Effect of Irrigation, Fertilizer Rate and Placement, and Two Substrates on Growth of Rose and Hydrangea[1]

Anelle Ammons[2], Anthony V. LeBude[3*], James S. Owen, Jr.[4], and Michelle McGinnis[5]

Abstract

Current best management practices for containerized nursery crops maximize plant growth while minimizing nutrient leaching. This study tested how plant growth was affected by reducing the standard fertilizer rate when grown in two soilless substrates with different physical properties under two irrigation levels. Controlled-release fertilizer (CRF) treatments included 1.0x (45g) applied as topdress (TD), 1.0x (45 g) incorporated throughout (IT), or 0.75x (34 g) incorporated into only the top half (TH) of the container. *Rosa* 'BAIneon' Screaming Neon Red™ rose and *Hydrangea* macrophylla 'PIIHM-II' Endless Summer® Bloomstruck® hydrangea were potted using Aeration+Potting Mix (AS40) or All-purpose Potting Mix (PM2) substrates. Plants received higher [12.7 mm (0.5 in)] or lower [8.3 mm (0.33 in)] irrigation per day for 18 weeks. Final dry weight (DW) was most affected by fertilizer, to a lesser extent substrate, and not at all by irrigation. Regardless of taxa, the largest DWs were produced when plants were grown in PM2 and received nutrients via IT or TD compared to TH. Electrical conductivity was greatest in PM2 substrate with a 1.0x fertilizer rate, regardless if applied IT or TD. Taxa were unsaleable in the TH treatment, thus negating the environmental benefits achieved by reductions in leaching from lower fertilization rates.

Species used in this study: 'Screaming Neon Red™' rose (*Rosa* 'BAIneon'); 'Endless Summer® Bloomstruck®' hydrangea [*Hydrangea macrophylla* (Thunb.) Ser.]'PIIHM-II').

Index words: fertilizer placement, substrate, irrigation rate, *Rosa* 'BAIneon', *Hydrangea macrophylla* 'PIIHM-II'.

Significance to the Horticulture Industry

There is an ever-increasing need to more effectively use water and mineral nutrient resources to maximize profitability, minimize environmental impact, and ensure climate resiliency. 'Screaming Neon Red™' rose and 'Endless Summer® Bloomstruck®' hydrangea were produced in 7.3 L (2 gal) of substrate with differing water to air ratio, controlled release fertilizer (CRF) application method, CRF rate, and irrigation volumes via daily cyclic irrigation over an 18-week period. A reduction in daily irrigation from 1.27 cm (0.5 in) to 0.76 cm (0.3 in) had no direct impact on either rose or hydrangea growth. Compared to the Aeration+ Potting Mix (AS40), the All-purpose Potting Mix (PM2), conventionally used by many growers, with 7% more water retention and 5% less air space, increased rose and hydrangea crop shoot growth by 8% and 18%, respectively, most likely due to increased water and nutrient availability and subsequent decreased crop stress. A 0.75x CRF rate incorporated into the top half of the substrate only decreased rose and hydrangea growth on average 14% and 35%, respectively, when compared to the 1x rate of CRF applied as either a top-dress or incorporated throughout the container profile. Future research is needed to look at the interaction between substrate physical properties and fertilizer rate and placement under varying irrigation regimes for high and low feeder crops to identify additional opportunities to conserve resources and possibly increase nursery crop profitability.

Introduction

Water and mineral nutrients are finite resources in container-grown production that are balanced to ensure growth of a healthy and profitable crop. In accordance with best management practices (BMP), growers should apply the least amount of water and fertilizer to maximize plant growth while minimizing nutrient leaching (Bilderback et al. 2013). Substrates do not substantially contribute mineral nutrients independently. Container substrates do provide the physical and chemical properties to form the matrix necessary to balance water and air while delivering the desired nutrient forms for plant utilization (Owen 2007). Conventional substrates in the eastern U.S., comprised primarily of pine bark, reduce and mitigate the risk of being too "wet" by being exceedingly porous (70% to 90% total porosity) and ensure adequate drainage and air exchange (Altland et al. 2018). Finding the right substrate combination, routine irrigation rate and volume, and mineral nutrient supply, growers can optimize utilization of resources by suppling an adequate volume of water to not limit root development and subsequent plant growth, nor leach mineral nutrient latent water from the container.

Received for publication October 18, 2021; in revised form May 20, 2022.

[1] This publication is a portion of a thesis submitted by Anelle Ammons in partial fulfillment of the degree of Master of Science at NC State University. The use of trade or brand names in this publication does not constitute a guarantee or warranty of the product by N.C. State University or USDA-ARS and does not imply its approval to the exclusion of other products or vendors that also may be suitable. We thank Pacific Organics for donating the two substrates.

