INVESTIGATION OF DRAINAGE AND PLANT GROWTH FROM NURSERY CONTAINER SUBSTRATE

H. Zhu, J. M. Frantz, R. C. Derksen, C. R. Krause

ABSTRACT. *The amount of water and major nutrients lost through drainage from a nursery container substrate treated with different amounts of nitrogen (N), phosphate (P), and potassium (K), and potted with butterfly bush plants were investigated. The substrate was mainly composed of aged pine bark and steamed composted nursery trimmings as well as leftover potting mix from a commercial nursery. Plastic containers with nominal capacity of 3.8 L were equally divided into 10 groups containing the substrate with or without plants, and treated with different amounts of N, P, and K applied to the surface of the substrate. A total of 4.8 L of water was applied to the substrate in each container during a 28-day period of the test. There was 48.4% of NO_3-N and 6.3% of P leached away when 0.8 g of NO_3-N and 0.4 g of P were applied to the substrate in the container with plants during the test. The amount of nutrients in the substrate with the greatest plant growth and the lowest nutrient loss through drainage was 0.44 g for N and 0.18 g for P. Substrate with plants had less water drainage and nutrient loss than the substrate with no plants. When the substrate moisture content was below 25%, the maximum amount of water that could be added into the substrate with plants before drainage was 257 mL of water/L of the substrate. Excess fertilizers applied to the container plants resulted in high nutrient loss and low plant growth rate. Current fertilizer use rates should be reduced to improve nursery production efficiency.*

Keywords. *Fertilizer, Irrigation, Leachate, Butterfly bush, Water quality, Ornamentals.*

Although the horticultural industries use less total irrigation water and fertilizers than traditional field crops, the frequency of water and fertilizer use in nursery production is greater due to high demands for each type of species to meet healthy and marketable requirements. Efficient use and availability of a quality water source has been a major concern in the nursery industry for many years. During the growing season, over 80% of water from sprinkler systems may be lost through runoff, drainage, and evaporation (Weatherspoon and Harrell, 1980). Due to lack of scientific methodologies to guide irrigation practices in the nursery industry, growers usually apply water to the crops by simply turning on valves without knowing how much water is lost through runoff and drainage. Similarly, fertilizers are often over-applied without knowing the amount of nutrient loss through drainage. Little knowledge is available on how to properly manage the waste water containing leached chemicals by either recycling or releasing it to the environment. Scientific guidelines for the proper use of water drainage and runoff must be developed in order to prevent potential environmental pollution.

Substrates in containers usually have very low water and nutrient holding capacity due to their soilless properties with high porosity. As a result, container nursery production requires frequent irrigation and fertilizer applications to maintain high crop growth rates. Knowledge of water and nutrient holding capacity of a substrate can improve irrigation and nutrition application management. Because of variable field conditions, there is no universally-satisfactory technology to precisely manage irrigation practice for nursery production. Volumetric water content probes have significant advantages to reduce losses of water and nutrients through drainage compared to the irrigation method using container weight (Murray et al., 2002).

Due to a wide range of species in every nursery, it is expensive for growers to use species-specific water and fertilizer management practices. It is a common practice to use the same substrate and water-fertilizer management practice for different species. Current irrigation and fertilization practices in nursery production have raised concerns over efficient use of water and fertilizer because of water loss through the containers and the extent of nutrient and chemical leaching with the drainage water to the soil and ground water (Yeager et al., 1993; Fare, 1994). Concerns also include how to monitor the recycled water, how to establish water quality standards for nursery production, and how to monitor the level of nutrient residues existing in nursery fields. Little research has been conducted on solving problems specific to the diverse nursery industry associated with water runoff, drainage or potential chemical leaching because of the wide variety of canopy structure characteristics, growing circumstances, and marketing requirements.

To obtain efficient use of water and nutrients and to implement automatic irrigation control for producing healthy quality trees with low cost, it is important to know how much water can be applied to each container before drainage be-

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gins. Zhu et al. (2004, 2005) established an experimental monitoring system in a commercial nursery field to investigate water and nutrient use, drainage, chemical loss through drainage, tree growth, and weather conditions in pot-in-pot nursery production. In that system, volumetric water content probes were used to monitor water content near root zones during four seasons of a year, and "tipping-bucket" rain gauges were used to measure drainage water loss through the pot-in-pot production system. To correlate with the monitoring system, further research is needed to investigate substrates for container nursery production and determine the release and loss of major nutrients and other environmental concern elements from various nursery substrates in the greenhouse and nursery field production.

The objective of this research was to investigate the capacity of a popular nursery substrate to retain water and nutrients during early butterfly bush growth at various fertilizer application rates in container production systems, in an effort to provide scientific information for growers to produce healthy ornamental crops with minimum losses of water and nutrients through drainage.

MATERIALS AND METHODS

CONTAINER SUBSTRATE

Experiments were conducted in a heated polyethylene-covered greenhouse. The nursery container substrate selected for the experiments was composed of 55% aged pine bark, 3% sharp silica sand, 5% expanded shale Haydite soil conditioner (Hydraulic Press Brick Company, Indianapolis, Ind.), 20% steamed composted nursery trimmings and leftover potting material that was predominantly peat moss and pine bark from a commercial nursery, 12% fibrous light Sphagnum peat, and 5% composted municipal sewage sludge, on a volumetric basis. The substrate was prepared in the commercial nursery and then was amended in a soil mixer based on 1.0 m^3 with 4.75-kg dolomitic limestone (extra fine, agricultural grade), 0.6-kg granulated iron, 0.42-kg Step trace elements, 1.19-kg gypsum, and 0.42-kg Blue-Chip urea formaldehyde slow release fertilizer. During a 3-min process, water was added by pouring small amounts and allowing it to seep into and hydrate the substrate to raise the moisture content of the substrate to 50% on a total weight basis. The major elements of this container substrate were chosen because they were widely used by commercial nurseries.

