Nutrient Leaching from Container-Grown Ornamental Tree Production[1]

H. Zhu[2], R.H. Zondag[3], J. Merrick[4], T. Demaline[4], and C.R. Krause[2]

Abstract

Economical production of marketable container-grown ornamental shade trees with minimum amounts of nutrients in leachate requires careful management of fertilizer applications during a growing season. Sixteen fertilizer treatments were evaluated for their nutrient leaching potential in container-grown 'Red Sunset' red maple (*Acer rubrum* L.) production in a commercial nursery. Tests were conducted at two sites that were irrigated with either city or recycled pond water. Two slow-release granular fertilizers (18-5-12 and 12-0-42) were applied separately or together, by incorporation, top-dressed, or both, to trees grown in #7 containers and placed above or below ground. Trees irrigated with pond water also received supplemental liquid nutrients throughout the growing season along with nitric and phosphoric acids. Compared to either top-dressed or incorporation of fertilizer, incorporation of fertilizer combined with top-dressing doubled the amounts of nutrients applied but did not increase tree growth and caused greater nutrient leaching through the container substrate. Adding nitric and phosphoric acids to the supplemental liquid nutrients had little effect on lowering pH of the container substrate to the desired level. Trees irrigated with pond water had greater caliper growth than trees irrigated with city water, but this practice caused greater nutrient loss through the leachate and required additional nutrient inputs and labor throughout the growing season. Among the 16 fertilizer practices, the top-dressed fertilizer applications in the above- and below-ground containers were the most efficient method to produce fast tree growth with low nutrient leaching.

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

Species used in this study: 'Red Sunset' red maple (*Acer rubrum* L.).

Significance to the Horticulture Industry

Because of the vast varieties and species grown in nurseries, scientific guidelines are lacking for growers to improve their nutrition practices based on their specific production circumstance. There is a significant labor cost associated with top-dressing, incorporating, and liquid fertilizer application methods, with varying concerns about nutrient leaching for these methods. To provide solutions to this problem, this research compared 16 fertilizer treatments by determining tree growth and concentrations of nutrients (N, P, K, EC, pH) in leachate for red maples grown in above- or below-ground containers and irrigated with city water or recycled and buffered pond water. Application of two slow-release granular fertilizers that were incorporated, top-dressed or both, and fertigation were compared. Shorter tree production time with reduced nutrients in leachates could be achieved by maximizing the one-year growth of container-grown trees with top-dressed 18-5-12 fertilizers in above- or below-ground containers without the use of liquid delivery systems. The pond water buffered with nitric and phosphoric acids for irrigation did not adequately maintain the substrate pH at an acceptable level. Also, the production cost was significantly increased for the slow-release granular practices plus supplemental nutrients and nitric and phosphoric acids injected into pond water drip lines.

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[2]USDA/ARS, ATRU, Wooster, OH 44691. Corresponding author: heping.zhu@ars.usda.gov.

[3]The Ohio State University Extension, Lake County, OH 44077.

[4]Willoway Nurseries, Inc., Avon, OH 44011.

Introduction

Container production has become a major part of the nursery industry because of its flexibility in positioning plants, managing the plant density, and shipping year round. However, container production practices are very expensive in recent years due to the large increase in labor and fertilizer costs (Fain et al. 2000, Jerardo 2006, Huang 2009). Fertilizer use is an integral part of nursery production, but it can also create a serious environmental issue.

Proper fertilizer management practices are critical to ensure healthy plants to meet stringent market requirements and protect the environment from eutrophication. The recommended specification for each fertilizer management practice is one of the most complicated aspects of nursery crop production. Extensive research on improving nutrient applications has been reported (Maynard and Lorenz 1979, Lea-Cox and Syvertsen 1996, Ku and Hershey 1997a, Blythe et al. 2002, Cabrera 2003, Ristvey et al. 2007, Zhu et al. 2013). These findings have helped growers to grow better plants. Despite these efforts, significant reduction of fertilizer use has not been achieved (Bilderback 2002, Broschat 2005).

The current lack of scientific methodologies to guide fertilizer practices for specific plants under particular growing circumstances also causes inefficient fertilizer applications (Lea-Cox et al. 1996). The primary nutrients (N, P, K) need to be applied in a manner that optimizes plant growth with minimal loss through leachates. Variations in container substrate characteristics, tree sizes, nursery species, container sizes and irrigation schedules also impact fertilizer management programs in container production. With high porosity, the soilless substrate cannot hold nutrients easily, causing low nutrient uptake efficiency and a high runoff rate (Yeager et al. 1993, Fare et al. 1994, Ku et al. 1997a and 1997b, Ristvey et al. 2004 and 2007). Consequently, nursery growers often apply excessive nutrients to container-grown crops by 'guessing' without knowing how much nutrient loss occurred through leaching (Zhu et al. 2005). Use of intensive fertilizer practices has brought concerns about the environmental impact because nutrients in leachate are harmful to surface and ground water qualities (Yeager et al. 1993, Fare et al. 1994, Cabrera 2005).

Growers have been acutely aware of the consequences of fertilizer runoff and taken extensive remedial measures to minimize fertilizer leaching and optimize its application efficiency using newer production methods. They have modified the level and timing of N, P, and K application to optimize fertility management practices (Zhu et al. 2005) and protect water resources by recycling the drainage water from nurseries (Chong et al. 2004, Zhu et al. 2013). However, the benefits from these practices are not obvious to growers. They have questioned whether the delivery of liquid nutrients through drip irrigation normally used in greenhouses can replace the use of slow-release granular fertilizers in container-grown tree production. The hypothesis for using the liquid delivery system is that the captured nutrients in ponds can be recycled back to plants and a supplemental liquid formulation can replace the use of granular phosphorous to reduce its loss in leachates.

