BC):bloodmeal 12N–0P–0K (BioFert Manufacturing Inc.)] was incorporated into the growing substrate, with the remainder of the fertilizer top-dressed in two equal applications on 31 July and 21 Aug. 2015. An additional OG top-dressed application at the same rate was done on 8 June 2016. No fertilizer was applied to the OL fertilizer method at planting, but at each watering event thereafter, after a 1-week establishment period, OL plants were fertilized with a 1:13.1 stock solution of general-purpose 2.5N–13.1P–4.2K liquid fertilizer (BioFert Manufacturing Inc.):0N–0P–0K + 6CaO (BioFert Manufacturing, Inc.) diluted at tap water:stock solution ratios of 80:1, 66:1, 52:1, 38:1, and 24:1 to produce one of five rates (i.e., 12.2, 14.7, 18.6, 25.3, and 39.5 mmol·L⁻¹ N) with target EC values between 1.0 and 3.5 mS·cm⁻¹.

After transplanting, ≈2 L tap water was added by hand to each container with a hose to settle the growing substrate around the plant roots, and all plants were watered by hand with a hose for the first week after transplanting, as needed, to reduce stress and facilitate establishment. All plants with the same fertilization method were watered when the average growing substrate moisture for the fertilization method was at or less than 20% volumetric water content (VWC), as measured by a Pro-Check hand-

held meter and a GS3 VWC/temperature/EC sensor (Hoskin Scientific Ltd., Burlington, ON). Plants grown with the C fertilization method were watered with 1.5 L tap water by hand with a hose fitted with a Gardena electronic water meter (Gardena Canada Ltd., Brampton, ON). Before 28 July 2015, OG plants were watered with 1.5 L tap water and, after this date, OG plants were watered with tap water adjusted to pH 5.0 ± 0.2 using apple cider vinegar (Bio-Ag Consultants & Distributors, Inc., Wellesley, ON). Plants grown with the OL fertilization method were watered alternating with either 1.5 L tap water or 1.5 L of the appropriate rate of OL fertilizer, measured manually for each container, which was pH-adjusted to 5.0 ± 0.2 using apple cider vinegar during the 2015 and 2016 growing seasons.

Growing environment and experimental design. All planted containers were placed outdoors at the Vineland Research and Innovation Center (Vineland Station, ON) on a black fabric-covered surface in a randomized block design, grouped by fertilization method. Ten replications of each fertilization method were arranged randomly within growing substrate groups, without space between pots. Plants within blocks were rerandomized monthly, and fertilization method blocks were rerandomized every 2 months to reduce location effect. Additional potted blueberry plants were placed around the perimeter of the plants to reduce perimeter effects. All plants were overwintered between 7 Jan. and 28 Apr. 2016 on a well-drained area in a covered outdoor structure at the Vineland Research and Innovation Center. Total monthly precipitation for the region and monthly mean minimum and maximum outdoor air temperatures are outlined in Table 1.

Measurements. Five plants per fertilization method were evaluated for plant growth, leaf chlorophyll content, growing substrate [intact in pot (i.e., root zone)] pH and EC, nutrient deficiency symptoms, and overall appearance 1 week after transplanting (6 July 2015), biweekly thereafter until 30 Sept.

Table 1. Outdoor environmental conditions during potted blueberry production in the 2015 and 2016 growing seasons.

Month	Total monthly precipitation (mm) ^z	Mean monthly air temp (°C) ^z	
		Minimum	Maximum
2015			
July	20.7	15.8	26.6
August	29.6	15.4	25.3
September	98.1	14.7	24.2
October	75.4	7.1	15.4
November	28.6	3.9	11.9
December	42.8	1.9	8.3
2016			
January	23.4	−4.2	1.6
February	69.2	−4.8	3.1
March	81.8	−0.4	7.8
April	26.1	0.7	9.4
May	15.5	8.6	19.6
June	19.2	13.5	24.6
July	48.1	18.2	28.7
August	41.1	19.2	28.9

²Data obtained from Environment Canada (2016).

