

Fertilizer Applications for Container-Grown Ornamental Tree Production¹

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Abstract

Better management of nutrient applications during a growing season is needed to economically produce marketable container-grown ornamental shade trees. Fertilizer practices were used to test the growth of *Acer rubrum* 'Red Sunset' trees in two commercial nursery fields (each containing four plots) that were irrigated with either city or pond water. In each field, the same 16 treatments were replicated. Two slow-release granular fertilizers (18-5-12 and 12-0-42) were applied separately or together by incorporation, topdress or both to a potting mix for trees grown in 26 liter (7 gal) containers and placed above or below ground. Trees irrigated with pond water also received supplemental liquid nutrients throughout the growing season along with nitric acid to lower the pH of the potting substrate. Tree growth was assessed by stem diameter (caliper), height, canopy size, leaf color and root measurements. Significant higher caliper increases occurred in trees treated with 18-5-12 fertilizer and irrigated with either pond or city water than trees treated with the 12-0-42 fertilizer. Significantly higher percent increases in caliper also occurred for trees irrigated with pond water and top-dressed with 18-5-12 fertilizer than trees with incorporated 18-5-12 fertilizer. With the same slow-release fertilizer applications, trees irrigated with pond water and supplemental nutrients had greater percent increases of caliper, larger canopy areas and better root systems than trees irrigated with city water. The differences in tree height increase were not as great as the caliper increases. However, tree growth irrigated with pond water required additional inputs with extra nutrients and labor costs throughout the growing season.

Index words: container production, granular fertilizer, irrigation, nutrient, tree growth.

Species used in this study: *Acer rubrum* 'Red Sunset'.

Significance to the Nursery Industry

Because of vast varieties and species in nurseries, scientific guidelines are lacking for growers to improve their nutrition practices based on their specific production circumstance. Fertilizer practices with topdressing, incorporating and liquid feeding methods can cause substantial labor cost and excessive nutrient runoff loss. To provide solutions to this problem, this research compared various fertilizer practices and nutrient applications by determining the *Acer rubrum* growth (caliper, height, canopy size, leaf color and root systems) in above- or below-ground containers. The comparison also included irrigation practices for trees with buffered pond or city water, and fertilizer practices with fertigation and with the potting substrate that had nutrients incorporated, top-dressed or both with slow-release granular fertilizers. Test results demonstrated that shortening tree production time and saving labor costs could be achieved by maximizing the one-year growth of container-grown trees through the optimal fertilizer practices.

Introduction

Growth of container-grown ornamental shade trees in nurseries is predicated on nutrients. However, the amount of

fertilizers required varies greatly with tree species and production circumstances. The necessity of particular nutrients, especially phosphorous, is poorly understood and leaching of excessive nutrients can contaminate runoffs (4, 12). Thus, many fertilizer practices are inefficient and detrimentally impact the environmental (1, 8, 17, 13).

Optimal nutrient applications rely on judicious use of irrigation, fertilizers, potting substrate materials, and plant species (4, 13). Many variables affect tree growth. For example, the same tree species grown in different locations with the same nutrient management can have different growth rates (2, 7, 10). Because interactions among the different tree species to different production conditions are complex, available guidelines for nutrition practices based on specific production conditions are limited.

Numerous studies to optimize nutrient applications have been reported (3, 5, 6, 11, 14, 15, 18, 19). Also, nursery growers have made significant strides in the use of technology to improve nutrient application efficiency, increase net profit, and reduce potential fertilizer pollution. These practices include drip irrigation with water soluble nutrients to supplement slow-release fertilizers (9, 16) and drainage systems to channel leachate into catch basins to recycle runoff water (20). However, many problems remained unresolved.

Acer rubrum 'Red Sunset' is a preferred nursery stock because of its stately characteristics, adaptability to diverse growing conditions and commercial utilizations. The bare-root stock is usually transplanted to either above- or below-ground container nurseries, grown for several years, and then marketed. Marketable red maple trees require multiple fertilizer applications during a growing season. These multiple fertilizer applications include incorporating a slow-release fertilizer into the potting substrate, topdressing the potting substrate with fertilizer, a combination of incorporation and topdressing methods, or applications of liquid fertilizers through drip irrigation.

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Fig. 1. Red maple trees irrigated with city or pond water for fertilizer application tests in either above- or below-ground containers.

Above- and below-ground container production systems as well as different fertilizer practices have advantages and disadvantages (21). Trees grown in the above-ground container system are easier to manage but they are subjected to more ambient air temperature fluctuations and their root growth may be concentrated on one side of the container. Trees grown in the below-ground container tree system avoid these disadvantages but they require much higher initial investment. Fertilizer application is beneficial to plants but it also creates its own problems. The application schedule for top-dressed fertilizer is flexible but care must be exercised to avoid spillage and insufficient fertility problems. Fertilizer incorporation into potting substrate places nutrients close to the root zone but to avoid toxicity the fertilizer must be thoroughly mixed during potting substrate preparation. Drip irrigation of liquid nutrients may be used during the growing season, but specialized equipment and irrigation facilities are required.

Topdressing, incorporating and liquid feeding fertilizer application methods may involve substantial labor costs and cause nutrient runoffs. Questions commonly raised on container production related to these costs and problems include: Are multiple applications of nutrients needed throughout a growing season? Are there optimal combinations of the three different fertilizer practices to improve fertilizer application efficiency? How do fertilizer application practices with different concentrations of nitrogen, phosphate and potassium affect tree growth (caliper, height, foliage, etc.) in above- or below-ground container production? Are the differences significant for tree growth between incorporated and top-dressed fertilizer practices? Can buffered nutrient pond water lower the pH of the substrate to a desired level?