Growers have also questioned whether multiple applications of nutrients are needed throughout a growing season, how incorporating and top-dressing fertilizer application practices affect tree growth and nutrient loss through leachate in above- or below-ground container production, if there are optimal combinations of top-dressing, incorporating and liquid fed fertilizer practices, and whether buffered nutrient pond water can lower the substrate pH to a desired level. Hence, scientific guidelines for optimal nutrient applications are needed to address concerns from growers and meet legislation requirements to avoid limitations placed on future nursery crop production (Beeson et al. 2004).

The goals of this research were to determine optimal fertilizer practices that maximize the one-year growth of container-grown trees with minimal levels of nutrients in leachate to shorten tree production time and save labor costs.

Table 1. Sixteen treatments with 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[z]	Container location[y]
1	18-5-12	I	A
2	18-5-12	T	A
3	No fertilizer	None	A
4	18-5-12	I and T	A
5	18-5-12	I	B
6	18-5-12	T	B
7	No fertilizer	None	B
8	18-5-12	I and T	B
9	12-0-42	T	A
10	12-0-42	I	B
11	12-0-42 (I) and 18-5-12 (T)	I and T	B
12	12-0-42 (I) and 18-5-12 (I)	I	B
13	12-0-42 (I) and 18-5-12 (T)	I and T	A
14	12-0-42 (I) and 18-5-12 (I)	I	A
15	12-0-42	T	B
16	12-0-42	I	A

[z]I – 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.

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

Effects of these variables on tree growth were previously reported (Zhu et al. 2013). 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 city water or buffered pond water on losses of primary nutrients (N, P, K) and on leachate EC, as well as how additional nutrients and nitric and phosphoric acids could change the substrate pH.

Materials and Methods

Tests were conducted with two sets of trees in two areas irrigated with two different water sources in Willoway Nurseries in Avon, Ohio. One set of trees was irrigated with pond water originally collected from rainfall and recycled runoff water from nursery production fields. The other set of trees was irrigated with city water as a reference. There were 16 different fertilizer application treatments in each area (Table 1). These treatments were designed to compare tree growth and nutrients in leachate among slow-release fertilizer systems, a liquid fertilizer delivery system and the combination of both systems. Trees were grown in above-ground containers and below-ground (pot-in-pot) containers. Slow-release fertilizers were applied top-dressed, incorporated, or a combination of both methods to determine the tree growth and nutrient loss with different nutrient rates. The combination of both top-dressed and incorporated application practices was also to determine if doubling the amount of nutrients could double the tree growth with minimal nutrients leached.

Slow-release granular fertilizers Osmocote® 18-5-12 (Scotts Company LLC, Marysville, OH) and Plantacote K-Knight 12-0-42 (X-Calibur Plant Health Company, LLC, Summerville, SC) were used. Osmocote® 18-5-12 is commonly used in Ohio nursery productions because it can continuously release nutrients for up to 5 to 6 months. The 18-5-12 granules were coated with a polymeric resin film to encapsulate nutrients. Plantacote K-Knight 12-0-42 was used to test if replacement of granular phosphorous with supplemental liquid phosphorous through drip irrigation would minimize phosphorous leaching out of the container and still promote healthy tree growth. The 12-0-42 granules were coated with an elastic polymer film and the release of nutrients was controlled over a period of approximately 5 to 6 months.

The container substrate on a volumetric basis was composed of 55% aged pine bark, 3% sharp silica sand, 5% expanded shale Haydite soil conditioner (Hydraulic Press Brick Company, Indianapolis, IN), 20% steamed and composted nursery trimmings and potting mix waste, 12% fibrous light sphagnum peat, and 5% composted municipal sewage sludge. The air porosity of the substrate was 35%, the water holding capacity was 49%, and initial pH was between 5.5 and 5.8.

'Red Sunset' red maple trees were grown in #7 containers after transplanting from #3 containers on April 6. The experimental design was a randomized complete block design that divided each set of trees irrigated with either city water or pond water into four main blocks, each to accommodate the 16 treatments and four replications for each fertilizer treatment. There were three trees for each fertilizer application and 48 trees in each block. Altogether, there were 192 total trees in the four city water blocks and another 192 trees in the four pond water blocks.

For trees in the pond water-irrigated area, supplemental liquid nutrients along with nitric and phosphoric acids were

Table 2. **Total amounts of supplemental liquid nutrients applied to each tree over the growing season by injection into drip irrigation lines for the pond water-irrigated area.**

Nutrients	Amount (g)	Source
N	9.76	From nitric acid 67% and other injected supplements below
P	2.51	From phosphoric acid 85%
Ca	2.17	From $CaNO_3$, 0.6 kg L^{-1}
Mg	0.26	From $MgNO_3$, 0.24 kg L^{-1}
K	2.65	From KNO_3, 0.12 kg L^{-1}
NH_4NO_3	1.09	From NH_4NO_3, 0.6 kg L^{-1}
Iron Chelate	0.71	Iron Chelate, 13.2 g L^{-1}
Mn Chelate	0.02	Mn Chelate, 5.3 g L^{-1}

injected into drip irrigation lines throughout the growing season. Addition of liquid nutrients was to determine if additional nutrients could accelerate tree growth during the growing season. Acids were added to the pond water to lower its pH as well as to hopefully lower the substrate pH to the target range between 5.5 and 6.2, which was the recommended range to grow deciduous trees with better nutrient uptake (Lucas and Davis 1961, Argo 1998). Trees in the city water-irrigated area were not applied with the supplemental liquid nutrients and acids to determine how these supplements affected tree growth and leaching of nutrients. Total amounts of supplemental nutrients applied to each tree in the pond water-irrigated area through drip irrigation are listed in Table 2. The application of supplemental liquid nutrients during the growing season was based on the analysis of nutrients in container leachates that were collected each week as described below. After interpretation of leachate analysis, the amount of individual nutrients injected was adjusted to meet the plant nutritional needs for growth based on the concentration of individual nutrients in the previous leachate samples. Phosphoric acid was applied in July, August and September, with the highest concentration applied in September (Fig. 1a). Applications of N from supplements and acids and K started in May, and the highest amounts of N and K were applied in July and August, respectively. The nutrients NO_3, Mg and Ca were also extensively applied in May, with a lower concentration applied in June, and a higher level applied in July and August (Fig. 1b).

