Leachate Volume Effects on pH and Electrical Conductivity Measurements in Containers Obtained Using the Pour-through Method

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SUMMARY. Well-established protocols exist for using the pour-through extraction method to estimate substrate pH and electrical conductivity (EC) values for small root volumes. However, little work has been done to test the accuracy and consistency of these measurements in large containers. Our objective was to determine if the amount of distilled water applied to #1, #3, #5, and #10 (2-, 8-, 11-, and 27-L media volume, respectively) containers would affect leachate pH and EC values or consistency of measurements. Boxwood (*Buxus × koreana* ‘Green Velvet’) was selected for this study because it is a common container-grown nursery crop. Distilled water was poured evenly over the media surface in each container 1 h after irrigation to obtain a leachate volume of either 50 mL or 2.5% of media volume and leachate EC and pH were measured. Media pH values were 0.1 to 0.3 points higher when 50 mL leachate was collected, but the difference was only significant during the first 2 weeks of measurements. There were no consistent differences in pH over container sizes or leachate volume. Leachate EC values were similar when measured in leachate collected as 50 mL total volume or 2.5% of media volume in 8- and 11-L containers. However, in 27-L containers, obtaining 50 mL leachate resulted in higher EC values than when 2.5% media volume was obtained. Both pH and EC values obtained from 50-mL leachate fractions over container sizes were more consistent than when 2.5% of the media volume was collected. Growers should collect 50 mL of leachate to test media pH and EC regardless of container size.

Improper nutrient management is one of the primary causes of poor crop quality and plant losses in nurseries and greenhouses. However, few commercial operations routinely monitor the media solution properties related to nutritional status of their container-grown crops. There are three accepted methods for monitoring substrate pH and electrical conductivity (EC) on-site: the pour-through (PT), the saturated media extract, and the 1:2 water:substrate (v/v) suspension test (1:2) (Camberato et al., 2009; Cavins et al., 2000, 2004; Pennisi and Thomas, 2009; Ruter and Garber, 1993). Among these, the PT method is a widely accepted practice for both nurseries and greenhouses.

The PT method is a bulk solution displacement method that was

developed as a simple, rapid, non-destructive, and cost-effective means of monitoring pH, EC, and nutrient availability of soilless substrates, including those that contain slow- or controlled-release fertilizers (Blythe and Merhaut, 2007; Yeager et al., 1983). The PT method as described by Wright (1986) and adapted by Cavins et al. (2008) is as follows. The crop should be irrigated 30 to 60 min before collecting leachate to ensure that the container substrate is at or near full water-holding capacity. If using constant liquid fertilization, the crop should be irrigated with fertilizer solution as usual. A collection vessel is placed under the container. A sufficient amount of distilled water should be applied to the surface of the container so that ≈50 mL of leachate is

collected. Generally, applying 75, 150, or 350 mL of water to #1, #3, and #5 containers is sufficient (Bilderback, 2001; Cavins et al., 2000). The leachate is then collected and pH and EC values are determined.

The advantages of the PT method over other methods are that it is fast, the sampling solution is easily obtained, and it is not destructive (Wright, 1986; Yao et al., 2008). In small containers, the leachate collected by the PT method should sample the solution from the entire root zone. However, as container size increases, it is increasingly difficult to displace the solution from the entire root zone without using large quantities of water. It is unclear how the ratio of applied water to displaced root zone solution affects the pH and/or EC values of the leachate used for testing. If larger amounts of water are used, channeling through the root zone may result in inaccurate and/or inconsistent measurement values resulting from non-uniformity of the substrate and fertilizer distribution within the substrate (Altland, 2006). General recommendations are to collect 50 mL of leachate each time a PT test is conducted for a variety of container sizes up to #1 (Cavins et al., 2000). However, few if any well-defined recommendations exist for leachate volumes of larger containers.

Values of EC obtained with the PT method accurately reflect EC values obtained with more direct measurements taken through media solution samples (Cabrera, 1998). This, combined with the ease of leachate collection and reproducibility, make the PT method an ideal technique for container substrate management. There is little information, however, on the use of this method in large containers.