The goal of this research is to determine optimal fertilizer practices that maximize the one-year growth of container-grown trees with minimal leachate levels to shorten tree production time and save labor costs. The specific objective of this study was to compare the effects of various fertilizer practices and nutrient application methods in above or below ground containers that were irrigated with buffered pond or city water on the growth response of *Acer rubrum* (caliper, height, canopy size, leaf color and root growth).

Materials and Methods

Tests were conducted in two fields with two different water sources (Fig. 1). In one field, the irrigation water was buffered nutrient pond water originally collected from rainfall and runoff water from nursery production fields. In the second field, the city water was used for irrigation. There were 16 fertilizer application treatments (Table 1) in both fields.

The two slow-release granular fertilizers were Osmocote® 18-5-12 (Scotts Company LLC, Marysville, OH) and Plantacote K-Knight 12-0-42 (X-Calibur Plant Health Company, LLC, Summerville, SC). Osmocote (18-5-12) is commonly used in Ohio nursery productions. Plantacote (12-0-42) was used to test if replacement of granular phosphorous with supplemental liquid phosphorous through drip irrigation to minimize phosphorous leaching contamination would still

Table 1. Incorporation or top-dressed slow-release 18-5-12 and 12-0-42 granular fertilizers in the potting substrate for red maple trees grown in above or below ground containers.

Treatment no.	Slow-release fertilizer applied	Application ²	Container location ³	Treatment label ⁴
1	18-5-12	I	A	F1(I,A)
2	18-5-12	T	A	F1(T,A)
3	No fertilizer	None	A	None(A)
4	18-5-12	I and T	A	F1(IT,A)
5	18-5-12	I	B	F1(I,B)
6	18-5-12	T	B	F1(T,B)
7	No fertilizer	None	B	None(B)
8	18-5-12	I and T	B	F1(IT,B)
9	12-0-42	T	A	F2(T,A)
10	12-0-42	I	B	F2(I,B)
11	12-0-42 (I) and 18-5-12 (T)	I and T	B	F1(T)F2(I)(B)
12	12-0-42 (I) and 18-5-12 (I)	I	B	F1(I)F2(I)(B)
13	12-0-42 (I) and 18-5-12 (T)	I and T	A	F1(T)F2(I)(A)
14	12-0-42 (I) and 18-5-12 (I)	I	A	F1(I)F2(I)(A)
15	12-0-42	T	B	F2(T,B)
16	12-0-42	I	A	F2(I,A)

¹I – Fertilizer was incorporated in the potting substrate; T – Fertilizer was top-dressed on the surface of the potting substrate; I and T – Fertilizer was incorporated in the potting substrate and top-dressed on the surface.

²A – Container was above the ground; B – Container was below the ground (or pot-in-pot system).

³F1 – Fertilizer 18-5-12, F2 – Fertilizer 12-0-42.

Table 2. Amounts of nutrients added through drip irrigation to buffer pond water.

Nutrients	Amount (g)	Note
Nitric acid	9.76	from nitric acid 67% and second injection
Phos. acid	2.51	From phosphate acid 85%
Ca	2.17	From CaNO ₃ , 0.6 kg·liter ⁻¹
Mg	0.26	From MgNO ₃ , 0.24 kg·liter ⁻¹
K	2.66	From KNO ₃ , 0.12 kg·liter ⁻¹
NH ₄ NO ₃	1.09	From NH ₄ NO ₃ , 0.6 kg·liter ⁻¹
Iron chelate	0.71	Iron Chelate, 13.2 g·liter ⁻¹
Mn chelate	0.02	Mn Chelate, 5.3 g·liter ⁻¹

promote healthy tree growth. Treatments with both fertilizers, either together or separately, were incorporated in the potting substrate or top-dressed on the substrate surface, or incorporated and top-dressed in the potting substrate. The rate of fertilizer application per container was 110 g for 18-5-12 and 36 g for 12-0-42 (Table 1). The containers with a capacity of 26 liters (or 7 gal) were filled with substrate and treatments applied on April 6, 2011.

For trees irrigated with pond water, supplemental liquid nutrients were injected into drip irrigation lines throughout the growing season. The additional nutrients were intended to buffer the substrate pH and increase the micronutrient availability for root uptake. The amounts liquid nutrients for each tree irrigated with pond water are listed in Table 2.

Trees irrigated with city water did not receive additional nutrients. Total amounts of nitrogen (N), phosphorous (P) and potassium (K) applied to each tree through topdress, incorporation, or both in the potting substrate and through the injection of additional liquid nutrients into drip lines are listed in Table 3. Another purpose of treatments with the combination of 18-5-12 and 12-0-42 fertilizers was to test if additional N and K would accelerate the tree growth.

On the same day as the preparation of potting substrates, red maple trees (*Acer rubrum* 'Red Sunset') grown in 11 liter (or 3 gallon) containers were transplanted to the 26 liter containers for the respective treatments. The experimental design was to divide each city water or pond water field into four main plots, each to accommodate the 16 treatments and was four replications for each fertilizer treatment. There were three trees for each fertilizer application and 48 trees

in each plot. Therefore, there were 192 trees in four city water plots and another 192 trees in four pond water plots for 384 trees in total.

The volumetric basis of the container substrate composed of 20% aged pine bark, 30% play ground chips, 10% expanded shale Haydite soil conditioner (Hydraulic Press Brick Company, Indianapolis, IN), 10% steamed composted nursery trimmings and potting substrate waste, 15% fibrous light Sphagnum peat, and 15% composted municipal sewage sludge. The air porosity of the substrate was 35% and water holding capacity was 49%.

Plot irrigation started on May 22 due to the constant rainfall during April and May and was terminated on October 4. Each container-grown tree was irrigated with a 11.4 liter·h⁻¹ spray stake (Part Number 01SSAYL-36, Netafim USA, Fresno, CA). A total of 152 liter (40.2 gal) water was applied to each tree during the growing season.