2015, before dormancy (23 Oct. 2015), and for the duration of the 2016 growing season. Plant growth was evaluated by measuring plant height and width, in two perpendicular direc-

tions, with the aboveground plant growth index calculated as $[(\text{Height} \times \text{Width}_1 \times \text{Width}_2)/300]$, as outlined by Ruter (1992). Leaf chlorophyll content was measured using

a CCM-300 Chlorophyll Content Meter (Opti-Sciences, Inc., Hudson, NH). Growing substrate pH, EC, and nutrient content were measured for the growing substrate solution obtained using the pour-through method (Wright, 1986). Growing substrate nutrient content (i.e., $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, P, and K) was determined for the OG 10.2-g/pot N and OL 18.6-mmol-L⁻¹ N fertilization methods at five time points using a Varian Vista Pro inductively coupled plasma optical emission spectrometry with an axially viewed plasma (Varian Inc., Palo Alto, CA; SGS Agri-Food Laboratories). Visual nutrient disorder symptoms were noted, and overall appearance for five plants per fertilization method was ranked from 1 (worst) to 5 (best), relative to plants within the same fertilization method treatment. Overall appearance ranking values were based on foliage density and color, plant vigor, and extent of branching. Weeds were removed from containers as observed. During the second growing season, fresh fruit weight was measured two to three times weekly between 30 June and 8 Aug. 2016. After a total of 15 months of growth, leaves were removed from five representative plants for each of the C, OG, and OL fertilization methods, and leaf area per plant was evaluated in early Aug. 2016 using a leaf area meter (LI-3100; LICOR, Lincoln, NE). Leaves and stems cut at the surface of the growing substrate were dried in paper bags in an oven at 70 °C until a constant weight was achieved to determine shoot dry weight per plant.

Statistical analysis. All data sets were analyzed using GraphPad Prism version

Fig. 1 Concentration of nitrate nitrogen ($\text{NO}_3\text{-N}$), ammonium-nitrogen ($\text{NH}_4\text{-N}$), phosphorus (P), and potassium (K) during the 2015 and 2016 growing seasons in the root zone of #5 potted 'Duke' northern highbush blueberry plants fertilized with 10.2 g/pot N organic granular (OG; 1:1.82 general-purpose 4N-1.3P-7.5K: bloodmeal 12N-0P-0K) or 18.6 mmol-L⁻¹ organic liquid [(OL) 1:13.1 general-purpose 2.5N-13.1P-4.2K: 0N-0P-0K + 6CaO (calcium oxide)] fertilizers. Values are means of three replications $\pm$ SE. When significance over time was observed ($P < 0.05$), lines indicate the calculated regression; otherwise, no lines are shown. Vertical dashed lines indicate the dates of OG top-dressed fertilizer application.

Fig. 2. Growing substrate electrical conductivity (EC) and pH for #5 containerized 'Duke' northern highbush blueberry grown in conventional growing substrate with Osmocote Plus 15N-3.9P-9.9K 5- to 6-month controlled-release fertilizer or in organic growing substrate with granular [1:1.82 general-purpose 4N-1.3P-7.5K: bloodmeal 12N-0P-0K] or liquid [1:13.1 general-purpose 2.5N-13.1P-4.2K: 0N-0P-0K + 6CaO (calcium oxide)] organic fertilizers at five rates. Values are means of five replications $\pm$ SE. When significance over time was observed ($P < 0.05$), lines indicate the calculated regression; otherwise, no lines are shown. Vertical dashed lines indicate the dates of top-dressed fertilizer application.

Fig. 3. Growth index on 23 Oct. 2015 and 18 July 2016 for #5 containerized 'Duke' northern highbush blueberry grown in conventional growing substrate with Osmocote Plus 15N-3.9P-9.9K 5- to 6-month controlled-release fertilizer or in organic growing substrate with granular (1:1.82 general-purpose 4N-1.3P-7.5K: blood meal 12N-0P-0K) or liquid [1:13.1 general-purpose 2.5N-13.1P-4.2K: 0N-0P-0K + 6CaO (calcium oxide)] organic fertilizers at five rates. Values are means of five replications $\pm$ SE. When significance over time was observed ($P < 0.05$), lines indicate the calculated regression; otherwise, no lines are shown. Symbol omission for the conventional fertilization method at 16.0 g/pot nitrogen on 18 July 2016 is a result of the lack of plant survival.