Total amounts of nitrogen (N), phosphorous (P) and potassium (K) applied to each container for the 16 treatments in either city or pond water-irrigated area throughout the growing season are listed in Table 3. Rates of slow-release granular fertilizers 18-5-12 and 12-0-42 were based on the manufacturer's medium recommended rate for a #7 container-grown tree. Details on the experimental design, the container substrate composition, nutrition application, irrigation schedule, and tree growth with different treatments were previously reported by Zhu et al. (2013).

Leachate solution from containers for each treatment was collected and measured every week for 23 weeks from April 14 to September 14 with the following steps: one tree along with its container was randomly selected from each block of each treatment and was placed in a #15 container (57 L or 15 gal capacity). One liter of distilled water was poured over the surface of each container. The leachate solution from each container was collected 20 minutes after the distilled water was applied. Because the amount of leachate from one container was very low, the leachate solutions from the four containers for the same treatment at each weekly sample collections were combined to measure the average concentration of K in leachate with a Cardy Potassium meter, nitrate nitrogen (NO_3-N) with a Cardy Twin Nitrate meter, EC with a Fieldscout direct soil EC meter, and pH with a Fieldscout SoilStik pH meter. All these meters were purchased from Spectrum Technologies, Inc. (Elysburg, PA). For each treatment, there were 23 weekly measurements during the growing season. The concentration of P in leachate was also measured four times in May, June, July and August for each treatment with a Simultaneous ICP analyzer in an independent chemical analytical laboratory (Brookside Laboratories Inc., New Knoxville, OH). Data analysis was based on a randomized complete block design and the nutrient loss means were compared between two treatments with a paired sample t-test using a statistical program (ProStat version 3.8, Poly Software International, Inc., Pearl River, NY) at the 0.05 level of significance.

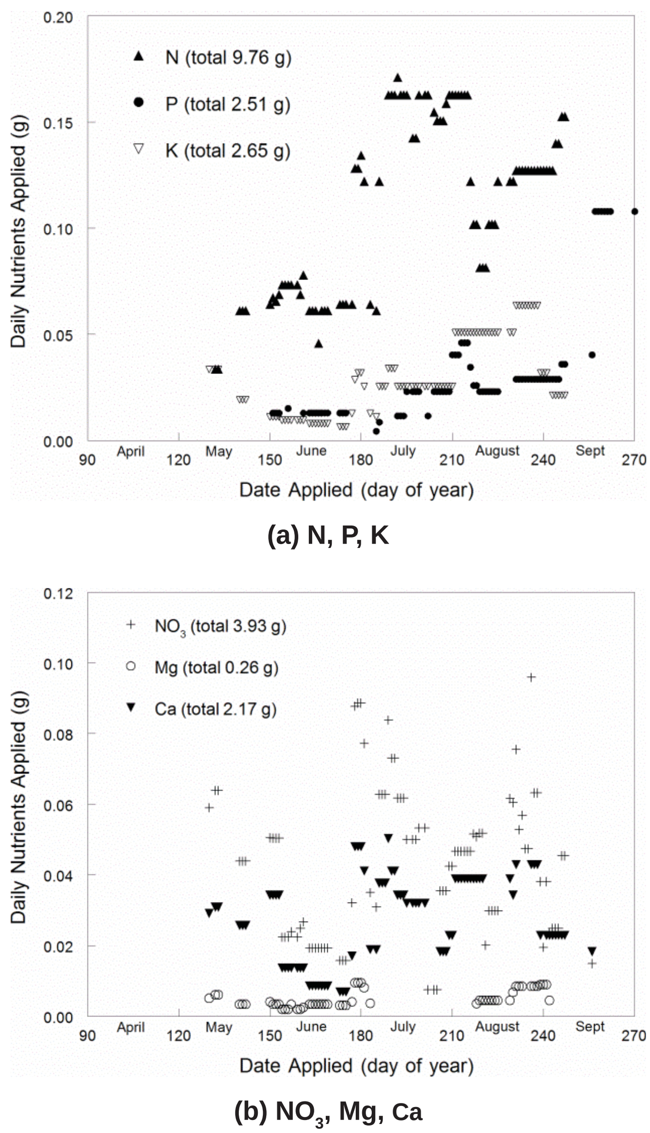


Fig. 1. **Supplemental liquid nutrients: (a) N, P, K; and (b) NO_3, Mg, Ca, applied daily through drip irrigation to each tree in the pond water-irrigated area during the growing season.**

Table 3. **Total amounts of nitrogen (N), phosphorus (P) and potassium (K) applied to each tree irrigated with pond or city water throughout the growing season[z]**

Treatment no.[y]	Pond water-irrigated area			City water-irrigated area		
	N (g)	P (g)	K (g)	N (g)	P (g)	K (g)
1	33.5	8.0	15.9	19.8	5.5	13.2
2	33.5	8.0	15.9	19.8	5.5	13.2
3	13.7	2.5	2.7	0.0	0.0	0.0
4	53.3	13.5	29.1	39.6	11.0	26.4
5	33.5	8.0	15.9	19.8	5.5	13.2
6	33.5	8.0	15.9	19.8	5.5	13.2
7	13.7	2.5	2.7	0.0	0.0	0.0
8	53.3	13.5	29.1	39.6	11.0	26.4
9	18.0	2.5	17.8	4.3	0.0	15.1
10	18.0	2.5	17.8	4.3	0.0	15.1
11	37.8	8.0	31.0	24.1	5.5	28.3
12	37.8	8.0	31.0	24.1	5.5	28.3
13	37.8	8.0	31.5	24.1	5.5	28.3
14	37.8	8.0	31.0	24.1	5.5	28.3
15	18.0	2.5	17.8	4.3	0.0	15.1
16	18.0	2.5	17.8	4.3	0.0	15.1

[z]Trees in pond water area received both slow-released fertilizers and supplemental liquid nutrients and trees in city water area received only slow-release fertilizers.