When the trees were transplanted from 11 liter to 26 liter containers, the average caliper and height was 10.5 mm (0.41 in) and 1.7 m (5.5 ft), respectively. Four and three measurements were taken for the caliper and height, respectively of each tree during the growing season. Caliper measurements were taken at 18 cm above the substrate surface with a mechanical digital reading caliper, and tree heights were measured with a scaled telescopic height rod. Trees also were pruned twice during the growing season.

On October 13 (day of year was 286), a digital image of each tree in plot 1 in the city or pond water field was taken to determine average canopy cross-sectional area, and leaf redness. Two images of each tree were taken from two sides at 90° from perpendicular against a white background under cloudy conditions. A MATLAB® software program (Version 7.7.0.471, the Mathworks, Inc. Natick, MA) was used to analyze images and calculate average canopy area and leaf redness level of each tree. The cross-sectional canopy area of each tree was measured from the two images projected to the white background behind the tree. The leaf redness was ranked from level 1 to 255. Redness level 1 was colorless and level 255 was reddest.

On October 18 (day of year was 291), the health of the root systems of trees from one plot irrigated with city or pond water were evaluated. The root system was rated on a scale

Table 3. Total amounts of nitrogen (N), phosphorous (P) and potassium (K) applied to each tree irrigated with pond or city water.

Treatment no.	Treatment label ^a	City water field			Pond water field		
		N (g)	P (g)	K (g)	N (g)	P (g)	K (g)
1	F1(I,A)	19.8	5.5	13.2	33.5	8.0	15.9
2	F1(T,A)	19.8	5.5	13.2	33.5	8.0	15.9
3	None(A)	0.0	0.0	0.0	13.7	2.5	2.7
4	F1(IT,A)	39.6	11.0	26.4	53.3	13.5	29.1
5	F1(I,B)	19.8	5.5	13.2	33.5	8.0	15.9
6	F1(T,B)	19.8	5.5	13.2	33.5	8.0	15.9
7	None(B)	0.0	0.0	0.0	13.7	2.5	2.7
8	F1(IT,B)	39.6	11.0	26.4	53.3	13.5	29.1
9	F2(T,A)	4.3	0.0	15.1	18.0	2.5	17.8
10	F2(I,B)	4.3	0.0	15.1	18.0	2.5	17.8
11	F1(T)F2(I)(B)	48.2	11.0	56.7	61.9	13.5	59.5
12	F1(I)F2(I)(B)	24.1	5.5	28.3	37.8	8.0	38.0
13	F1(T)F2(I)(A)	48.2	11.0	56.7	61.9	13.5	59.5
14	F1(I)F2(I)(A)	24.1	5.5	28.3	37.8	8.0	38.0
15	F2(T,B)	4.3	0.0	15.1	18.0	2.5	17.8
16	F2(I,A)	4.3	0.0	15.1	18.0	2.5	17.8

^aTreatment labels are defined in Table 1.

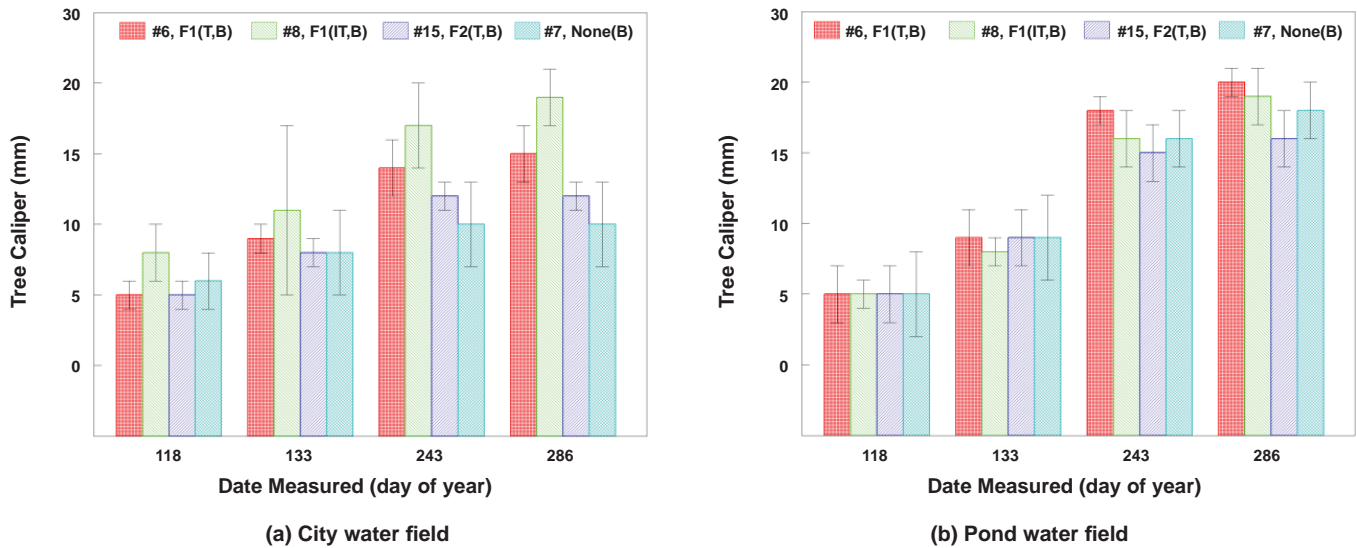


Fig. 2. Caliper measurements of trees in below-ground containers irrigated with city or pond water and top-dressed (T) or incorporated (I) with or without 18-5-12 (F1) or 12-0-42 (F2) fertilizers in treatments #6, 8, 15 and 7.

of 0 to 5: 0 represented dead roots in a dead or dying tree, and 5 represented a healthy root system which was pot-bound in the container.