According to Ruter and Garber (1993) and Cavins et al. (2008), growers do not use the PT method because of 1) lack of uniformity in testing procedures; 2) few recommended values for interpretation;

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
1	mmho/cm	dS·m ⁻¹	1
1	ppm	mg·L ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

and 3) limited knowledge on how to interpret results. Therefore, it is important to identify potential sources of variation such as leachate volume. We tested the effects of two leachate volumes (50 mL or 2.5% of container volume) on the pH and EC values obtained from leachate of four container volumes (2, 8, 11, or 27 L). Our objectives were to determine if leachate volume affected the values obtained or the uniformity of results in large containers.

Materials and methods

The experimental design was a randomized complete block design with four container sizes (2, 8, 11, and 27 L), two leachate volumes (50 mL or 2.5% of container volume), and 10 blocks. For the 2-L containers, 50 mL leachate is the same as 2.5% of substrate volume. Therefore, there were seven treatments and 10 blocks for a total of 70 plants. Data were analyzed using the PROC GLM procedure in SAS (Version 9.1; SAS Institute, Cary, NC). Repeated-measures analysis was used to determine differences among dates.

Plants of 'Green Velvet' boxwood were obtained from commercial nurseries on 25 June 2009. Soilless media was washed from the roots of plants under a stream of tap water and #1 size were transplanted into #1 (2 L) and #3 (8 L) containers; plants of #5 size were transplanted into #5 (11 L) and #10 (27 L) containers. Plants were transplanted into a commercial soilless substrate composed of peat-moss, perlite, and bark (Metro-Mix 510; SunGro Horticulture, Bellevue, WA). Plants were then maintained for 9 weeks at the Purdue Horticulture Plant Growth Facility in West Lafayette, IN. Plants were irrigated (municipal water source) by hand as necessary with acidified water supplemented with water-soluble fertilizer (Peters Excel 21N-2.2P-16.5K; Scotts, Marysville, OH) to provide, according to product label, the following concentration at each irrigation ($\text{mg}\cdot\text{L}^{-1}$): 200 nitrogen, 21 phosphorous, 157 potassium, 1.0 iron, 0.25 copper and boron, 0.5 manganese and zinc, and 0.1 molybdenum. Irrigation water was supplemented with 93% sulfuric acid (Ulrich Chemical, Indianapolis, IN) at $0.08\text{ mL}\cdot\text{L}^{-1}$ to reduce alkalinity to $100\text{ mg}\cdot\text{L}^{-1}$ and pH to a range of 5.7 to 6.0.

Plants were grown in a glass-glazed greenhouse with an exhaust fan and evaporative-pad cooling, radiant hot water, and retractable shade curtains controlled by an environmental computer (Maximizer Precision 10; Priva Computers, Vineland Station, Ontario, Canada). During the course of the experiment, mean temperature was $24.1 \pm 1.8\text{ }^{\circ}\text{C}$ and mean relative humidity was $71.2\% \pm 9.2\%$. Plants were grown under a 16-h photoperiod (0600 to 2200 HR) with supplemental lighting from high-pressure sodium lamps (e-system HID; PARsource, Petaluma, CA). Mean daily light integral over the experimental period was $16.6\text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$.

Beginning on 6 Aug. 2009 (6 weeks after transplanting), leachate was collected weekly from containers using the PT method (Cavins et al., 2008) 1 h after the crop had been irrigated. Distilled water was poured evenly over the surface of each container by hand and the extract was allowed to drain for 10 min into 850-, 1500-, 3000-, and 4000-mL saucers placed under the 2-, 8-, 11-, and 27-L containers, respectively. For each container size, water was applied to obtain either 50 mL or 2.5% leachate (these values are the same for the 2-L container size). Table 1 lists the amount of water applied and average leachate fractions.

Leachate was then analyzed for pH and EC using a handheld pH and EC meter (HI 9811-0; Hanna Instru-

ments, Woonsocket, RI) immediately after leachate collection. After the final leachate measurement, leaf greenness was estimated with a SPAD-502 meter (Konica Minolta, Ramsey, NJ). The average of three readings for the same leaf and three different leaves per plant was recorded from five randomly chosen plants in each treatment.

Results and discussion

We determined the effects of various leachate volumes on the pH and EC values obtained from measurements of leachate from 2-, 8-, 11-, and 27-L containers. Boxwood was used because it is a common container-grown nursery crop. Relative chlorophyll values of boxwood plants were obtained at the completion of the study to confirm uniform appearance among treatments and to identify any chlorosis as a result of watering differences among treatments. The mean SPAD value was 80.9 ± 3.5 for all treatments, which is within the normal range for healthy plants (personal observations). Furthermore, no obvious chlorosis or differences among treatments were identified.