After 70 kg of the substrate was brought from a commercial nursery to the polyethylene greenhouse, it was agitated again for 3 min in a 290-L electric tumbling agitator to ensure ingredients in the substrate were uniformly distributed. After the agitation, the substrate was weighed and equally loaded into 50 plastic containers. The nominal capacity of the container was 3.8 L, but its actual capacity was 2.6 L. Each container was filled with 1.2±0.05 kg of substrate or approximately 2.4 L. The moisture content was 20% at the time when the containers were filled. Substrate properties were determined by sealing the bottom of the container and filling the pot containing substrate with water until the water reached the top of the substrate. This was weighed and then allowed to drain for 30 min. The leachate was collected and checked for pH and EC. The drained substrate with pot was weighed again. Finally, the entire pot was dried in a forced-air oven to constant weight, and weighed a third time. From these measurements, an initial pH (5.6), EC (2.32 dS/m with the 1:1 dilution method), water-holding capacity (52.4%), aeration porosity (28.7%), total porosity (81.1%), and bulk density (0.30 kg/L) were determined.

PLANTS

A total of 40 bare-root butterfly bush (*Buddleia davidii* 'black knight') plants were transplanted to 40 containers. The butterfly bush was selected because it was a fast growing plant so that the test time could be shortened. Also, the butterfly bush is a fragrant flowering woody shrub favored by many growers, homeowners, and landscapers (Warr, 2004). The average height of plants was 20 cm when they were transplanted into the containers.

The plants were exposed to natural light in the greenhouse. The height of each plant was measured every seven days until the end of the test. The experiments were conducted between 1 and 29 April to correspond to butterfly bush production in nurseries. Most of the plants at four weeks after the completion of this study were representative of those grown in commercial nurseries.

Ambient air temperature and relative humidity in the polyethylene greenhouse were measured every 30 min with a CM-6 weather system (Campbell Scientific, Inc., Logan, Utah). The average ambient air temperature was 26°C with 11% coefficient of variation, and the average relative humidity was 40% with 35% coefficient of variation.

FERTILIZER

Fertilizers of ammonium nitrate (NH_4NO_3, 34-0-0), concentrated superphosphate ($Ca(H_2PO_4)_2$-H_2O, 0-46-0), and potassium sulfate (K_2SO_4, 0-0-50) were applied on the top of the substrate after butterfly plants were transplanted into the containers. The 50 containers were divided into 10 groups, and each group had five containers. In each group, the first four containers had butterfly bush plants and the fifth container had only substrate without a plant. The unplanted container was used as a reference for drainage comparisons. The substrate in group 1 did not receive additional fertilizer. Table 1 shows the actual amounts of NH_4-N, NO_3-N, P, and K present in each group of containers after additional fertilizers were applied to the substrate. The total nitrogen (N) is the sum of NH_4-N and NO_3-N. The amount of NO_3-N, P, and K initially existing in the substrate was 0.02, 0.08, and 1.48 g, respectively, which was determined from three original substrate samples before fertilizers were applied using the analytical methods described later. For this type of substrate, growers normally applied 1.6 g of N, 0.4 g of P, and 0.64 g of K to the nominal 3.8-L container during the first week after plants are transplanted. No reference was found as to why this rate is used and if this rate is optimal. Hence, the growers' rate was used as a medium rate in group 6 to establish the rates of fertilizers listed in table 1 for the test.

WATER

Each plant with its container was placed on a block (5 cm tall) inside a plastic tray on a screen table, 0.65 m above the floor. The plastic tray was 30 cm in diameter and 4 cm deep, and was used to collect drainage water from the substrate in each container. When irrigation was beyond container capacity, the irrigation water drained completely out of the

Table 1. Amount of total ammonium nitrogen (NH_4 -N), nitrate-nitrogen (NO_3 -N), phosphate (P) and potassium (K) provided to the substrate in 10 groups of containers.

Group No.	Container No.	NH_4-N (g)	NO_3-N[a] (g)	P[a] (g)	K[a] (g)	Total (g)
1	1 to 5	0.00	0.02	0.08	1.48	1.58
2	6 to 10	0.10	0.12	0.13	1.56	1.91
3	11 to 15	0.20	0.22	0.18	1.64	2.24
4	16 to 20	0.40	0.42	0.28	1.80	2.90
5	21 to 25	0.60	0.62	0.38	1.96	3.56
6	26 to 30	0.80	0.82	0.48	2.12	4.22
7	31 to 35	1.00	1.02	0.58	2.28	4.88
8	36 to 40	1.20	1.22	0.68	2.44	5.54
9	41 to 45	1.40	1.42	0.78	2.60	6.20
10	46 to 50	1.60	1.62	0.88	2.76	6.86