In addition to the measurements of tree growth with all the fertilizer treatments, the amounts of major nutrient losses through drainage were also measured weekly and would be reported separately from this paper.

Percentage tree growth was calculated from the increase based on the initial measurement of caliper and height. Data analysis was based on a complete random block and the means of percentage increases in tree calipers and heights were compared with one-way analysis of variance (ANOVA) using a statistical program (ProStat version 3.8; Poly Software International, Inc., Pearl River, NY) to test the null hypothesis that treatment means were statistically not different. If the null hypothesis was rejected, Fisher's least significant difference (LSD) multiple comparison test at the 0.05 level of significance was used for means separations.

Results and Discussion

City and pond water fields. The effects of fertilizer treatments on tree caliper and height of trees irrigated with pond or city water are shown in Figs. 2 and 3. Generally, the percent increase of caliper diameters in trees irrigated with pond water was significantly greater than trees irrigated with city water (Table 4). Height increases of trees irrigated with pond water were also significantly greater than trees irrigated with city water in 8 of 16 treatments. Caliper and height increases in trees irrigated with pond water without incorporated or top-dressed fertilizer application were significantly greater than trees irrigated with city water. However, the caliper growth of trees with the incorporated and top-dressed 18-5-12 fertilizer treatments (#2, 4, 11) in city water plots was similar to those with different fertilizer application treatments in pond water plots (#1, 13, 12, 16, 15, 11, 14), and was better than those with two 12-0-42 treatments in pond water plots (#9, 10). Hence, adding the top-dressed or incorporated

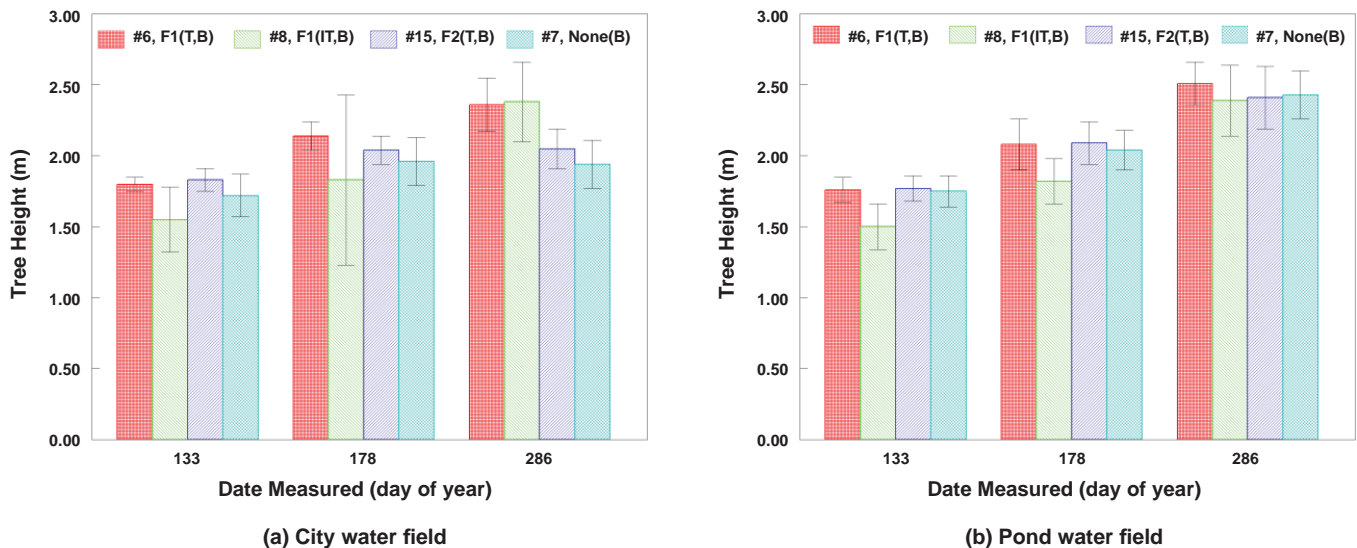


Fig. 3. Height measurements on different days for below-ground grown trees applied with and without slow-release top-dressed (T) or incorporated (I) fertilizers 18-5-12 (F1) and 12-0-42 (F2) of treatments #6, 8, 15 and 7 in (a) city and (b) pond water fields.

Table 4. Percent increase in calipers and heights of *Acer rubrum* ‘Red Sunset’ red maple trees irrigated with pond or city water for different fertilizer treatments. Treatment No. was ranged based on the rank of the caliper increase from greatest to smallest in the pond water field.

No.	Treatments Label ^a	Mean caliper increase (%) ^b		Mean height increase (%) ^b	
		Pond	City	Pond	City
2	F1(T,A)	172 (27)a	113 (22)b	33 (14)A	33 (20)A
4	F1(I,T,A)	169 (28)a	133 (24)b	53 (22)A	39 (21)A
6	F1(T,B)	161 (39)a	103 (16)b	43 (9)A	31 (9)B
8	F1(I,T,B)	150 (31)a	78 (22)b	60 (22)A	58 (35)A
5	F1(I,B)	140 (30)a	99 (21)b	41 (7)A	32 (18)A
1	F1(I,A)	138 (26)a	90 (25)b	30 (12)A	19 (8)B
13	F1(T)F2(I)(A)	133 (46)a	86 (28)a	50 (25)A	50 (25)A
12	F1(I)F2(I)(B)	130 (32)a	75 (19)b	39 (24)A	48 (22)A
16	F2(I,A)	129 (31)a	44 (7)b	28 (12)A	39 (18)A
7	None(B)	126 (38)a	38 (9)b	40 (17)A	13 (6)B
15	F2(T,B)	120 (33)a	64 (19)b	36 (11)A	12 (6)B
11	F1(T)F2(I)(B)	116 (45)a	110 (22)a	61 (29)A	41 (16)B
3	None(A)	116 (18)a	42 (10)b	38 (22)A	14 (7)B
14	F1(I)F2(I)(A)	112 (35)a	97 (31)a	37 (22)A	22 (15)A
10	F2(I,B)	101 (32)a	36 (11)b	54 (21)A	27 (21)B
9	F2(T,A)	99 (25)a	58 (10)b	43 (22)A	18 (9)B

^aTreatment labels are defined in Table 1.