Initial trials were conducted to determine the necessary amount of water applied to various sized containers to obtain either a total leachate volume of 50 mL or 2.5% of the substrate volume. Substrate volume was estimated by filling containers with water to the media level and determining the volume of water. Leachate

Table 1. Container size and volume, target leachate [50 mL (1.7 fl oz) total leachate or 2.5% of media volume], volume of distilled water applied, actual leachate volume, and the leachate (percent media volume) of treatments in the experiment.^z

Container size	Container volume (L) ^y	Target leachate ^x	Volume applied (mL) ^y	Actual leachate (mL)	Leachate (%)
#1	2	2.5%	70	50.6 d ^w	2.53 b
#3	8	2.5%	300	203.4 c	2.54 b
#3	8	50 mL	85	52.9 d	0.66 c
#5	11	2.5%	450	283.6 b	2.58 b
#5	11	50 mL	120	53.5 d	0.49 d
#10	27	2.5%	1600	734.6 a	2.72 a
#10	27	50 mL	150	76.8 d	0.28 e
<i>P</i> value ^v				0.0001	0.0001
Treatment (T)					
Date (D)				NS	NS
T × D				NS	NS

^zContainers planted with boxwood were maintained for 9 weeks. Values presented are the mean of data collected weekly for 4 weeks ($n = 40$).

^y1 L = 0.2642 gal, 1 mL = 0.0338 fl oz.

^xFor 2-L containers, leachate volume of 2.5% = 50 mL.

^wAny two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ based on Tukey's honestly significant difference test.

^vMeans within a category are significantly different at $P \leq 0.001$ based on analysis of variance.

NS = nonsignificant.

was collected weekly over a period of 4 weeks. There were no differences in leachate collected (volume or percent media volume) among the four collection dates nor was there a date $\times$ treatment interaction. Therefore, leachate collection data presented are the mean of the 4 weeks of data collection.

Although it was impossible to obtain exactly 50 mL of leachate for all containers in those treatments, there was no difference in the amount of leachate recovered from containers for the 50-mL treatments regardless of container size (Table 1). To obtain a leachate volume of 50 mL, regardless of the media volume, the volume of water applied to the media surface was 70, 85, 120, and 150 mL of media volume for 2-, 8-, 11-, and 27-L containers, respectively (Table 1). Therefore, the leachate obtained represented a smaller percentage of media volume as container volume increased. It was more difficult to obtain consistent volumes of leachate from the 27-L containers; therefore, the percent leachate (percent media volume) was slightly higher.

The target leachate of 2.5% media volume was achieved in all containers except the 27-L containers (Table 1) because it was difficult to estimate the amount of water to apply to these large containers at each watering, possibly as a result of pore space changes with compaction and/or root growth.

For this experiment, we used a handheld portable pH and EC meter, similar to what would be used in a typical commercial greenhouse or nursery. The average leachate pH over all container sizes and leachate volumes was 6.59, 6.63, 6.46, and 6.70 in Weeks 1, 2, 3, and 4, respectively. There was no consistent change in pH that would suggest a change with time. In Weeks 1 and 2, pH of the 50-mL treatments was higher in all container sizes, but these differences were mostly absent in Weeks 3 and 4 (Table 2). There were no consistent differences in pH of different container sizes, suggesting that existing guidelines for appropriate pH values can be used when measuring leachate from large containers.

A larger volume of distilled water was used to obtain 2.5% leachate than 50 mL leachate in each container and the average pH of distilled and fertilizer water was 6.6 and 6.2, respectively. However, the larger volume of

distilled water used in the 2.5% treatments did not increase the measured pH as we expected. In fact, within a container size, the pH obtained from leachate collected as 50 mL was higher than when obtained from leachate volumes that were 2.5% of media volume (Table 2). Leachate pH of 2.5% of media volume treatments was $\approx 95\%$ to 98% that of 50 mL leachate values from the same sized container.