[2] Formerly Department of Horticulture, N.C. State University, Raleigh, NC 27695. Currently Contract Forester – transmission vegetation management regional programs for Duke Energy Carolinas.

[3] Department of Horticulture, N.C. State University, Raleigh, NC 27695. :.

[4] Department of Agriculture, Agricultural Research Service, Application Technology Research Unit, 1680 Madison Avenue, Wooster, OH 44691.

[5] Formerly Agronomic Field Services Section Chief at the North Carolina Department of Agriculture and Consumer Services, Raleigh, NC 27695.

*Corresponding author to whom reprint requests should be addressed. Email address: avlebude@ncsu.edu.

Refining these production inputs, however, takes a combination of time, management, skill, and technology. Despite positive perceptions about the benefits of wireless sensors, few producers employ these relatively new technologies to monitor substrate water availability or control irrigation frequency, due in part to reliability concerns and cost (Majsztrik et al. 2013). Instead, growers continue to rely on experience, intuition, and weather monitoring. When adoption increases and more marketable technology exists, having cultural practices in place to manage these inputs would benefit improved water and nutrient use efficiency.

Air-filled porosity is the minimum substrate pore volume filled with air when a porometer, a laboratory device used to measure and compare static physical properties (i.e., minimums and maximums) of soilless substrates, is slowly bottom saturated to container capacity and drained in a controlled environment (Fonteno and Harden 2010). Regardless of laboratory procedure or container type, larger sized particles result in larger pores and greater air space, which, in turn, causes less water to be available to plants (Fields et al. 2015). This can cause an inadequate reservoir of water and lead to crop water stress, resulting in reduced plant growth in seedlings (Lea-Cox and Smith 1997). Conversely, smaller pores result in a greater reservoir of capillary water that can last for longer periods of time when smaller sized particles constitute a larger portion of the substrate (Fields et al. 2015); however, too high a percentage of fine particles, and subsequent micropores, can result in water-logged substrates with reduced plant growth from lowered oxygen levels and respiration (Lea-Cox and Smith 1997). Because solutes move through saturated substrates more slowly than unsaturated substrates (Hoskins et al., 2014), the amount of water held within the pores of the substrate during an irrigation event can influence how quickly mineral nutrients move through the container, how much is absorbed by the plant, and how much leaches out of the container.

Leaching of mineral nutrients from controlled release fertilizers (CRF) can be reduced by simply reducing the rate applied (Cabrera et al. 1993, Jackson and Wright 2009) or varying the placement of fertilizer within the container (Hoskins et al. 2014a). For example, CRF incorporated within the substrate results in greater nutrient leaching at the beginning of production (Cox 1993) and throughout the season compared to top dressed (Cabrera 1997, Hoskins et al. 2014a, Warren et al. 1997), presumably because roots have not spread throughout the container to create additional micropores (Altland et al. 2011) or are able to interact with mineral nutrients available throughout the substrate profile. Moreover, prills of topdressed CRF are not in contact with moist substrates continuously, and mineral nutrient salts hydrated and released must travel the distance of the substrate column (i.e., container height) before leaching.

Hoskins et al. (2014) measured nutrient concentrations in 50 ml (1.7 fl oz) increments of effluent leached from containers during a simulated irrigation event. The nutrient loads leached for both incorporated and top dressed CRF peaked within the first 50 mL (1.7 fl oz) of effluent then diminished quickly (Hoskins et al. 2014). When the CRF was dibbled, placing the entire mass of fertilizer in one place under the plant (centered about halfway down the column of the container), the peak mineral nutrient concentration was not measured until 150 mL of effluent was collected. Thus, if less irrigation was used and nutrients were dibbled, rather than topdressed or incorporated, fewer nutrients might have leached from containers at each irrigation event. In that study, greater volumes of irrigation were applied to capture all nutrients that might leach during irrigation. A similar total concentration of nutrients was leached for incorporated and dibbled CRF, but not topdressed. For example, fifteen weeks after potting, approximately 22% of nitrate-N remained in the substrate for both incorporated and dibbled treatments, whereas 54% remained for topdressed (Hoskins et al. 2014a). A similar trend occurred for ammonium-N (NH_4-N). Topdressed CRF reduces total leaching over the growing season, but this means more mineral nutrients remain unused within the container system. Thus, the preferred cultural practice would be to place the CRF similarly to a dibble and minimize irrigation and subsequent leachate to ensure retention and crop use of mineral nutrients, possibly resulting in a fertilizer rate reduction while maintaining optimal crop growth.

Additionally, water tends to move preferentially through channels in the substrate (Hoskins et al. 2014b); therefore, fully incorporated fertilizer only in the top half of the container would allow water to interact with fertilizer more than with dibbling, while still avoiding the loss of nutrients from the bottom of the container at the beginning of the growing season. Placement of 25% fewer nutrients incorporated into just the top half of the substrate coupled with reduced irrigation levels might capitalize all factors into reduced leaching and reduced nutrient use and similar plant quality. Therefore, this study tested the effect of irrigation rate, substrate air-filled porosity, and fertilizer placement and rate on substrate EC and pH levels and subsequent crop growth.