[y]Table 1 contains the components of each treatment.

Results and Discussion

Nitrate nitrogen (NO_3-N) leaching. For the same treatment, the cumulative concentration of NO_3-N in leachate from containers in the area irrigated with pond water (Table 4) was much higher than that from containers in the area irrigated with city water (Table 5). During the 23-week measurement, the cumulative concentration of NO_3-N leached from the 16 treatments in the pond water-irrigated area was 1.62 times the concentration of NO_3-N leached in the city water-irrigated area while the total amount of NO_3-N applied to the 16 treatments in pond water-irrigated area was 1.81 times the total amount of NO_3-N applied to the city water-irrigated area. Therefore, injection of additional liquid nutrients into irrigation water for containers that already received slow-release fertilizer contributed to excessive nitrogen leaching. Doubling the nitrogen rate roughly doubled the NO_3-N concentration in the leachate.

Treatment 8, which was the combination of the top-dressed and incorporated 18-5-12 fertilizer application, in the pond water-irrigated area had the highest cumulative concentration of NO_3-N leached among all the treatments (Table 4) and it had twice the cumulative concentration of NO_3-N leached compared to the same treatment in the city water-irrigated area (Table 5). Containers receiving both top-dressed and incorporated slow- release fertilizers had more nitrogen leached than containers receiving just top-dressed or incorporated fertilizers. This was true for both pond water and city water treatments. Among the 16 treatments irrigated with city water, treatment 11 had the numerically highest concentration of NO_3-N in leachate but it was still 359 ppm lower than the same treatment irrigated with pond water (Table 4). The lowest concentration of NO_3-N in leachate was with treatment 3 (non-fertilized) irrigated with city water and it had 60% of the cumulative concentration from the same non-fertilized treatment irrigated with pond water. The cumulative concentrations of NO_3-N leached from treatments 11, 12, 13 and 14 were similar to those from treatments 4 and 8 in both city and pond water-irrigated areas despite the amounts of NO_3-N applied with treatments 4 and 8 were 1.64 times those applied to treatments 11, 12, 13 and 14. The release rates of nitrogen from the 12-0-42 fertilizer may differ from that for the 18-5-12 fertilizer.

The concentration of NO_3-N in leachate decreased over time for all treatments in both the pond and city water-irri-

Table 4. **Cumulative concentrations of leached nitrate nitrogen (NO_3-N), phosphorus (P) and potassium (K), and total EC from substrate throughout the growing season, and percent increase in caliper diameters of red maple trees for each of 16 fertilizer treatments in the pond water-irrigated area during a growing season.**

Treatment no.[z]	Nutrients in leachate				Caliper increase[y] (%)
	NO_3-N (ppm)	P (ppm)	K (ppm)	EC (dS/m)	
1	1,710	43.4	2,355	23.5	138 (26)
2	2,344	39.9	2,994	30.3	172 (27)
3	1,148	28.6	1,585	17.7	116 (18)
4	2,936	44.4	3,023	30.9	169 (28)
5	1,858	55.4	2,335	24.1	140 (30)
6	1,949	57.7	2,543	27.1	161 (39)
7	1,373	42.9	2,051	21.0	126 (38)
8	3,117	63.8	3,362	35.2	150 (31)
9	1,594	37.2	2,112	21.4	99 (25)
10	1,871	48.0	2,792	25.5	101 (32)
11	2,416	46.4	2,909	29.5	116 (45)
12	2,756	57.7	3,407	31.3	130 (32)
13	2,856	43.2	3,414	31.6	133 (46)
14	2,966	51.5	3,662	32.7	112 (35)
15	1,797	35.5	2,034	22.5	120 (33)
16	2,240	48.0	2,901	31.6	129 (31)

[z]Table 1 contains the components of each treatment.

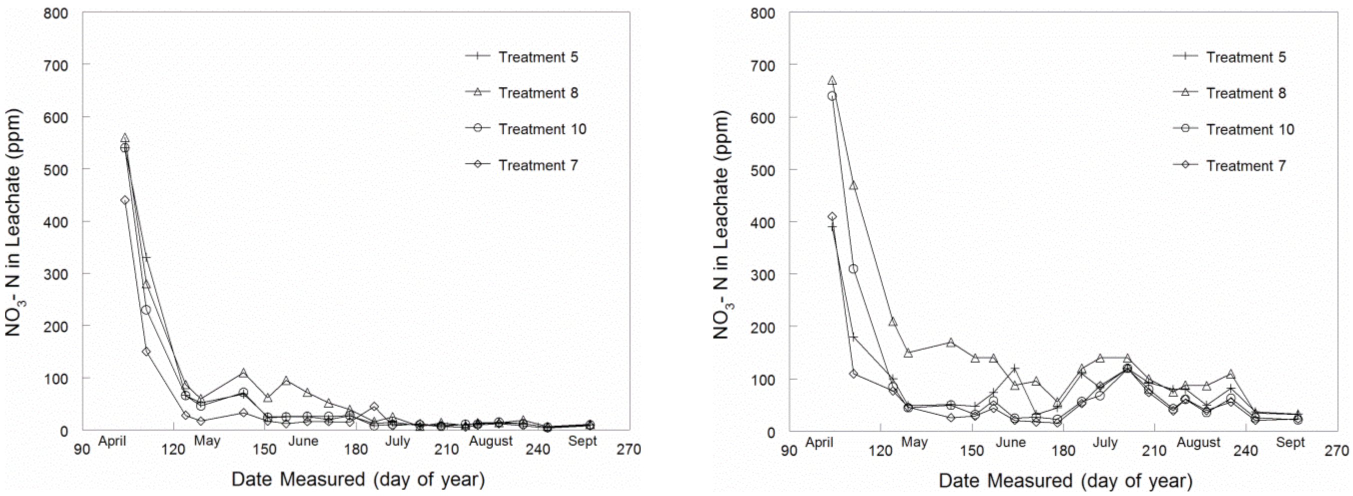
[y]Standard deviations are presented in parentheses.