5.03 software (GraphPad Software Inc., La Jolla, CA). A two-way repeated-measures analysis of variance (ANOVA) with a Bonferroni posttest was used to evaluate differences for fertilizer rate and fertilization method combinations among time points for growth index, chlorophyll content, leaf color, overall appearance, and growing substrate EC and pH. A one-way ANOVA was conducted for substrate nutrient content, total fruit yield, leaf area, and shoot dry weight among fertilization methods, with differences among means determined according to Tukey's multiple comparison test. Pearson correlation coefficients were calculated to compare substrate EC and pH with substrate nutrient content. Regression analyses were used to relate overall appearance, substrate nutrient content, EC and pH among time points, as well as leaf color and growth index

among fertilization methods to estimate regression parameters for the best-fit regression model (linear, quadratic, or cubic). Using significant regression equations, the best ranges of fertilizer application rates for each fertilization method were calculated as the upper 90% range on the quadratic curve for growth index. All data were evaluated using a significance level of $P < 0.05$.

Results

Growing substrate nutrient content, EC, and pH. Substrate $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and P contents increased over time from July to Oct. 2015 and decreased over time from May to July 2016 for OG at 10.2 g/pot N (Fig. 1). For OL at 18.6 mmol·L⁻¹ N, substrate K, $\text{NH}_4\text{-N}$, and P contents decreased over time from July to Oct. 2015, and increased over time from May to July 2016. In both 2015 and 2016, $\text{NO}_3\text{-N}$ had the most variability over time for the OG fertilization method. At the end of the 2015 growing season (i.e., 1 Oct. 2015) and as the study was finishing (i.e., 18 July 2016), growing substrate $\text{NO}_3\text{-N}$ content was less whereas $\text{NH}_4\text{-N}$, P, and K values were greater for OL in 2016 than OG in 2015 and 2016. Growing substrate EC and pH correlated positively with $\text{NH}_4\text{-N}$, P, and K (0.56, 0.72, and 0.78) in 2015, and with $\text{NH}_4\text{-N}$ and P (0.56 and 0.70) content in 2016 for OL at 18.6 mmol·L⁻¹ N. No correlations between OG at 10.2 g/pot N and growing substrate EC and pH were observed in 2015 or 2016.

Growing substrate EC decreased in 2015 and increased in 2016 for all C fertilizer rates (Fig. 2). For OG, growing substrate EC decreased during 2015 at 4.4 and 7.3 g/pot N, but remained constant in 2016 at these rates. At 10.2, 13.1, and 16.0 g/pot N, OG growing substrate EC increased or remained constant in both 2015 and 2016. A decreasing or constant growing substrate EC was observed for OL at all rates except 39.5 mmol·L⁻¹ N in 2015, whereas EC increased greatly at all OL rates in 2016 (Fig. 2).

During 2015, growing substrate pH increased for all C rates and for OG at lower rates (i.e., 4.4 and 7.3 g/pot N), but tended to decrease for the remainder of OG and all OL rates (Fig. 2). Decreasing pH was observed in 2016 for all fertilizer types and rates except OG at 4.4 g/pot N.

Plant growth. At the end of the 2015 growing season and at the study completion in 2016, growth index showed a quadratic relationship with fertilizer rate for OG (Fig. 3). Decreasing linear and quadratic relationships for growth index in response to C and OL fertilizer rates, respectively, were observed at the study completion in 2016, with no surviving plants remaining for C at 16.0 g/pot N. At the end of the study in Aug. 2016, leaf area and total shoot dry weight were greatest for C at 4.4 and 7.3 g/pot N, OG at 10.2 g/pot N, and OL at 12.2 and 14.7 mmol·L⁻¹ N (data not shown).

Chlorophyll content and visual leaf color observations. Chlorophyll content of leaves in the lower portion of the plant canopy was

greater than chlorophyll content of the last fully expanded leaves in the upper portion of the plant canopy for C, OG, and OL treatments at all fertilizer rates at the end of the 2015 growing season and at the study completion in 2016 (Fig. 4). In general, the greatest chlorophyll content was observed at midrange fertilizer rates in 2015 and low fertilizer rates in 2016.