Materials and Methods

On 30 May 2017, 0.76 m^3 each (one cubic yard) of two pine bark substrates, *Aeration+* Potting Mix (AS40) and *All-purpose* Potting Mix (PM2) from Pacific Organics (Henderson, NC) with differing physical properties (B. Oakley, Pacific Organics, unpublished data, Table 1) were amended with 0.68 kg (1.5 lb) of a micronutrient package (Micromax, ICL, Dublin OH) and pH adjusted with 3.78 kg (7 lb) lime comprised of 1.59 kg (3.5 lb) pelletized dolomitic lime and 1.59 kg (3.5 lb) pulverized lime. AS40 contains pine bark particles 1.6 cm (5/8 in) or less while PM2 contains pine bark particles 1.3 cm (0.5 in) or less. Trade #2 (7.3 L, C900 Nursery Supplies, Chambersburg, PA) containers were filled with substrates with fertilizer being the treatment. A 18N:1.7P:6.6K 8-9-month CRF (18-4-8, Harrell's LLC, Lakeland, FL) rate and method of application was as follows: 45 g per container top dressed after potting (TD, high label rate for topdress), 45 g per container incorporated throughout the substrate (IT,

Table 1. Physical properties of two pine bark substrates, *Aeration+* Potting Mix (AS40) and *All-purpose* Potting Mix (PM2)[z].

Substrate	Total porosity (by vol)	Container capacity (by vol)	Airspace (by vol)	Bulk density (g/cc)	Bulk density (lb/cu.ft)
AS40	79%	39%	40%	0.19	11.9
PM2	81%	46%	35%	0.18	11.5

[z]Data obtained from Pacific Organics, Inc., Henderson, NC, May 2017.

medium label rate for incorporation), and 34 g per container (0.75x rate) incorporated into the top half only of the substrate (TH, low label rate for incorporation). For the TD application, fertilizer was spread evenly over the top of the surface after planting. The IT placement was pre-mixed using an incorporation rate 6.11 kg of CRF per cubic meter (10.3 lb per cubic yd) and then used to fill the containers. The TH containers were first pre-filled to half the container height with approximately 3.7 L (1 gal) of substrate not containing any CRF and then the remainder of the volume (approximately 1 gal) was filled with pre-mixed substrate with CRF mixed throughout at the 1.5x rate [9.14 kg per m^3 (15.4 lb per cu yd)], resulting in a 0.75x CRF rate on a per container basis.

Rosa 'BAIneon' Screaming Neon Red™ rose and *Hydrangea macrophylla* 'PIIHM-II' Endless Summer® Bloomstruck® hydrangea (Bailey Nurseries, Inc., Yamhill, OR) were planted, and fertilizer was applied as a top dress for the TD treatments. All plants were watered thoroughly using overhead impact sprinklers (P5R, Rainbird Corporation, Azusa, CA, U.S.) and placed in a randomized complete block design (within each irrigation treatment, see below) on an outdoor uncovered gravel container pad at the Mountain Horticultural Research Station in Mills River, NC (USDA Plant Hardiness Zone 7a). Irrigation treatments were applied as a split block with each block replicated twice. For the irrigation treatments, either the higher rate [12.7 mm (0.50 in)] or the lower rate [8.3 mm (0.33 in)] of water was applied daily. Both volumes were applied cyclically at 0800, 1200, and 1600 HR up until 9 WAP, then increased to 17 mm (0.67 in) and 11.2 mm (0.44 in), respectively. Irrigation water was provided from a well with pH 6.3, electrical conductivity (EC) 0.12 $mS{\cdot}cm^{-1}$, and 37 ppm total alkalinity.

The pour-through extraction method (LeBude and Bilderback 2009) was used to measure pH and EC for two randomly selected replications at 4, 8, 12, and 18 WAP using a portable meter (Model HI9813-5, Hanna Instruments, Woonsocket, RI). At 18 WAP, all plants were severed at the substrate level, then all stems and leaves were dried together for 72 hours at 70 C (158 F) and weighed.

A split block experimental design was used to accommodate two overhead irrigation treatments. Each irrigation block was replicated twice. In each irrigation treatment block were 2 substrate and 3 fertilizer placement treatments replicated four times for a total of 96 containers per species (2 blocks, 2 Irrigation treatments, 2 substrate treatments, 3 fertilizer placement treatments, 4 replications per treatment within a block). Data were processed using SAS® University Edition (SAS® Institute Inc., Cary, NC) to run analysis of variance, means separation and multiple regression. Tukey's honest significant difference (HSD) was used to weight block, irrigation, substrate, and fertilizer for each separate species. The relationship between both EC and pH to irrigation rate, substrate, and fertilizer treatment for each WAP was evaluated using multiple regression, means separation, and Tukey's HSD; data were pooled when nonsignificant by averaging within each block, and then the two blocks were averaged together.