Table 5. **Cumulative concentrations of leached nitrate nitrogen (NO_3-N), phosphorus (P) and potassium (K), and total EC from substrate throughout the growing season, and percent increase in caliper diameters of red maple trees for each of 16 fertilizer treatments in the city water-irrigated area during a growing season.**

Treatment no.[z]	Nutrients in leachate				Caliper increase[y] (%)
	NO_3-N (ppm)	P (ppm)	K (ppm)	EC (dS/m)	
1	1,229	36.1	2,247	17.5	90 (25)
2	1,294	27.2	2,001	17.8	113 (22)
3	695	29.5	1,919	12.5	42 (10)
4	1,924	37.5	2,344	23.3	133 (24)
5	1,286	46.2	2,482	20.2	99 (21)
6	1,339	45.0	2,573	21.6	103 (16)
7	863	33.7	1,632	13.9	38 (9)
8	1,552	44.9	2,241	21.8	78 (22)
9	934	25.5	1,828	13.6	58 (10)
10	1,182	39.4	2,705	17.9	36 (11)
11	2,057	41.2	3,156	24.4	110 (22)
12	1,589	46.7	2,907	20.5	75 (19)
13	1,808	30.5	3,135	20.9	86 (28)
14	1,717	40.7	2,573	19.8	97 (31)
15	1,047	36.4	1,952	16.0	64 (19)
16	1,055	29.7	2,038	13.9	44 (7)

[z]Table 1 contains the components of each treatment.

[y]Standard deviations are presented in parentheses.



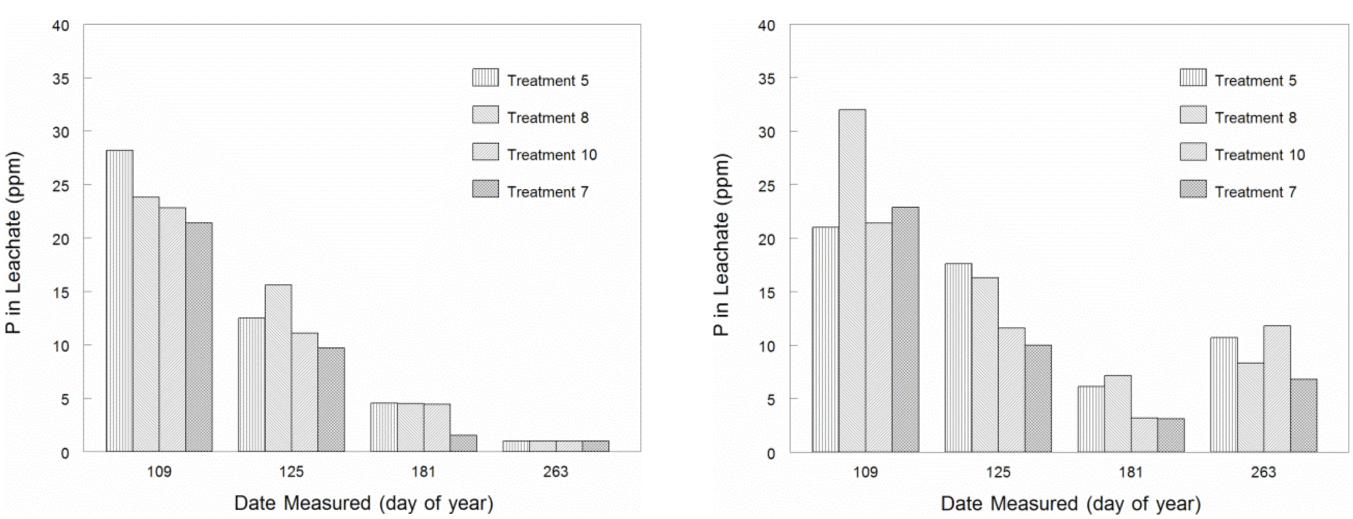
(a) City water-irrigated area **(b) Pond water-irrigated area**

Fig. 2. Nitrate nitrogen (NO_3-N) in leachate measured on different days for below-ground grown trees applied with and without slow release incorporated or top-dressed fertilizers 18-5-12 and 12-0-42 of treatments 5, 8, 10 and 7 in (a) city water- and (b) pond water-irrigated areas.

gated areas, but the decrease was less for all treatments in the pond water-irrigated area because of supplemental nutrients applied to the trees in this area (Table 4). For all 16 treatments in both irrigation areas, a large amount of NO_3-N leached in the first three weeks after the trees were transplanted (Fig. 2). For example, the concentration of NO_3-N in leachate in the first three measurements for treatment 8 in the pond water area was 43.3% of the total NO_3-N in leachate during the 23 weeks of measurements. In comparison, this percentage in the first three measurements was 60% for the same treatment in the city water-irrigated area. Therefore, the application timing to match tree growth and the release rate of applied nutrients could be critical to minimize nutrient leaching.