^bMeans across rows followed by different lower-case or upper-case letters are significantly different. Standard deviations are in parenthesis.

slow-release fertilizers into potting substrate along with the supplemental nutrients applied through the drip irrigation increased tree growth in pond water plots but not greatly compared to those only receiving the incorporated or top-dressed 18-5-12 fertilizer in city water plots.

Average caliper increases in Treatments #1, 2, 4, 5, 6, 8 for trees irrigated with pond water or city water were 52 and 8%, respectively (Table 4). The caliper increases of trees irrigated with pond water in treatments #9, 10, 15, and 16 and with 12-0-42 fertilizer added were significantly different from trees similarly fertilized but irrigated with city water. The height percent increase of trees in the same treatments irrigated with pond water was significantly higher in three of four treatments. Caliper and height measurements were variable in treatments #11, 12, 13, 14 with both 18-5-12 and 12-0-42 fertilizers. Caliper and height measurements in below-ground containers in treatments #12 and 11, respectively were significantly different. However, the caliper and height measurements of trees in above-ground containers in treatments #13 and 14 were not significantly different. Thus, the combination of two fertilizers created more variations in tree growth.

Increases in percent growth measurements were not significantly different among treatments with 12-0-42 or 18-5-12 fertilizer applications to trees irrigated with pond water (#9, 10, 15, 16) or city water (#1, 2, 5, 6), respectively, or in treatments without any slow-release fertilizers (#3, 7). The average increase of caliper and height measurements in trees irrigated with city water in treatments #1, 2, 5, 6 was $101 \pm 9\%$ and $29 \pm 6\%$, respectively; in treatments #9, 10, 15, 16 for trees irrigated with pond water, they were $112 \pm 14\%$ and $40 \pm 11\%$, respectively; and in treatments #3 and 7 without any fertilizer, they were $121 \pm 7\%$ and $39 \pm 1\%$, respectively.

The fluctuations in growth of trees irrigated with city water were greater than trees irrigated with pond water and suggested additional fertilizer applications might minimize fluctuations. However, this approach did not consider additional economical and environmental costs. Each tree irrigated with pond water had received an additional 13.7 g

of N, 2.5 g of P and 3.6 g of K. Additionally, supplemental nutrient solutions and nitric acid were injected into irrigation drip lines throughout the growing season for trees irrigated with pond water. Furthermore, caliper growths in trees irrigated with pond water without a slow-release fertilizer (#3, 7) were slower than most trees with 18-5-12 fertilizer. Lastly, to improve caliper growth, the incorporation and topdress together or independently of large amounts of slow-release fertilizer and buffered nutrient pond water for tree growth was prohibitively expensive.

Above- and below-ground containers. Among 8 pairs of 16 treatments (Table 5), there was only one pair of treatments (#10 and 16, both with incorporated 12-0-42 only) that had significant differences in caliper increases between trees grown above and below ground containers in pond water plots. There were three pairs of treatments (#4 and 8, #11 and 13, #12 and 14) that had significant differences in caliper increases between trees grown above and below ground containers in city water plots. For tree height increases, there were three pairs of treatments (#1 and 5, #2 and 6, #10 and 16) that had significant differences between above and below ground container-grown trees in pond water plots, and two pairs of treatments (#1 and 5, #12 and 14) that had significant differences between above and below ground container-grown trees in city water plots. For those treatments when there were significant differences in either caliper or height increase between the above and below ground container practices, the difference degree was not very strong. Therefore, in general, the production practices with trees planted in either above or below ground containers did not result in great differences in tree growths.

Fertilizer practices. Table 6 lists six groups to compare caliper and height increases among three fertilizer applications (18-5-12, 12-0-42, and combination of both) in city and pond water plots. Except for group 1, with the same fertilizer applications (incorporated, top-dressed, or both) and the same container position (above or below ground), the trees applied with the 18-5-12 fertilizer in both pond and city water

Table 5. Comparison of percent increases in caliper and height between above and below ground treatments in pond and city water fields from beginning to the end of growing season.

Group	Treatments		Mean caliper increase (%) ^y		Mean height increase (%) ^y	
	No.	Label ^x	Pond	City	Pond	City
1	1	F1(I,A)	138 (26)a	90 (25)b	30 (12)B	19 (8)C
	5	F1(I,B)	140 (30)a	99 (21)b	41 (7)A	32 (18)B
2	2	F1(T,A)	172 (27)a	113 (22)b	33 (14)B	33 (20)B
	6	F1(T,B)	161 (39)a	103 (16)b	43 (9)A	31 (9)B
3	3	None(A)	116 (18)a	42 (10)b	38 (22)A	14 (7)B
	7	None(B)	126 (38)a	38 (9)b	40 (17)A	13 (6)B
4	4	F1(IT,A)	169 (28)a	133 (24)b	53 (22)A	39 (21)A
	8	F1(IT,B)	150 (31)a	78 (22)c	60 (22)A	58 (35)A
5	9	F2(T,A)	99 (25)a	58 (10)b	43 (22)A	18 (9)B
	15	F2(T,B)	120 (33)a	64 (19)b	36 (11)A	12 (6)B
6	16	F2(I,A)	129 (31)a	44 (7)c	28 (12)B	39 (18)B
	10	F2(I,B)	101 (32)b	36 (11)c	54 (21)A	27 (21)B
7	13	F1(T)F2(I)(A)	133 (46)a	86 (28)b	50 (25)A	50 (25)A
	11	F1(T)F2(I)(B)	116 (45)a	110 (22)a	61 (29)A	41 (16)A
8	14	F1(I)F2(I)(A)	112 (35)a	97 (31)a	37 (22)A	22 (15)B
	12	F1(I)F2(I)(B)	130 (32)a	75 (19)b	39 (24)A	48 (22)A

^xTreatment labels are defined in Table 1.