[a] The amounts of NO_3-N, P, and K in the table included the initial amount of NO_3-N, P, and K existing in the substrate and the added amount of NO_3-N, P, and K in the substrate. The amount of NO_3-N, P, and K initially existing in the substrate was 0.02, 0.08 and 1.48 g, respectively.

container and into the plastic tray and did not re-hydrate the substrate after draining. The containers with plants and no plants were irrigated with equal amounts of water during the test. A total 4.8 L of water was applied to each container during the 28 days of the test. The irrigation schedule was based on the substrate moisture measured by a three-way ML2X Theta probe (Delta-T Devices Ltd, Cambridge, England) in each of the containers containing plants. Each container was given 0.2 L of water when the moisture indicator for all containers was below 25% by slowly distributing the water evenly over the surface of the pot. The amount (0.2 L) was selected because preliminary tests revealed that it provided just enough water to wet the medium in each container without saturation for drainage. However, on days 8, 20, and 28 after transplanting, each container was given 1.0 L of water. During field production, the butterfly bush would rarely receive this much irrigation in a single event, instead receiving anywhere from 0.2 (container capacity in this study) to 0.3 L depending on the grower and fertilizer used. This large amount was applied during this study for the following reasons: 1) to ensure complete saturation of the substrate in each treatment regardless of plant size; 2) to ensure sufficient amounts of drainage water could be obtained several times during the course of the study for experimental purposes; 3) to prevent salt buildup in the media caused by minimal leaching during the other irrigations, especially with the high fertilizer treatments; 4) to represent conditions reported by Weatherspoon and Harrell (1980) that over 80% of the water from sprinkler systems is lost through runoff, drainage, and evaporation during the nursery growing season. Standard recommendations for container production dictate 10% to 15% of the irrigation water should be allowed to drain off at each application, with greater need for rinsing substrate with higher fertilization rates (Jozwik, 2000). Assuming this crop was grown in the field and 0.2 L could be supplied in the field to reach container capacity with an additional 10% supplied to reduce salt build up, the butterfly bush could receive 3.08 L per pot in 28 days if watered every other day with low fertilizer, and up to 6.7 L per pot in 28 days if a leaching fraction of 15% is used and if containers are watered daily. While the total irrigation used per pot in this study may not be representative of common field production conditions, the amounts used would be representative of a grower that had a higher than recommended leaching fraction with frequent irrigations. The amount of drainage water from each container was measured 30 min after water was applied, and about 100 mL of drainage water from each container was collected for determining the concentration of NO_3-N, P and K in drainage and pH level.

Drainage and Nutrient Loss Measurement

The drainage water samples collected at 8, 20, and 28 days after transplanting were stored in a refrigerator before the analysis of NO_3-N, P, and K in drainage. Total concentration of NO_3-N from each water sample was determined by the method recommended by the Soil Science Society of America (Gelderman and Beegle, 1998; Mulvaney, 1996) with a liquid ion chromatography analyzer (model DX120, Dionex Corporation, Strongsville, Ohio). Total amount of P and K from each drainage sample was determined with the standard method (Greenberg et al., 1992) by an inductively coupled plasma (ICP) emission spectrometry (Model PS2000, Leeman Labs, Inc., Lowell, Mass.). The pH of drainage water samples was measured with a pH meter (model MA235, Mettler-Toledo GmbH, Schwerzenbach, Switzerland) under laboratory conditions.

Plant Growth Measurements

At the start of the experiment, plant height was recorded to ensure no differences in starting materials. Height was measured weekly for the duration of the study. Height data was used to measure weekly relative plant height increase (%), which is defined as the percent height difference between the beginning and end of a 7-day period divided by the height at the beginning of the period. Total relative plant height increase (%) is defined as the percent height difference between the first day and 28th day after transplanting divided by the height at the first day. Total projection leaf area of a plant based on a side view of the plant on day 28 was determined non-destructively by digital photography and image analysis software (Klassen et al., 2003; Assess, American Phytopathological Society, St. Paul, Minn.). Chlorophyll content was measured non-destructively with a portable chlorophyll meter (SPAD-502, Minolta Camera Co., LTD, Tokyo, Japan) on the fourth fully-expanded leaf from the top of the main shoot apex on days 8, 20 and 28, and partial preliminary results were reported (Frantz et al., 2005).

To understand the N, P, and K content in a whole plant, one plant from each group was removed from the container at 28 days after the plants were transplanted. The entire plant was then cut into small pieces and placed in a 55°C oven to dry for 96 h before it was ground to at least 40-mesh. The same ion chromatography analyzer and ICP emission spectrometry mentioned previously were used to determine the plant N, P, and K contents. The remainder of the plants was not destructively harvested at the completion of the experiment because they were used as target plants in subsequent pesticide spray studies for nursery production.

Statistical Analysis

Data were analyzed by a Two-Way ANOVA, with the time (8, 20, and 28 day sampling events) and plant status of the containers (with and without plants) as the main factors, and differences among means were determined with Fisher's LSD using ProStat version 3.8 (Poly Software International, Pearl River, N.Y.). All significant differences were determined at $P < 0.05$. Linear regression was used to determine significant trends ($P < 0.05$) between supplied fertilizer and drainage amounts, contents, and pH.