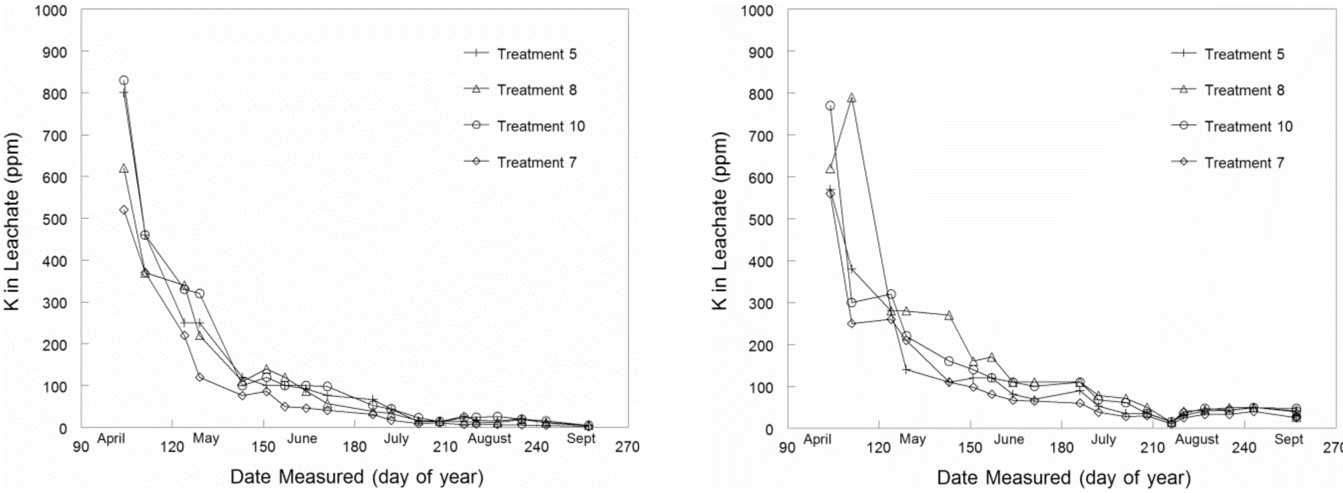
In the pond water-irrigated area, considerable amounts of NO_3-N leached through the substrate even after April because of supplemental nutrients injected into the pond water feeding line. In general, top-dressed 18-5-12 fertilizer applications caused more NO_3-N to leach than for the incorporated fertilizer applications. The reason might be that the top-dressed slow-release granules were directly exposed to sunlight, air and rain, which might break down the protective coatings faster than the incorporated granules in the substrate. During the growing season, the average concentration of NO_3-N leached from two top-dressed fertilizer treatments (treatments 2 and 6) in the pond water-irrigated area was 2,145 ppm, with only 1,784 ppm for the incorporated treatments (1 and 5).

Phosphorus leaching. For the same treatment, the concentration of P in leachate during the growing season in the pond water-irrigated area was higher than that in the city water-irrigated area due to the higher amounts applied



(a) City water-irrigated area **(b) Pond water-irrigated area**

Fig. 3. Phosphorous (P) in leachate measured on different days for below-ground grown trees applied with and without slow release incorporated or top-dressed fertilizers 18-5-12 and 12-0-42 of treatments 5, 8, 10 and 7 in (a) city water- and (b) pond water-irrigated areas.



(a) City water-irrigated area **(b) Pond water-irrigated area**

Fig. 4. Potassium (K) in leachate measured on different days for below-ground grown trees applied with and without slow release incorporated or top-dressed fertilizers 18-5-12 and 12-0-42 of treatments 5, 8, 10 and 7 in (a) city water- and (b) pond water-irrigated areas.

to the area irrigated with pond water (Tables 4 and 5). The cumulative concentration of P leached from the 16 treatments in the pond water-irrigated area was 1.26 times the cumulative concentration of P in leachate in the city water-irrigated area while the total amount of P applied to the 16 treatments in pond water-irrigated area during the growing season was 1.38 times the total amount of P applied to the city water-irrigated area.

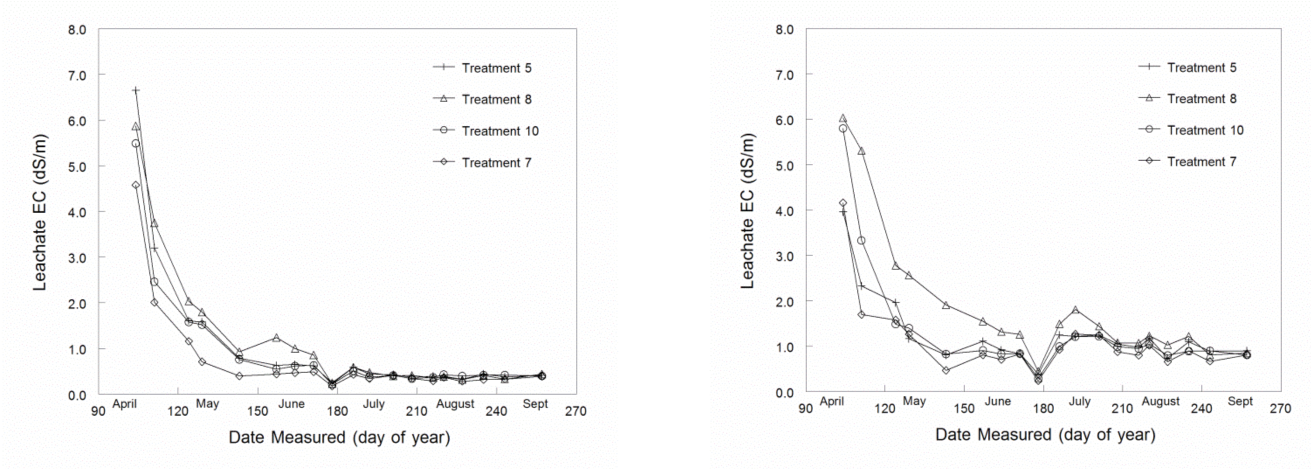
Phosphorous leached continuously throughout the growing season (Fig. 3). Most of the leaching occurred in April and decreased as the season continued. In September, the P in leachate from all treatments in the city water-irrigated area was close to 1 ppm, while the leaching from all treatments in the pond water-irrigated area was still 7 to 12 ppm. In general, treatments containing the 18-5-12 fertilizer had more P leaching than other treatments in both the city and the pond water-irrigated areas, and treatments applied to below-ground containers had higher P leaching than those with above-ground containers. Treatment 8 had the highest concentration of leached P among the 16 treatments in the pond water-irrigated area (Table 4), and treatment 12 had the highest P in leachate among the 16 treatments in the city water-irrigated area (Table 5).

Potassium (K) leaching. For the same treatment, the concentration of K leached in the pond water-irrigated area (Table 4) was slightly higher than that in the city water-irrigated area (Table 5). During the growing season, the cumulative concentration of K in leachate measured from the 16 treatments in the pond water-irrigated area was 2,717 ppm while it was 2,358 ppm in the city water-irrigated area (or 1.15 times). In comparison, the total amount of K applied to the 16 treatments in the pond water-irrigated area was 1.15 times that applied to the city water-irrigated area (Table 1), so a 15% increase in K application rate resulted in a 15% increase in the K concentration in the leachate.