^yMeans in the same group followed by different lower-case or upper-case letters are significantly different (p<0.5). Standard deviations are in parenthesis.

plots had significantly higher caliper increases than those applied with the 12-0-42 fertilizer. Data in groups 1 and 4 show that adding the 12-0-42 fertilizer to containers already with the 18-5-12 fertilizer did not increase tree growth (#1 vs #14 in group 1, #5 vs #12 in group 4). The caliper growth for the treatments with both incorporated and top-dressed fertilizer 18-5-12 (#4 in group 3, #8 in group 6) in pond water plots was significantly higher than the treatments

with top-dressed 18-5-12 and incorporated 12-0-42 (#13 in group 3, #11 in group 6). Therefore, adding granular slow release N and K to the 18-5-12 treated trees did not increase tree growth because these trees already had enough N and K for the growth.

However, within each group for trees grown in pond water plots, there was no significant difference in percent tree height increase between the 18-5-12 and 12-0-42 fertil-

Table 6. Comparison of percent increases in caliper and height among three fertilizer applications in pond and city water fields from beginning to the end of growing season.

Group	Treatments		Mean caliper increase (%) ^y		Mean height increase (%) ^y	
	No.	Label ^x	Pond	City	Pond	City
1	1	F1(I,A)	138 (26)a	90 (25)b	30 (12)A	19 (8)B
	16	F2(I,A)	129 (31)ab	44 (7)c	28 (12)A	39 (18)A
	14	F1(I)F2(I)(A)	112 (35)b	97 (31)b	37 (22)A	22 (15)B
2	2	F1(T,A)	172 (27)a	113 (22)b	33 (14)A	33 (20)A
	9	F2(T,A)	99 (25)b	58 (10)c	43 (22)A	18 (9)B
3	4	F1(IT,A)	169 (28)a	133 (24)b	53 (22)A	39 (21)A
	13	F1(T)F2(I)(A)	133 (46)b	86 (28)c	50 (25)A	50 (25)A
4	5	F1(I,B)	140 (30)a	99 (21)b	41 (7)AB	32 (18)B
	10	F2(I,B)	101 (32)b	36 (11)d	54 (21)A	27 (21)B
	12	F1(I)F2(I)(B)	130 (32)a	75 (19)c	39 (24)B	48 (22)A
5	6	F1(T,B)	161 (39)a	103 (16)b	43 (9)A	31 (9)A
	15	F2(T,B)	120 (33)b	64 (19)c	36 (11)A	12 (6)B
6	8	F1(IT,B)	150 (31)a	78 (22)c	60 (22)A	58 (35)A
	11	F1(T)F2(I)(B)	116 (45)b	110 (22)b	61 (29)A	41 (16)A

^xTreatment labels are defined in Table 1.

^yMeans in the same group followed by different lower-case or upper-case letters are significantly different (p < 0.5). Standard deviations are in parenthesis.

Table 7. Comparison of average combined percent increases in caliper and height between incorporated and top-dressed treatments in pond and city water fields from beginning to the end of growing season.

Group	Treatments		Mean caliper increase (%) ^y		Mean height increase (%) ^y	
	No.	Label ^x	Pond	City	Pond	City
1	1, 5	F1(I,A), F1(I,B)	139 (27)a	95 (23)c	36 (11)B	25 (15)B
	2, 6	F1(T,A), F1(T,B)	167 (33)a	108 (20)c	38 (12)B	32 (15)B
	4, 8	F1(IT,A), F1(IT,B)	159 (30)a	106 (36)c	57 (22)A	48 (30)AB
2	16, 10	F2(I,A), F2(I,B)	115 (34)a	40 (10)c	41 (22)A	33 (20)A
	9, 15	F2(T,A), F2(T,B)	109 (31)a	61 (15)b	39 (17)A	15 (8)B

^xTreatment labels are defined in Table 1.

^yMeans in the same group followed by different lower-case or upper-case letters are significantly different ($p < 0.5$). Standard deviations are in parenthesis.

izer applications. In city water plots, trees with the 18-5-12 fertilizer in treatments #2 in group 2 and #6 in group 5 had higher height growth than trees with the 12-0-42 fertilizer in treatments #9 and #15, but it was opposite in group 1 and no difference in group 4. That is, in general tree height growth did not vary with the three fertilizer applications.

Incorporated and top-dressed fertilizer applications. Because there were no significant differences in tree growth between trees grown in above- and below-ground container productions, above and below ground treatments for the same fertilizer applications were combined as a group to compare tree caliper and height increases between incorporated and top-dressed fertilizer applications (Table 7). In pond water plots, trees with the top-dressed 18-5-12 fertilizer (treatments #2 and 6) had significantly higher percent increases in caliper than those with the incorporated 18-5-12 fertilizer (treatments #1 and 5), but with the same treatments in city water plots there was no significant difference. Also, in pond water plots, there were no significant differences in either caliper or height increase between top-dressed and incorporated 12-0-42 fertilizer applications (#1 and 5 vs #2 and 6 vs #4 and 8; #16 and 10 vs #5 and 15). Thus, the slow-release 18-5-12 fertilizer applied as a topdress to trees grown in either above- or below-ground container was the

better treatment if the caliper growth was considered as a growth parameter.