RESULTS AND DISCUSSION

DRAINAGE

The amount of water drainage from 1.0 L of water applied to the substrate in each container varied with the plant status (with plants or without plants) and plant age (table 2). The amount of drainage from the substrate with no plants was significantly higher than the substrate with plants during the 28-day period. There was no significant difference in the amounts of drainage water between substrate compounds with no plants at 8 and 20 days after transplanting, but less drained from pots containing plants on the 28th day. There was more leachate from unplanted pots on the 28th day compared to the 8th and 20th day.

Data in table 2 illustrated that the substrate with plants had a lower amount of drainage water than the substrate with no plants. Due to the plant growth, the amount of drainage water from the substrate with plants stayed stable before 20 days after transplanting and then decreased at 28 days after transplanting. However, the amount of drainage water from the substrate with no plants increased as the time increased. If the water absorbing capacity by the substrate before watering at day 8 is defined as the difference between the 1 L of water applied to the substrate and the amount of drainage water on this date divided by the substrate capacity of 2.4 L, then the average, early water absorbing capacity was 257 mL of water/L of substrate. After 28 days, the water absorbing capacity was 277 mL of water/L of substrate for the substrate with plants, but with no plants it was only 184 mL of water/L of substrate. The fact that the substrate with plants could absorb higher amount of water than the substrate with no plants was because the water consumption by plants made the substrate drier and also plant roots might change the substrate structure to retain more water.

Table 2. Average amount of drainage (mL) from 1.0 L of water applied to the 2.4-L substrate in the nominal 3.8-L containers with plants or no plants at 8, 20, and 28 days after they were transplanted.

Plant Status in Containers	Amount of Drainage Water (mL)		
	8 days	20 days	28 days
With plants	382.5 (86.0) bB[a][b]	385.6 (59.0) bB	335.9 (63.5) bA
No plants	460.0 (52.3) aA	504.5 (43.0) aB	559.0 (28.7) aC

[a] Means in a column followed by a different lowercase letter are significantly different ($p < 0.05$); Means in a row followed by a different uppercase letter are significantly different ($p < 0.05$).

[b] Standard deviations are given in parentheses.

The amount of water drainage from planted pots at 8 and 20 days after transplanting slightly increased as the amount of total N, P, and K applied increased, from 1.58 to 6.20 g, but slightly decreased as the amount of total N, P, and K applied increased at 28 days after transplanting (fig. 1a). As the plants grew, the amount of water drainage decreased, presumably because daily water usage increased as plants were larger. For the substrate without plants, the amount of drainage water did not vary with the amount of total N, P, and K applied (fig. 1b). The plants in group 10 received the greatest amounts of fertilizers and showed salt-stress symptoms shortly after the fertilizer treatments began with leaf curling, marginal necrosis, and eventual plant death for some of the treatment's plants. The amount of drainage water from the substrate from this group was very close to the amount of drainage water from the substrate without plants, suggesting little root growth during the 28 days.

NUTRIENT LOSS

The amount of NO_3-N, P, and K losses through drainage at 8, 20, and 28 days after transplanting increased as the amount of NO_3-N, P, and K applied to the substrate with

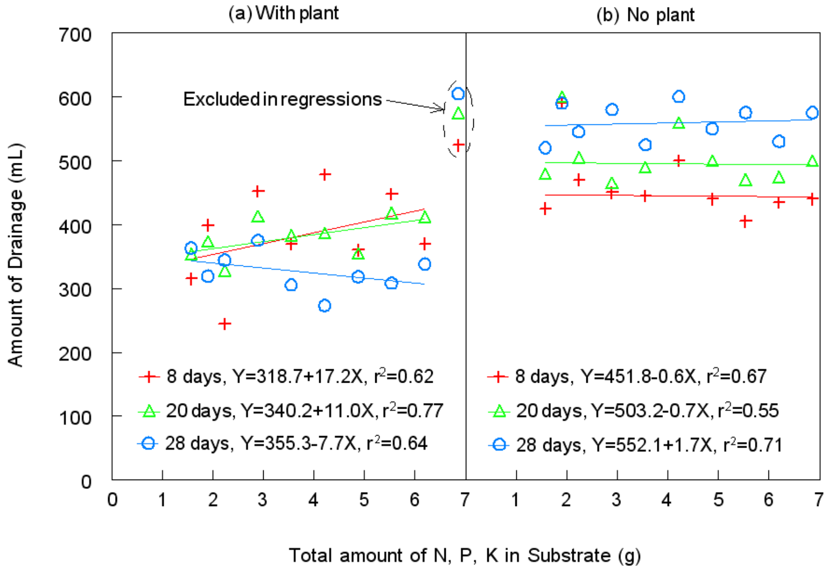

Figure 1. Amount of drainage water from the 2.4-L substrate in a nominal 3.8-L container with and without a plant initially applied with1.0 L of water and various amounts of N, P, and K at 8, 20, and 28 days after transplanting.

plants or no plants increased (figs. 2, 3, and 4). A large portion of NO_3-N, P, and K were collected (i.e. lost from the pot) on day 8. There was no apparent difference for the amount of NO_3-N, P, and K losses through drainage between 20 and 28 days after transplanting. Because plants consumed N, P, K, and water, the amount of NO_3-N, P, and K losses through drainage at 2.24 g of total N, P, and K applied to the substrate with plants in group 3 was significantly lower than that at 2.89 g or higher rate of total N, P, and K applied to the substrate.