Visual observations of leaf color for the C fertilizer method detected interveinal chlorosis for more plants at 16.0 g/pot N than 4.4 and 7.3 g/pot N at the majority of time points in 2015. No significant difference for C leaf color among fertilizer rates was observed for the majority of time points in 2016. For OG, interveinal chlorosis decreased over time for 4.4 and 7.3 g/pot N in 2015, and increased over time for all but 4.4 g/pot N in 2016. Interveinal chlorosis for OL decreased over time for all rates in 2015 and did not change significantly over time in 2016 for the majority of rates.

Overall appearance. Plants with the greatest overall appearance had large plant sizes, consistent foliage density, a compact shape and no interveinal chlorosis. Mean overall appearance rankings per fertilization method among bi-weekly evaluations in 2015 increased linearly over time for C at 4.4 and 7.3 kg·m⁻³ N, OG at 7.3 kg·m⁻³ N, and OL at 14.7 mmol·L⁻¹ N (data not shown). The greatest fertilizer application rate for C, OG (i.e., 16.0 g/pot N), and OL (i.e., 39.5 mmol·L⁻¹ N) resulted in a linear decline in overall appearance ranking with time during the 2015 growing season. Overall appearance for OL at 39.5 mmol·L⁻¹ N was less than all other OL application rates except 25.3 mmol·L⁻¹ N at the end of the 2015 growing season (23 Oct. 2015). At the end of the study in 2016, the greatest overall appearance was observed for C at 4.4 and 7.3 g/pot N, and OL at 12.2, 14.7, and 18.6 mmol·L⁻¹ N. No difference in overall appearance occurred among OG rates at the end of the study in 2016.

Blueberry fruit yield. In 2015, no fruit was produced by plants in any growing substrate. In 2016, a large total fruit fresh weight (i.e., 243.2–344.5 g/plant) (Fig. 5) was produced by OG plants at all fertilizer rates, with no significant difference among rates. For C plants, fertilization at rates of 4.4, 7.3, and 10.2 g/pot N produced the greatest total fresh weight of fruit, whereas OL plants produced the greatest fresh weight at 12.2, 14.7, and 18.6 mmol·L⁻¹ N. Surviving plants in all fertilization methods set fruit, with the lowest yields produced by the greatest C (i.e., 10.9 g for 13.1 g/pot N) and OL (i.e., 15.0 g for 39.5 mmol·L⁻¹ N) fertilizer rates.

Discussion

A desirable fertilization method should provide plants with adequate amounts of available nutrients, without excess nutrient leaching to the environment. The current study investigated the efficacy of different fertilization methods (i.e., different fertilizer types and application methods) for use in potted blueberry production. Analysis of pour-through solution from midrange fertilizer rates for

Fig. 4. Chlorophyll content on 23 Oct. 2015 and 19 July 2016 for leaves of #5 containerized 'Duke' northern highbush blueberry plants grown in conventional growing substrate with Osmocote Plus 15N-3.9P-9.9K, 5- to 6-month controlled-release fertilizer or in organic growing substrate with granular (1:1.82 general-purpose 4N-1.3P-7.5K:bloodmeal 12N-0P-0K) or liquid [1:13.1 general-purpose 2.5N-13.1P-4.2K:0N-0P-0K + 6CaO (calcium oxide)] organic fertilizers at five rates. Values are means $\pm$ SE. When significance over time was observed ($P < 0.05$), lines indicate the calculated regression; otherwise, no lines are shown. Symbol omission for the conventional fertilization method at 16.0 g/pot N on 19 July 2016 is a result of the lack of plant survival.

OG and OL showed that nutrient content in the growing substrate varied greatly over time. In particular, for OG, $\text{NO}_3\text{-N}$ showed the greatest variability of any nutrient for this fertilization method, whereas $\text{NH}_4\text{-N}$ was continually observed at low levels. For OL, $\text{NO}_3\text{-N}$ increased over time in 2015, whereas $\text{NH}_4\text{-N}$ increased over time in 2016. The different nutrient content patterns observed for these two N sources over time were likely a result of both the initial composition of N sources in the fertilizers, as well as preferential uptake of $\text{NH}_4\text{-N}$ rather than $\text{NH}_3\text{-type N}$ by blueberry roots (Bryla et al., 2010; Strik, 2016). The decrease in $\text{NH}_4\text{-N}$, P, and K over time with OL in 2015 likely indicates plant uptake or leaching of these nutrients during a period of active plant growth and adequate soil moisture. However, increasing $\text{NH}_4\text{-N}$, P, and K nutrient levels over time in 2016 suggests excess nutrient availability compared with plant requirements during this time. For OG, the low levels of P and K throughout the study