In city water plots, there were no significant differences in either caliper or height increase between incorporated and top-dressed 18-5-12 applications (#1 and 5 vs #2 and 6 vs #4 and 8; #16 and 10 vs #5 and 15), but trees with top-dressed 12-0-42 fertilizer had significantly higher caliper and height increases than trees with incorporated 12-0-42 fertilizer (#16 and 10 vs #5 and 15). The treatments with both top-dressed and incorporated 18-5-12 fertilizer (#4, 8) increased tree height growth significantly but not caliper growth in both city and pond water plots (Table 7).

Canopy areas, leaf redness and root systems. Average cross-sectional canopy areas measured on October 13 (286 day of year) for trees irrigated with pond or city water are listed in Table 8. The cross-sectional canopy areas of trees irrigated with pond water in treatments #13 or #16 and 7 were the largest and smallest, respectively. In contrast, the canopy areas of trees irrigated with city water with treatments #8 or #3 and 7 were the largest and smallest, respectively. Also, the canopy areas of trees irrigated with city water and added with 18-5-12 fertilizer were larger than trees added with 12-0-42 fertilizer. The canopy areas of trees irrigated with city or pond water and added with only the 12-0-42 fertil-

Table 8. Mean cross-sectional canopy areas of *Acer rubrum* ‘Red Sunset’ maple trees on October 13 (286 day of year).

Treatments in pond water field			Treatments in city water field		
Treatment no.	Treatment label ^x	Canopy area (m ²) ^y	Treatment no.	Treatment label ^x	Canopy area (m ²) ^y
13	F1(T)F2(I)(A)	0.620 (0.122)	8	F1(IT,B)	0.718 (0.078)
12	F1(I)F2(I)(B)	0.556 (0.117)	13	F1(T)F2(I)(A)	0.620 (0.122)
6	F1(T,B)	0.475 (0.141)	12	F1(I)F2(I)(B)	0.556 (0.117)
11	F1(T)F2(I)(B)	0.470 (0.078)	6	F1(T,B)	0.475 (0.141)
15	F2(T,B)	0.217 (0.053)	11	F1(T)F2(I)(B)	0.470 (0.078)
8	F1(IT,B)	0.718 (0.078)	2	F1(T,A)	0.436 (0.017)
2	F1(T,A)	0.436 (0.017)	14	F1(I)F2(I)(A)	0.412 (0.090)
5	F1(I,B)	0.129 (0.020)	4	F1(IT,A)	0.347 (0.122)
4	F1(IT,A)	0.347 (0.122)	5	F1(I,B)	0.297 (0.019)
9	F2(T,A)	0.264 (0.045)	1	F1(I,A)	0.282 (0.036)
1	F1(I,A)	0.282 (0.036)	16	F2(I,A)	0.272 (0.051)
14	F1(I)F2(I)(A)	0.412 (0.090)	9	F2(T,A)	0.264 (0.045)
3	None(A)	0.147 (0.029)	10	F2(I,B)	0.218 (0.047)
10	F2(I,B)	0.218 (0.047)	15	F2(T,B)	0.217 (0.053)
7	None(B)	0.272 (0.051)	3	None(A)	0.147 (0.029)
16	F2(I,A)	0.297 (0.019)	7	None(B)	0.129 (0.020)

^xTreatment labels are defined in Table 1.

^yStandard deviations are in parenthesis.

Table 9. Mean leaf redness level of *Acer rubrum* ‘Red Sunset’ maple trees on October 13 (286 day of year) for 16 different fertilizer treatments in pond and city water fields.

Treatments in pond water field			Treatments in city water field		
Treatment no.	Treatment label ^a	Redness level ^b	Treatment no.	Treatment label ^a	Redness level ^b
8	F1(IT,B)	39 (1)	1	F1(I,A)	40 (2)
5	F1(I,B)	42 (3)	2	F1(T,A)	44 (2)
6	F1(T,B)	43 (7)	5	F1(I,B)	44 (5)
4	F1(IT,A)	43 (2)	4	F1(IT,A)	50 (16)
11	F1(T)F2(I)(B)	45 (6)	14	F1(I)F2(I)(A)	51 (3)
7	None(B)	47 (2)	6	F1(T,B)	51 (5)
2	F1(T,A)	51 (5)	11	F1(T)F2(I)(B)	57 (8)
14	F1(I)F2(I)(A)	54 (10)	7	None(B)	65 (14)
10	F2(I,B)	57 (17)	16	F2(I,A)	66 (6)
1	F1(I,A)	62 (4)	12	F1(I)F2(I)(B)	66 (19)
13	F1(T)F2(I)(A)	63 (27)	8	F1(IT,B)	66 (3)
12	F1(I)F2(I)(B)	64 (12)	15	F2(T,B)	73 (12)
9	F2(T,A)	65 (10)	9	F2(T,A)	75 (11)
3	None(A)	68 (11)	13	F1(T)F2(I)(A)	76 (6)
15	F2(T,B)	68 (11)	3	None(A)	81 (12)
16	F2(I,A)	80 (12)	10	F2(I,B)	88 (7)

^aTreatment labels are defined in Table 1.

^bRedness level (1 to 255): 1 – colorless, 255 – reddest. Standard deviations are in parenthesis.

izer were no different from the canopy area of trees without any fertilizer applications. In general, for the same fertilizer applications, the canopy areas of trees irrigated with pond water plots were larger than trees irrigated with city water. However, there was lack of correlations of cross-sectional canopy areas with measurements in tree caliper and height, which was possibly related to the two seasonal pruning operations which removed tree branches.