The substrate with plants in group 3 containing 0.22 g of NO_3-N had the lowest NO_3-N loss rate through drainage in the tests (table 3). The total amount of NO_3-N loss through drainage from the substrate with plants increased from 0.02 to 0.17 g when the amount of NO_3-N applied in the substrate increased from 0.22 to 0.42 g. For the substrate with plants, the total loss rate increased from 42.1% to 76.4% when the amount of NO_3-N applied in the substrate increased from 0.42 to 1.62 g. For the same conditions, the total loss rate varied from 39.8% to 90.3% for the substrate with no plants. The average loss rate of NO_3-N from the substrate with no plants was about 10.6% higher than that with plants when the amount of NO_3-N initially existing in the substrate changed from 0.42 to 1.62 g. Retention of nitrogen in substrate mainly depends on exchanges between ions existing in the substrate; however, NO_3-N, as an anion, is poorly retained by most substrates. Therefore, for the soilless substrate, retention of NO_3-N mostly relies on the structure; coarse-textured substrates have large pore spaces, resulting in rapid NO_3-N downward movement when water is applied. The solid texture of

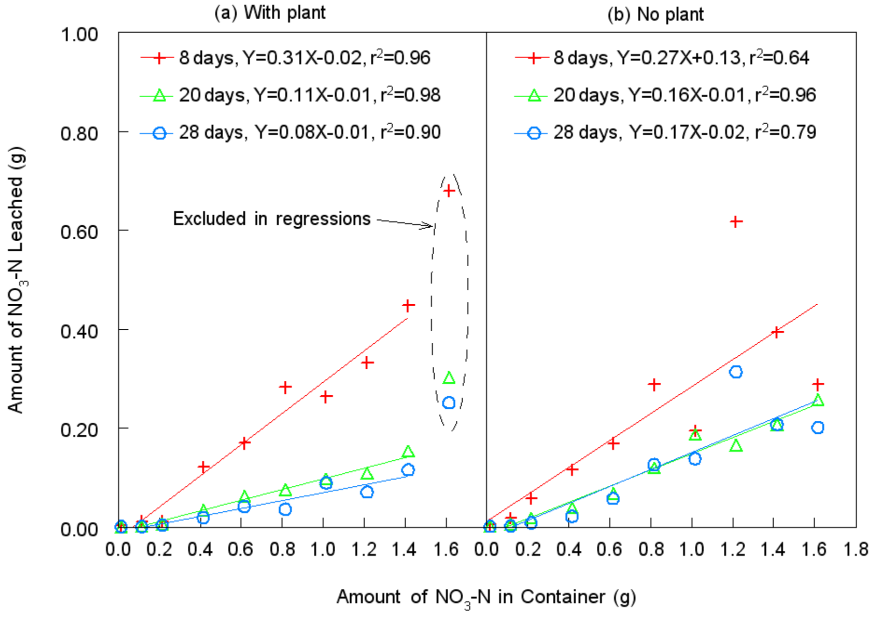

Figure 2. Amount of nitrate-nitrogen (N-NO_3) lost through drainage from the 2.4-L substrate with different amounts of N-NO_3 initially applied in the nominal 3.8-L container with a plant, or no plant at 8, 20, and 28 days after transplanting.

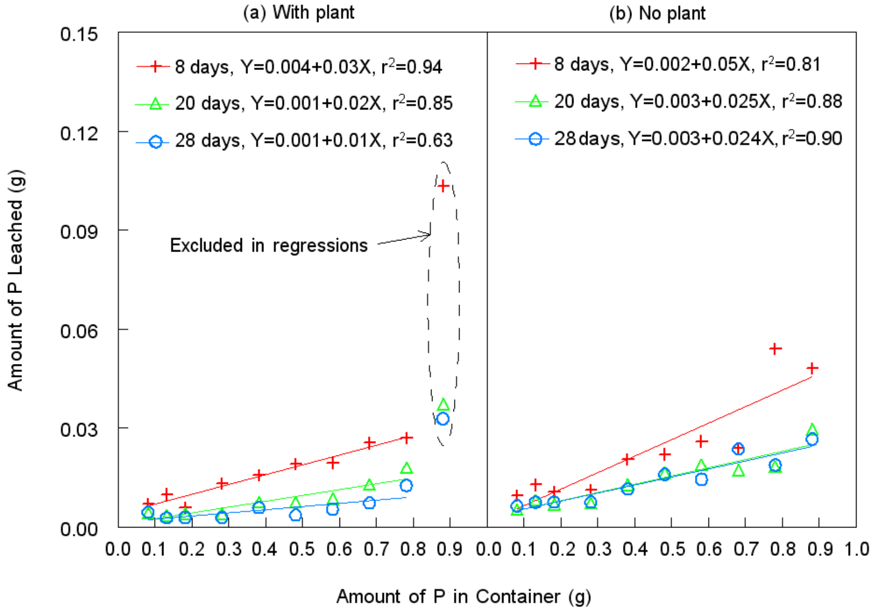

Figure 3. Amount of phosphate (P) lost through drainage from the 2.4-L substrate with different amounts of P initially applied in the nominal 3.8-L container with a plant, or no plant at 8, 20, and 28 days after transplanting.