likely reflected nutrient availability matching plant uptake or low levels of nutrient release resulting from characteristics of the fertilizer components (i.e., sulfate of potash, guano soft rock phosphate, rock phosphate, feather meal, sulfate of potash-magnesia, soybean meal, and humic acid derivatives).

Blueberry plants grown with high fertilizer rates for all fertilizer methods in 2015 showed low growth index, poor overall appearance, and interveinal chlorosis, likely a result of high EC levels (i.e., $>3.0 \text{ mS}\cdot\text{cm}^{-1}$). Irrigation water did not contribute to the observed high EC, because irrigation water EC ($0.2 \text{ mS}\cdot\text{cm}^{-1}$) and bicarbonate alkalinity ($0.1 \text{ mg}\cdot\text{L}^{-1}$) were less than recommended maximums for blueberries [i.e., $0.25 \text{ mS}\cdot\text{cm}^{-1}$ and $91.5 \text{ mg}\cdot\text{L}^{-1}$ (Puls, 1999)]. Because blueberry roots have a very fine texture (Valenzuela-Estrada et al., 2008), overapplication of fertilizer, resulting in high EC levels, poses a great risk of root damage and poor blueberry plant health (Bryla and Machado,

2011). For the OG and C treatments at the majority of fertilizer rates, and for the OL treatment at 12.2 and 14.7 $\text{mmol}\cdot\text{L}^{-1} \text{ N}$, EC was maintained at levels less than $3.0 \text{ mS}\cdot\text{cm}^{-1}$ during the 2015 growing season. Interestingly, growing substrate EC during Sept. 2015 for OL and OG at high fertilizer rates was at the lowest and highest levels, respectively, since the beginning of the study. The low OL growing substrate EC at high fertilizer rates in Sept. 2015 likely occurred because plants were large enough to take up nutrients (e.g., $\text{NH}_4\text{-N}$, P, K) at sufficient levels to lower the growing substrate EC, whereas high EC for OG at high fertilizer rates suggest plants had excess nutrients available in the substrate at that time. During the 2016 growing season, growing substrate EC levels increased or remained constant, which was likely the cause of desirable plant growth and fruit yield. Growing substrate pH levels decreased during 2016 for the majority of fertilizer rates, likely the result of acidified water for OG and OL as well as the influences of fertilizer, because high $\text{NH}_4\text{-N}$ fertilizer can lower growing substrate pH via plant uptake and nitrification.

Understanding the adequate amount of nutrients required by blueberry plants at different stages of growth is critical to developing nutrient management strategies for successful potted blueberry plant production. In addition, ensuring adequate nutrient availability by maintaining appropriate root-zone pH levels will encourage healthy plant growth. In our study, OG and OL substrates had an initial pH greater than the range appropriate for blueberry growth [i.e., 4.2–5.5 (Puls, 1999)] at all fertilizer rates. Although the pH decreased for some OG and OL fertilizer rates, the majority of OG and OL remained greater than 5.5 during the 2015 growing season, as did OG for low fertilizer rates in 2016, despite acidification of high-pH (6.91) irrigation water. Also, the pH of C increased and remained greater than 5.5 during the 2015 and 2016 growing seasons. Irrigation water during 2015 had an average pH of 6.91, which was not acidified with apple cider vinegar for the C fertilization method and therefore likely influenced the high pH of the growing substrate for C. In addition to low iron availability at high pH levels, blueberry plants are inefficient at taking up iron at pH levels more than 5.5 (Strik, 2016). Therefore, the combination of high growing substrate pH and EC levels likely combined to cause the observed interveinal chlorosis symptoms.