Leaf redness responses of trees to 16 treatments and irrigated with pond or city water on October 13 are listed in Table 9. At this time, leaves had begun to senesce and turned yellow or red. In pond water plots, leaf redness response of trees in treatments #9, 15, and 16 with only 12-0-42 fertilizer application was more intense than leaf redness in trees with other treatments; leaf redness responses of trees in treatments #8, #5, #6 with 18-5-12 fertilizer grown in below-

ground containers were less than trees with other treatments. Similar to leaf redness response in pond water plots, leaf redness responses of trees treated with 12-0-42 fertilizer in city water plots were also more intense than trees with other treatments, and leaf redness responses in trees with 18-5-12 fertilizer treatment were less than in trees with other treatments. In general, leaves of trees irrigated with city water were redder than trees irrigated with pond water. Also, in both city and pond water plots, leaves of trees with only the 12-0-42 fertilizer turned red earlier than those with the 18-5-12 fertilizer. Therefore, applying phosphate to trees could extend tree greenness and prevent premature senescence.

Comparisons of root systems among treatments are listed in Table 10. In general, with the same fertilizer, the root systems of trees irrigated with pond water were similar or slightly better than trees irrigated with city water. This

Table 10. Comparison of root systems of *Acer rubrum* ‘Red Sunset’ maple trees measured on October 18 for 16 different fertilizer treatments in pond and city water fields.

Treatments in pond water field			Treatments in city water field		
Treatment no.	Treatment label ^a	Mean root scale ^b	Treatment no.	Treatment label ^a	Mean root scale ^b
12	F1(I)F2(I)(B)	4.2 (0.3)	12	F1(I)F2(I)(B)	4.0 (0.5)
6	F1(T,B)	4.0 (0.0)	6	F1(T,B)	3.8 (0.3)
10	F2(I,B)	4.0 (0.5)	11	F1(T)F2(I)(B)	3.8 (0.8)
11	F1(T)F2(I)(B)	4.0 (0.5)	4	F1(IT,A)	3.7 (0.3)
5	F1(I,B)	3.8 (0.3)	8	F1(IT,B)	3.7 (0.6)
8	F1(IT,B)	3.8 (0.3)	2	F1(T,A)	3.5 (0.5)
13	F1(T)F2(I)(A)	3.8 (0.8)	5	F1(I,B)	3.5 (0.5)
1	F1(I,A)	3.7 (0.3)	13	F1(T)F2(I)(A)	3.5 (0.5)
4	F1(IT,A)	3.5 (0.5)	1	F1(I,A)	3.2 (0.8)
14	F1(I)F2(I)(A)	3.5 (0.5)	10	F2(I,B)	3.2 (0.3)
16	F2(I,A)	3.5 (1.3)	14	F1(I)F2(I)(A)	3.2 (0.3)
2	F1(T,A)	3.3 (0.8)	7	None(B)	3.0 (1.3)
7	None(B)	3.3 (0.6)	16	F2(I,A)	3.0 (0.5)
9	F2(T,A)	3.2 (0.3)	15	F2(T,B)	2.8 (0.8)
15	F2(T,B)	3.0 (0.5)	9	F2(T,A)	2.0 (0.0)
3	None(A)	2.8 (0.8)	3	None(A)	1.8 (0.3)

^aTreatment labels are defined in Table 1.

^bRoot scale (0 to 5): 0 – no roots and the tree is dead or close to dead, 5 – container was totally filled with the roots from top to the bottom. Standard deviations are in parenthesis.

might be because the root growth was dependant on shoot growth during the growing season. Roots might grow faster in early spring when the substrate warmed up and a large flush of growth from the buds on branches did not start. Root growths slowed or stopped when shoots continuously grew larger during later spring and summer. In the early spring, the amount of fertilizers applied to trees in both city and pond water plots were similar. In the later summer and early fall when the roots started to grow again, the containers in the pond water plot had more nutrients to feed the root growth than the containers in the city water plot.

The root systems of trees grown in below-ground containers were better than those grown in above-ground containers (Table 10). This is because the substrate in below-ground containers was surrounded by the ground soil and its temperature was more consistent than that in the above-ground containers (21). Also, the above-ground containers collected more sunlight heat on one side that inhibited the root development. Trees planted in the below-ground containers had a more protected environment and less root stress than those in the above-ground containers.

Similar to the canopy area results, the root systems of trees with only the 12-0-42 fertilizer applications (treatments #9, 15) and without any slow-release fertilizer applications (treatments #3, 7) in both city and pond water fields were similar and were lower than other tree root systems. Thus, limiting the use of phosphorous or feeding liquid nutrients alone reduced the root system development.

In summary, the percent increases of caliper but not of the height for trees irrigated with pond water were significantly greater than those irrigated with city water. A larger canopy area and better root system were noted for trees treated with the same fertilizer but irrigated with pond water than trees irrigated with city water. However, the increased growth for trees irrigated with pond water required additional nutrient and labor inputs throughout the entire growing season. The growth of trees in the above- or below-ground containers was similar, but the root systems of trees grown in below-ground containers were healthier than trees grown in above-ground containers.

The caliper of trees, regardless of water source, treated with 18-5-12 fertilizer was significantly larger than trees treated with 12-0-42 fertilizer. Also, adding the 12-0-42 fertilizer to containers that were already applied with the 18-5-12 fertilizer did not increase tree growth in caliper and height. Trees with the smallest canopy areas and lowest root ratings, regardless of water source, were those treated with 12-0-42 fertilizer only or without any slow-release fertilizer applications, and their leaves turned to red earlier than other trees in the fall.

Trees with the top-dressed 18-5-12 fertilizer in pond water plots had significantly higher percent increases in caliper than those with the incorporated 18-5-12 fertilizer, but no this significant difference was found in city water plots.

Many variables affect tree growth. This study focused on the effects of fertilizer applications on caliper, height, canopy size, leaf color and root growth of *Acer rubrum* 'Red Sunset'. Future studies will include different ages and species of trees that are applied with different amounts of slow-release fertilizers and liquid nutrients at different times during the growing season, and to investigate the optimal and economic tree growth with the phosphorous application in liquid or slow release granular formulations.

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