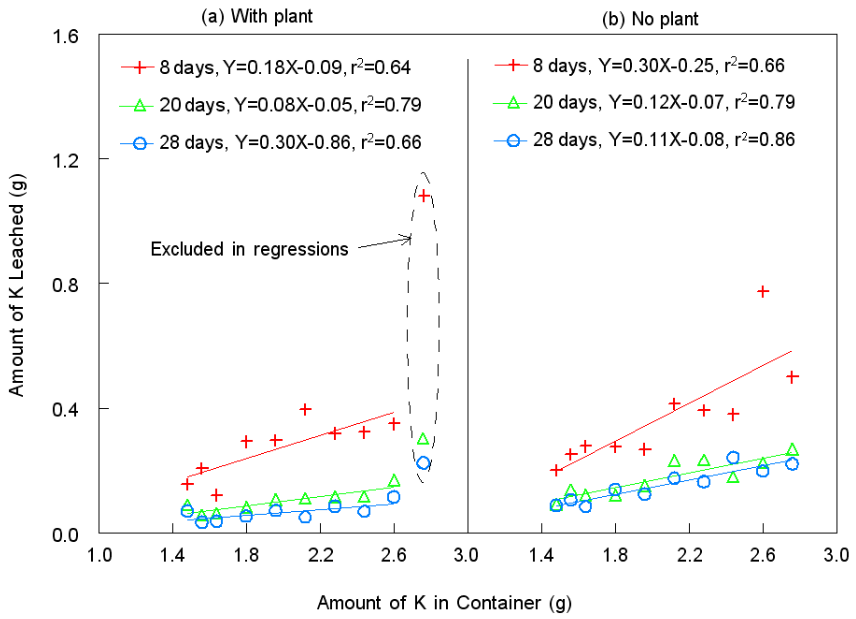

Figure 4. Amount of potassium (K) lost through drainage from the 2.4-L substrate with different amounts of K applied in the nominal 3.8-L container with a plant, or no plant at 8, 20, and 28 days after transplanting.

substrate can only block the NO_3-N movement, but can not retain NO_3-N. Therefore, except for the portion of NO_3-N taken up by plants, most NO_3-N will eventually leach away through drainage. A series of top dressing, low rate applications of NO_3-N may minimize nitrate leaching.

The rate of P loss through drainage from the substrate with plants was slightly lower than that with no plants (table 3). For the substrate with plants or no plants, the average loss of P among the 10 groups was 9.9% and 13.7%, respectively. Because the superphosphate is relatively insoluble in water, most P fertilizer in the test remained in the substrate with very little loss.

The rate of K loss through drainage from the substrate with no plants was higher than that with plants (table 3). For the substrate containing K ranging from 1.48 to 2.76 g, the average rate of K loss through drainage was 25.5% with plants, and 33.3% with no plants, respectively. Because K is in the form of cation, it can remain in the substrate after its ion exchange with other ions in particles of the substrate. However, over-application of K to the substrate exceeding the ion exchange capacity can result in extra K lost through drainage.

Table 3. Percentage of NO_3-N, P, and K lost through drainage from the 2.4-L substrate in the nominal 3.8-L containers with plants or no plants at different amounts of fertilizers initially applied to the substrate in 10 groups of containers during the 28-day test period.

	Rate of Fertilizers Lost Through Drainage (%)					
	NO_3-N		P		K	
Group No.	With Plant[a]	No Plant	With Plant	No Plant	With Plant	No Plant
1	30.6 (9.8)	45.0	19.4 (5.0)	25.8	21.4 (5.7)	25.7
2	12.2 (4.0)	22.7	12.3 (2.2)	21.5	19.0 (2.8)	31.8
3	9.8 (2.2)	39.8	7.0 (0.9)	13.9	13.5 (2.3)	29.5
4	42.1 (6.4)	42.5	7.1 (0.9)	9.2	23.8 (1.2)	29.8
5	44.5 (6.5)	48.0	7.7 (1.9)	11.7	24.2 (3.2)	27.7
6	48.4 (5.6)	65.5	6.3 (1.2)	11.3	26.3 (1.9)	38.7
7	44.3 (9.9)	51.2	5.7 (1.7)	10.2	22.8 (3.1)	34.8
8	42.2 (11.8)	90.3	6.7 (0.8)	9.5	20.9 (1.9)	32.9
9	50.7 (18.9)	57.2	7.4 (1.2)	11.6	24.4 (1.2)	46.1
10	76.4 (N/A)	46.3	19.7 (N/A)	11.8	58.5 (N/A)	35.9

[a] Standard deviations are given in parentheses.

NO_3-N had higher loss rate than K while K had higher loss rate than P for the substrate tested in this study (table 3). The loss rate of NO_3-N, P, and K from the substrate with plants was substantially higher than that from the substrate with no plants when a total of 6.86 g of N, P, and K was initially applied to the substrate (group 10).

The drainage water pH tended to decrease as the total amount of applied N, P, and K increased (fig. 5). When the total amount of N, P, and K applied to the substrate with plants increased from 1.91 to 6.86 g, the average pH decreased from 6.3 to 5.8 for the drainage water collected at 8 days after transplanting, from 6.9 to 6.0 for the water collected at 20 days after transplanting, and from 6.7 to 5.7 for the water collected at 28 days after transplanting, respectively. As nitrate leaches out of the substrate, NH_4-N is the dominant form of N, and as it is taken up by plants, the root zone can acidify. At 8 days after transplanting, there was no apparent difference in drainage water pH levels between substrates with and without plants at different amounts of N, P, and K applied. The pH at 20 and 28 days after transplanting was significantly higher than that at 8 days after transplanting, perhaps because the fine lime particles added during substrate mixing was reacting during this time (Argo and Biernbaum, 1996).