Fruit yield was influenced by fertilizer rate, with high C rates and all OL rates affecting fruit yield negatively. The high fruit yield observed for all OG rates and C at 4.4 and 7.3 g/pot N indicated that blueberry plants prefer low C rates, or OG fertilizer applied at any rate. When using conventional CRFs, low rates (i.e., 4.4–7.3 g/pot N) are sufficient for high fruit yield in this production system, and no yield benefit was observed from high application rates. When using the OG fertilization method, fruit production responded positively at all application rates; therefore, lower OG fertilizer rates are appropriate and cost-effective. Of the three fertilizer methods,

Fig. 5. Total fruit fresh weight at the end of the 2016 growing season for #5 containerized 'Duke' northern highbush blueberry plants grown in conventional growing substrate with Osmocote Plus 15N-3.9P-9.9K, 5- to 6-month controlled-release fertilizer or in organic growing substrate with granular (1:1.82 general-purpose 4N-1.3P-7.5K:bloodmeal 12N-0P-0K) or liquid [1:13.1 general-purpose 2.5N-13.1P-4.2K:ON-0P-0K + 6CaO (calcium oxide)] or organic fertilizers. Values are means of five replications $\pm$ se. When differences among treatments per fertilization method were observed, symbols bearing the same letter are not significantly different at $P < 0.05$.

OL is least suitable for high blueberry fruit yield using this production system.

For the blueberry plants in our study, fertilizer rate greatly influenced growth index. Specifically, overfertilization at high OG, OL, and C application rates in 2016 influenced growth index negatively, similar to the overfertilization observations by Wilber and Williamson (2008). The organic fertilizers may have accumulated within the growing substrate over time in 2016; therefore, applying organic fertilizers based on measured EC levels of the growing substrate is recommended. Based on growth index values, 8.50 to 13.95 g/pot N was calculated as the best range for plant growth with the OG fertilization method, whereas 4.4 and 7.3 g/pot N for C or 12.2 and 14.7 mmol·L⁻¹ N for OL would be most appropriate to encourage the best blueberry plant growth. In addition to preventing nutrient toxicity symptoms, and nutrient leaching, applying fertilizer at these C and OL rates and this OG range may be most cost effective for growers to encourage healthy blueberry plant growth using this type of production system.

No single fertilizer rate resulted in the greatest overall appearance for the duration of the study for any fertilization method, potentially because of nutrient needs changing over time or the result of effects from changes in EC or pH over time. Further study is needed to determine whether either optimal and consistent EC and pH levels, or time-adjusted EC and pH levels based on plant need, would be able to provide insight into ensuring a consistent, desirable overall appearance for blueberry plants in these growing systems.

Timing and method of fertilizer application allows growers to influence the nutrient status of the root zone (Bryla et al., 2010). Applying a liquid fertilizer is beneficial because it permits the grower to adjust fertilizer timing and concentration to suit the needs of the crop more effectively, whereas granular and CRF fertilizer types are less labor-intensive than liquid fertilization but offer a limited ability to change fertilization practices quickly in response to crop need. In our study, preparation and application of the liquid fertilizer resulted in an oily film on surfaces as well as rapid settling of particles in the organic fertilizer solution. As a result of these observations, the OL fertilizer used in our study may not be appropriate for use with some irrigation systems or nozzles because of the potential of the fertilizer to clog the lines or leave an oily residue. Because the OL fertilizer was applied directly to the surface of the growing substrate, the influence of this fertilizer on plant leaves was not observed.

Physical and chemical properties of the growing substrate play an important role in maintaining appropriate EC and pH levels in the root zone. In our study, no negative effects on blueberry plant growth were caused by the substrates; therefore, both substrates are suitable for potted blueberry production in both a nursery and home garden context.

Overall, with the goal of efficient plant growth in the nursery or high fruit yield for container blueberry production by home gardeners, this study found that high fertilizer application rates are not necessary, and can be detrimental to plant growth and fruit production. Considering blueberry plant growth index, shoot dry weight, leaf area, overall appearance, and fruit yield, the results suggest optimal fertilizer application ranges from 4.4 to 7.3 g/pot N for C treatments, from 12.2 to 14.7 mmol·L⁻¹ N for OL treatments, and from 8.50 to 13.95 g/pot N for OG treatments. With target EC and pH levels in mind, organic and conventional container blueberry growers can supply appropriate nutrient levels at the correct time to manage substrate fertility, while achieving healthy plant growth and high fruit yields.

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