Leachate EC over all treatments increased slightly with date (Table 3); however, there was no treatment $\times$ date interaction. According to Cavins et al. (2000), leachate volumes over 60 mL can yield lower EC values. However, in studies with #1 nursery containers, increasing the volume of

water applied to the surface of the container from 40 to 100 mL had no influence on nutrients extracted (Yeager et al., 1983). In this study, leachate EC values were similar when measured in leachate collected as 50 mL total volume or 2.5% of media volume in 8- and 11-L containers. However, in 27-L containers, obtaining 50 mL leachate always resulted in higher EC values than when 2.5% media volume was obtained (Table 3). The EC of the distilled water was $0.03 \text{ dS}\cdot\text{m}^{-1}$, and the volume applied and collected was ≈ 10 -fold higher in the 2.5% treatment than the 50 mL treatment in 27-L containers. Therefore, the large volume of low-EC water likely resulted in the leachate

Table 2. pH from leachate collected from 2-, 8-, 11-, or 27-L (0.5, 2.1, 2.9, or 7.1 gal) containers weekly for 4 weeks ($n = 10$).^z

Week no.	Leachate ^y	Container volume (L) ^x				P value ^w
		2	8	11	27	
		Leachate pH				
1	2.5%	6.57 bc ^v	6.54 c	6.33 d	6.57 bc	0.0001
	50 mL		6.68 b	6.65 bc	6.83 a	
2	2.5%	6.68 bc	6.58 cd	6.38 e	6.46 de	0.0001
	50 mL		6.89 a	6.73 b	6.68 bc	
3	2.5%	6.39 bc	6.45 abc	6.40 bc	6.33 c	0.0001
	50 mL		6.60 a	6.55 ab	6.49 abc	
4	2.5%	6.42 c	6.82 a	6.62 b	6.71 ab	0.0001
	50 mL		6.72 ab	6.79 a	6.84 a	

^z2.5% of container volume or 50 mL (1.7 fl oz) was collected from each container. Containers planted with boxwood were maintained for 6 weeks before measurements were begun.

^yFor 2-L containers, leachate volume of 2.5% = 50 mL.

^x1 L = 0.2642 gal.

^wSignificance of mean differences within a week based on analysis of variance.

^zAny two means within a week not followed by the same letter are significantly different at $P \leq 0.05$ based on Tukey's honestly significant difference test.

Table 3. Electrical conductivity (EC) from leachate collected from 2-, 8-, 11-, or 27-L (0.5, 2.1, 2.9, or 7.1 gal) containers weekly for 4 weeks ($n = 10$).^z

Week	Leachate ^y	Container volume (L) ^x				<i>P</i> value ^w
		2	8	11	27	
		Leachate EC (dS·m ⁻¹) ^x				
1	2.5%	2.15 bc ^v	1.97 de	2.25 ab	1.84 e	0.0001
	50 mL		2.09 cd	2.37 a	2.17 bc	
2	2.5%	2.42 bc	2.21 d	2.51 ab	2.01 e	0.0001
	50 mL		2.30 cd	2.57 a	2.36 c	
3	2.5%	2.37 b	2.16 cd	2.46 ab	2.04 d	0.0001
	50 mL		2.33 bc	2.58 a	2.34 bc	
4	2.5%	2.40 bc	2.26 cd	2.54 b	2.12 d	0.0001
	50 mL		2.30 cd	2.72 a	2.54 b	

^z2.5% of container volume or 50 mL (1.7 fl oz) was collected from each container. Containers planted with boxwood were maintained for 6 weeks before measurements were begun.

^yFor 2-L containers, leachate volume of 2.5% = 50 mL.

^x1 L = 0.2642 gal, $1 \text{ dS}\cdot\text{m}^{-1} = 1 \text{ mmho}/\text{cm}$.

^wSignificance of mean differences within a week based on analysis of variance.

^zAny two means within a week not followed by the same letter are significantly different at $P \leq 0.05$ based on Tukey's honestly significant difference test.

water having a lower EC than the substrate solution.

Both pH and EC values obtained from 50-mL leachate fractions over container sizes were more consistent than when 2.5% of the media volume was collected (based on SD calculations, data not shown). This is most likely the result of the dilution of leachate with applied distilled water (Cavins et al., 2000). Therefore, growers should collect 50 mL of leachate to test media pH and EC regardless of container size. This will provide growers with consistent results that can be compared with currently recommended values.

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