Treatments 11, 12, 13 and 14, with the combination of fertilizers 18-5-12 and 12-0-42, had four of the five highest cumulative concentrations of K in leachate among the 16 treatments in both city and pond water-irrigated areas (Tables 4 and 5). The cumulative concentrations of K in leachate from single applications of fertilizer 12-0-42 (treatments 9 and 15) was similar to those from treatment 7, which did not receive any fertilizer, in the pond water-irrigated area, and were similar to treatment 3, which did not receive any fertilizer, in the city water-irrigated area. Similar to the NO_3-N and P in leachate, a large amount of K leached in the first three weeks for all 16 treatments in both city and pond water-irrigated areas (Fig. 4). For example, the concentration of K leached during the first three weeks was 55.8% of the total K leached throughout the 23-week growing season for treatment 11 in the city water-irrigated area, and 57.1% for treatment 14 in the pond water-irrigated area. In the middle of July, K leaching dropped to its lowest level, as most of the nutrient had probably been absorbed by the trees or had leached out of the pots by then.

EC in leachate. During the 23-week measurements, the cumulative drainage EC for the 16 treatments in the pond water-irrigated area was 1.47 times the cumulative EC in the city water-irrigated area. Nevertheless, the EC for the 16 treatments in both city and pond water-irrigated areas had similar trends as NO_3-N and K leaching during the growing season (Tables 4 and 5). The EC values within the first three weeks were much higher than those in the rest of weeks (Fig. 5), indicating most of the nutrients had been released from the fertilizer prills and had leached downward in the pots. At the end of June, EC values dropped to the lowest level for all the treatments while trees at that time still required additional nutrients for growth. For the same treatment, the total EC values in the pond water-irrigated area were 19% (treatment 5) to 127% (treatment 16) higher than those in the city water-irrigated area. Also, for the same treatment after June, the EC values in the pond water-irrigated area were 2 to 3 times those in the city water-irrigated area, indicating greater nutrient leaching from containers in the pond water-irrigated area.

Substrate pH. The pH values for all treatments during the first two weeks were below 7.0 and some were below 6.0,



(a) City water-irrigated area **(b) Pond water-irrigated area**

Fig. 5. Leachate electric conductivity (EC) measured on different days for below-ground grown trees applied with and without the slow release incorporated or top-dressed fertilizers 18-5-12 and 12-0-42 of treatments 5, 8, 10 and 7 in (a) city water- and (b) pond water-irrigated areas.

although the pH value of the irrigation water was above 7.0 (Table 6). Despite adding acids to lower the pH of irrigation water for the pond water-irrigated area in May, June, July and August, the pH values of the substrate did not decrease. The paired t-test at the 0.05 level of significance indicated that there was no significant difference in pH values throughout the growing season for the same treatment between the pond water- and the city water-irrigated areas when weekly averages were treated as sample points. Hence, addition of acids to container-grown tree productions had little impact on stabilizing the substrate pH. The reason for this might be that the volume of substrate in containers was much greater than the amount of drip irrigation water applied. Thus, the amount of buffered pond water fed into the container was not high enough to bring the substrate pH value to the expected level.

Tree growth. Detailed tree growths for all treatments were reported by Zhu et al. (2013). Because increased amounts of nutrients (N, P, K) were used, trees in the pond water-irrigated area had greater increases in caliper diameter and more nutrient leaching than trees in the city water-irrigated area. The top-dressed fertilizer practice (treatments 2, 6) produced larger caliper trees than the incorporated fertilizer practice (treatments 1, 5) in both pond water and city water-irrigated areas, while the cumulative concentrations of nutrients (N, P, K) leached from the two practices were very similar. Compared to applications of the slow-release fertilizer 18-5-12 in the city water-irrigated area (treatments 1, 2, 5, 6), applying liquid supplemental nutrients to the trees in the containers with the slow-release fertilizer 12-0-42 in the pond water-irrigated area (treatments 9, 10, 15, 16) did not result in significantly greater tree growth. Also, by

Table 6. Monthly averaged pH values of the substrate from weekly measurements for 16 treatments and drip irrigation lines in pond and city water-irrigated areas.

Treatment no.[z]	April		May		June		July		August	
	Pond	City	Pond	City	Pond	City	Pond	City	Pond	City
1	6.68	6.46	7.40	7.42	7.56	7.48	7.21	7.58	7.31	7.38
2	6.51	6.60	7.26	7.35	7.57	7.47	7.14	7.55	7.40	7.38
3	6.90	6.75	7.51	7.53	7.57	7.51	7.26	7.58	7.39	7.44
4	6.39	6.58	7.06	7.18	7.18	7.19	6.89	7.49	7.14	7.25
5	6.59	6.33	7.45	7.50	7.27	7.41	7.11	7.61	7.26	7.31
6	6.63	6.19	7.56	7.72	7.59	7.50	7.27	7.65	7.35	7.31
7	6.51	6.71	7.54	7.66	7.60	7.46	7.39	7.60	7.42	7.32
8	6.06	6.25	7.22	7.32	7.45	7.30	7.19	7.38	7.27	7.14
9	6.58	6.73	7.44	7.62	7.78	7.65	7.29	7.61	7.41	7.38
10	6.27	6.45	7.74	7.41	7.69	7.55	7.43	7.66	7.54	7.38
11	5.99	6.24	7.62	7.47	7.67	7.66	7.24	7.72	7.41	7.37
12	6.37	6.36	7.64	7.63	7.55	7.44	7.07	7.57	7.25	7.21
13	6.56	6.63	7.36	7.55	7.60	7.67	7.10	7.47	7.25	7.11
14	6.29	6.43	7.42	7.32	7.57	7.67	7.15	7.65	7.25	7.30
15	6.67	6.72	7.62	7.70	7.73	7.60	7.25	7.76	7.42	7.37
16	6.48	6.80	7.57	7.74	7.79	7.70	7.28	7.85	7.43	7.41
Irrigation line	7.41	7.67	7.54	7.43	5.79	7.54	6.04	7.39	7.04	7.47