In many nurseries, due to the cost of labor, it is very common to leave containers with dead plants among containers with healthy plants before harvesting. Containers with plants or no plants receive equal treatments for irrigation, rainfall, and fertilizers. Although the total number of containers with no plants was low, its negative and disproportionate impact on the environment due to the nutrient loss from these containers should be considered during production.

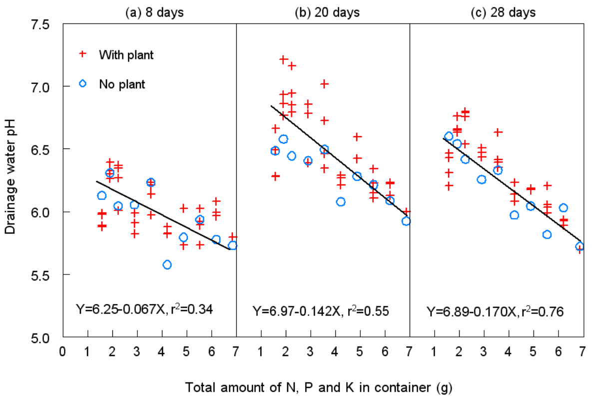

Figure 5. pH level of drainage water from the 2.4-L substrate initially applied with 1 L of water and various amounts of N, P, and K in the nominal 3.8-L container with a plant, or no plant at 8, 20, and 28 days after transplanting.

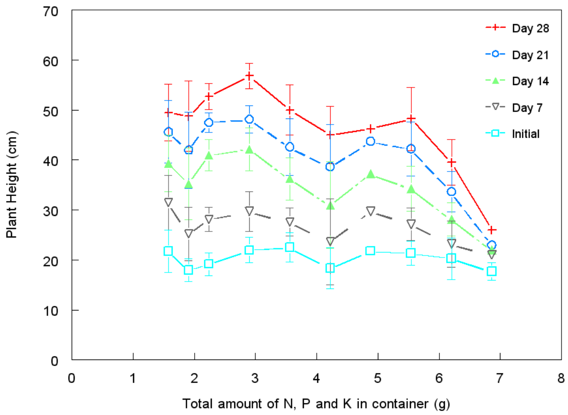

Figure 6. Height of plants with the substrate applied with different amounts of N, P, and K at various growing days after transplanting. Symbols represent the mean of live plant observations (± standard errors) in each fertilizer treatment group.

Plant Growth

Plants in group 4 and higher began to show symptoms of stress within a week after beginning treatments. These symptoms included some wilting and new shoot curling in the highest fertilizer treatments, chlorosis, leaf drop, and eventually marginal necrosis, suggesting the presence of high salts or other root-stresses. During the test, one out of four plants in each of group 4 and 6, two out of four plants in group 7, and three out of four plants in group 10 were dead about 10 days after they were transplanted. Butterfly bush has been reported to have low tolerance to irrigation with recycled water containing salt concentrations at or above 500 mg/L (Wu et al., 1999).

The plants grew faster during the first two weeks than the last two weeks. The total relative plant height increase tended to decrease as the total amount of N, P, and K increased (table 4). The height of plants in group 10 with 6.86 g of total fertilizer applied increased only 40.5% which is much lower than the height increase of other plants during 28 days of test. The plants in group 3 with 2.24 g of total N, P, and K had the highest total relative plant height increase among the 10 groups of plants during the 28 days of the test although the final height and leaf area in group 4 were highest (figs. 6 and 7). Plant size data and the observed mortality of plants in group 4 and higher indicated that fertilizers, especially NO_3-N, should be applied at low rates several times during production to avoid potential salt stress.

Chlorophyll was highest in groups 2 through 9 suggesting adequate nitrogen was supplied to meet the demands in those groups (fig. 8). With higher nitrogen (and other nutrients) in group 10, the plants were stunted and chlorotic. Data in table 5 shows percentage of total N, P, and K existing in plants 28 days after transplanting. The percent N absorbed by plants tended to increase as the total amount of nitrogen applied to the substrate increased from 0.02 (group 1) to 2.02 g (group 7). Similarly, the percent P absorbed by plants tended to slightly increase as the amount of total P applied to the substrate increased from 0.08 to 0.58 g. However, the percent K absorbed by plants was nearly constant for the amount of total K applied to the substrate from 1.48 to 2.76 g.

For the butterfly bush, the critical ranges of N, P, and K content for a healthy plant are reported to be 2.86% to 3.73% for N, from 0.23% to 0.65% for P, and from 1.26% to 2.93% for K (Mills and Jones, 1996). However, data in Table 3 illustrated that plants in the first three groups grew faster than plants in other 7 groups even though the N content in the plants in the first group was lower than the recommended range by Mills and Jones (1996). The fastest butterfly bush growth occurred in group 3 (table 3) in which the percentage

Table 4. Average weekly relative plant height increase with different total amounts of nitrogen (N), phosphate (P), and potassium (K) applied to the substrate with butterfly bush plants in 10 groups of containers.