[z]Table 1 contains the components of each treatment.

comparing treatments 11, 12, 13 and 14 with treatments 1, 2, 5 and 6 in the pond water-irrigated area, addition of the slow-release fertilizer 12-0-42 to the substrate already treated with the 18-5-12 fertilizer plus the supplemental nutrients did not result in increased tree caliper but the total N, P and K in leachate increased. In the pond water-irrigated area, the top-dressed fertilizer practice in the above-ground containers (treatment 2) had the numerically highest caliper increase, followed by the top-dressed plus incorporated fertilizer practice in the above-ground containers (treatment 4). In the city water-irrigated area, treatment 4, which received both incorporated and top-dressed 18-5-12 fertilizer, had the numerically highest caliper increase.

Greater tree growth in the pond water-irrigated area required additional nutrients through the liquid delivery system. At the same time, greater amounts of nutrient leaching were also produced. Compared with either top-dressed or incorporated fertilizer practices (treatments 1, 2, 5, 6), the use of both methods together (treatments 4, 8) applied twice the amount of nutrients but did not increase tree growth and caused greater amounts of nutrients to leach. Similarly, addition of 12-0-42 fertilizer to the 18-5-12 fertilizer did not increase tree growth but increased nutrient leaching. Buffered water with injection of acids into irrigation drip lines throughout the growing season did not lower the substrate pH to the desired level for adequate tree growth. The additional production costs and greater nutrient leaching would be a concern when considering supplementing granular fertilizer practices with a liquid fertilizer delivery system.

Literature Cited

Argo, W.R. 1998. Root medium chemical properties. HortTechnology 8:486–493.

Beeson, R.C., Jr., M.A. Arnold, T.E. Bilderback, B. Bolusky, S. Chandler, H.M. Gramling, J.D. Lea-Cox, J.R. Harris, P.J. Klinger, H.M. Mathers, J.M. Ruters, and T.H. Yeager. 2004. Strategic vision of container nursery irrigation in the next ten years. J. Environ. Hort. 22:113–115.

Bilderback, T.E. 2002.Water management is key in reducing nutrient runoff from container nurseries. HortTechnology 12:541–544.

Blythe, E.K., J.L. Mayfield, B.C. Wilson, E.L. Vinson, and J.L. Sibley. 2002. Comparison of three controlled-release nitrogen fertilizers in greenhouse crop production. J. Plant Nutr. 25:1049–1061.

Broschat, T.K. 2005. Rates of ammonium nitrogen, nitrate nitrogen, phosphorus, and potassium from two controlled release fertilizers under different substrate environments. HortTechnology 15:332–335.

Cabrera, R.I. 2003. Nitrogen balance for two container-grown woody ornamental plants. Scientia Hort. 97:297–308.

Cabrera, R.I. 2005. Challenges and advances in water and nutrient management in nursery and greenhouse crops. Agr. Mediterr. 135:147–160.

Chong, C., G. Lumis, P. Purvis, and A. Dale. 2004. Growth and nutrient status of six species of nursery stock grown in a compost-based medium with recycled nutrients. HortScience 39:60–64.

Fain, G.B., C.H. Gilliam, K.M. Tilt, J.W. Olive, and B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18:142–144.

Fare, D.C., C.H. Gilliam, G.J. Keever, and J.W. Olive. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. HortScience 29:1514–1517.

Huang, W.-Y. 2009. Factors contributing to the recent increase in U.S. fertilizer prices, 2002–08. U.S. Dept. Agr. Economic Res. Serv. AR-33.

Jerardo, A. 2006. Floriculture and nursery crops outlook. U.S. Dept. Agr. FLO-05.

Ku, C.S.M. and D.R. Hershey. 1997a. Growth response, nutrient leaching and mass balance for potted poinsettia I. Nitrogen. HortScience 122:452–458.

Ku, C.S.M. and D.R. Hershey. 1997b. Growth response, nutrient leaching, and mass balance for potted poinsettia II. Phosphorus. HortScience 122:459–464.

Lea-Cox, J.D. and D.S. Ross. 2001. A review of the Federal Clean Water Act and the Maryland Water Quality Improvement Act: The rationale for developing a water and nutrient management planning process for container nursery and greenhouse operations. J. Environ. Hort. 19:226–229.

Lea-Cox, J.D. and J.P. Syvertsen. 1996. How nitrogen supply affects growth and nitrogen uptake, use efficiency, and loss from citrus seedlings. HortScience 121:105–114.

Lucas, R.E. and J.F. Davis. 1961. Relationships between pH values of organic soils and availabilities of 12 plant nutrients. Soil Science 92:171–182.

Maynard, D.N. and O.A. Lorenz. 1979. Controlled-release fertilizers for horticultural crops. Hort Reviews 1:79–140.

Ristvey, A.G., J.D. Lea-Cox, and D.S. Ross. 2004. Nutrient uptake, partitioning and leaching losses from container-nursery production systems. Acta Hort. 630:321–328.

Ristvey, A.G., J.D. Lea-Cox, and D.S. Ross. 2007. Nitrogen and phosphorus uptake efficiency and partitioning of container-grown azalea during spring growth. HortScience 132:563–572.

Yeager, T.H., R.D. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback, and R.H. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206–208.

Zhu, H., R.H. Zondag, J. Merrick, T. Demaline, H. Jeon, C.R. Krause, and J.C. Locke. 2013. Fertilizer applications for container-grown ornamental tree production. J. Environ. Hort. 31:68–76.

Zhu, H., C.R. Krause, R.H. Zondag, R.D. Brazee, R.C. Derksen, M.E. Reding, and N.R. Fausey. 2005. A new system to monitor water and nutrient use efficiency in pot-in-pot nursery production systems. J. Environ. Hort. 23:47–53.