Group No.	Average Weekly Relative Plant Height Increase (%)[a]			
	Week 1	Week 2	Week 3	Week 4
1	45.2 (4.0)	25.8 (4.4)	16.0 (3.1)	8.8 (3.0)
2	39.9 (20.6)	39.9 (4.1)	19.7 (4.4)	16.8 (5.5)
3	47.1 (6.7)	46.0 (1.4)	16.1 (4.5)	11.0 (1.8)
4	29.8 (8.8)	42.5 (5.2)	14.6 (5.7)	18.1 (1.9)
5	23.0 (6.2)	31.4 (6.1)	17.4 (3.5)	17.7 (4.7)
6	30.5 (12.5)	33.8 (12.2)	26.1 (7.8)	17.9 (10.6)
7	31.4 (3.6)	25.5 (3.0)	17.5 (0.2)	5.7 (1.6)
8	27.1 (9.5)	26.2 (3.5)	23.4 (3.7)	14.2 (2.4)
9	16.0 (7.0)	22.9 (10.1)	19.6 (4.6)	17.4 (4.6)
10	13.5 (N/A)	4.8 (N/A)	4.5 (N/A)	13.0 (N/A)

[a] Standard deviations are given in parentheses.

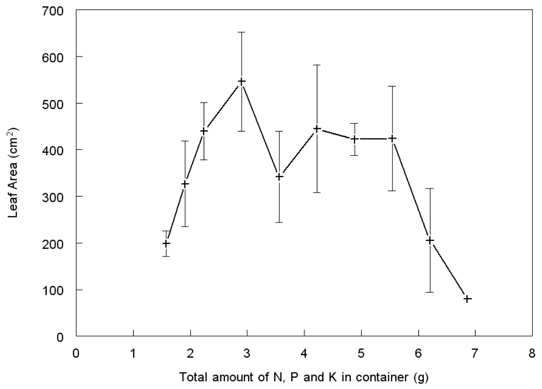

Figure 7. Total projection leaf area of single plants at different amounts of N, P, and K initially applied to the substrate. Symbols represent the mean of live plant observations (± standard errors) in each fertilizer treatment group.

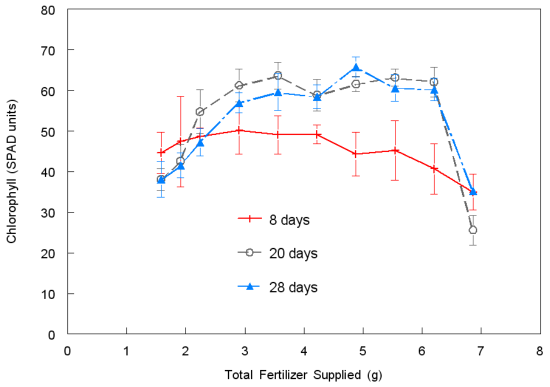

Figure 8. Chlorophyll of butterfly bush plants at 8, 20, and 28 days after transplanting at different amounts of fertilizer initially applied to the substrate. Symbols represent the mean of live plant observations (± standard errors) in each fertilizer treatment group.

Table 5. Percentage of nitrogen (N), phosphate (P) and potassium (K) in plants at 28 days after transplanting.

Group No.	Percentage in Plants		
	N[a]	P	K
1	1.852	0.48	2.74
2	1.737	0.50	2.57
3	2.054	0.42	2.32
4	3.124	0.58	2.72
5	3.443	0.65	2.96
6	3.570	0.64	2.42
7	3.921	0.68	2.47
8	3.425	0.66	2.69
9	4.765	0.74	2.80
10	3.536	0.60	2.73

[a] N – Total nitrogen of NH_4-N and NO_3-N.

of N in a plant was only 2.05% (table 5) while the greatest plant height and leaf area at day 28 occurred in group 4 (figs. 6 and 7) where the percentage of N in a plant was 3.12% (table 5). The plants containing N content lower than the recommended concentrations grew as well as, or better than, the plants containing the recommended N content.

Using the conditions of this study, the highest plant growth rate, the least nutrient loss was obtained with a fertilizer application rate of 0.40 g of N, 0.10 g of P, and no K, which is about one-half the rate that growers typically use.

CONCLUSIONS

- A large portion of fertilizers was lost through drainage when excessive amount of fertilizers was applied to the substrate. The fertilizer rate used by growers was not the optimal rate for the best plant growth and the least nutrient loss through drainage. During the 28-day test, 48.4% of NO_3-N and 6.3% of P were leached away when commonly used fertilizer rates of 0.8 g of NO_3-N and 0.4 g of P were additionally applied to the 2.4-L substrate in a nominal 3.8-L container with plants after transplanting. There are potential plant growth and environmental benefits from reducing the current fertilizer use rates of growers.
- When 0.4 g of N, 0.10 g of P, and 0.16 g of K were applied to the nominal 3.8-L container after transplanting, the substrate had the highest plant growth and the lowest amounts of drainage and nutrient loss. Compared to NO_3-N and P, although the loss rate of K through drainage was very low, the amount of K initially applied to the butterfly bush was much higher than the plant actually needed.
- The relative plant height increase began to decline from their highest levels when the total amount of N, P, and K initially applied to the 2.4-L substrate was 0.42, 0.18, and 1.64 g, respectively. Excess fertilizers applied to the container nursery production resulted in high nutrient loss and low plant growth rate.
- Results from this research provided information on better use of water and major nutrients (N, P, and K) for a nursery production substrate, and optimal nitrogen uptake in the butterfly plants with the substrate. Scientific management strategies and application methods could be recommended based on these research findings to optimize the use of water and fertilizer with highest plant growth and the least nutrient and water loss in container nursery production.

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