Results and Discussion

Dry weight of aboveground biomass for both species was affected by substrate and fertilizer, but not irrigation or any of their interactions (Table 2). When averaged over fertilizer and irrigation treatments, plants of both species grown in the PM2 substrate had larger dry weights than those grown in AS40 (Table 3). When results for fertilizer treatments were averaged over substrates and irrigation, plants for both species had similar dry weights when grown in TD and IT, but higher than those grown in TH (Table 4). After 18 weeks, saleable plants of both hydrangea and rose were produced in both 1.0x treatments (TD and IT), but not 0.75x (TH) (Table 3).

Nutrient availability for both species differed as a result of weeks after potting (WAP), fertilizer placement, and substrate, but not irrigation as a main effect (Table 2). Numerous interactions, however, occurred between the variables. For example, the average EC for rose over both irrigation treatments was 0.78 $mS{\cdot}cm^{-1}$; however, when EC was regressed on WAP for each treatment, the release rate for the higher irrigation was linear ($P=0.03$, $r^2=0.95$), while for the lower irrigation rate the response was quadratic ($P=0.07$, $r^2=0.99$) (Fig. 1), due in part to the high EC at 4 WAP compared to the precipitous decline 8 WAP. The EC response in hydrangea was linear for both treatments (higher, $P=0.07$, $r^2=0.86$) (lower, $P=0.03$, $r^2=0.95$), and similarly to rose, the low irrigation regime was affected by a high EC 4 WAP (Fig. 1). Hydrangea in the lower irrigation treatment had a mean EC of 0.70 $mS{\cdot}cm^{-1}$ while for the higher irrigation rate it was 0.58 $mS{\cdot}cm^{-1}$, which on average was less than that of rose. This indicates that irrigating less may increase the EC over time by reducing leaching, and hydrangea may require more nutrients compared to rose to produce the same biomass.

Electrical conductivity was greater in PM2 substrates for rose (0.90 ± 0.12 $mS{\cdot}cm^{-1}$) and hydrangea (0.70 ± 0.08 $mS{\cdot}cm^{-1}$) than measured for those same species grown in AS40 (rose=0.59 ± 0.07 $mS{\cdot}cm^{-1}$, hydrangea=0.51 ± 0.05 $mS{\cdot}cm^{-1}$) when averaged over all other treatments. Both substrates received the same nutrients; however, nutrients were more available in PM2 due in part to the combination of smaller particle size and greater water holding capacity (Table 1), keeping the nutrient solution in the container. This supports the finding that plants of both

Table 2. Analysis of variance for electrical conductivity (EC) and pH readings taken at 4, 8, 12, and 18 weeks after potting (WAP) and dry weight 18 WAP, for treatments with low and high irrigation levels, two substrates with differing physical properties, and three fertilizer treatments for rose and hydrangea cultivars.

	Rosa 'BAIneon'						*Hydrangea macrophylla* 'PIIHM-II'					
	EC		pH		Dry weight		EC		pH		Dry weight	
Source	DF	Pr > F	DF	Pr > F	DF	Pr > F	DF	Pr>F	DF	Pr>F	DF	Pr > F
WAP	3	<0.001	3	<0.001			3	<0.001	3	<0.001		
Irri[z]	1	0.921	1	0.491	1	0.876	1	0.464	1	0.577	1	0.555
WAP*irri	3	0.008	3	0.003			3	0.047	3	0.003		
Subs[y]	1	0.005	1	<0.001	1	0.046	1	0.005	1	0.001	1	0.003
WAP*subs	3	0.342	3	0.692			3	0.360	3	0.750		
Irri*subs	1	0.502	1	0.189	1	0.899	1	0.712	1	0.407	1	0.314
WAP*irri*subs	3	0.862	3	0.439			3	0.940	3	0.203		
Fert[x]	2	<0.001	2	<0.001	2	0.006	2	<0.001	2	<0.001	2	<0.001
WAP*fert	6	<0.001	6	<0.001			6	<0.001	6	<0.001		
Irri*fert	2	0.407	2	0.061	2	0.445	2	0.747	2	0.001	2	0.934
WAP*irri*fert	6	0.572	6	0.559			6	0.947	6	0.653		
Fert*subs	2	0.069	2	0.035	2	0.574	2	0.119	2	0.014	2	0.240
WAP*fert*subs	6	0.059	6	0.027			6	0.646	6	0.193		
Irri*fert*subs	2	0.680	2	0.665	2	0.700	2	0.818	2	0.302	2	0.559
WAP*irri*fert*subs	6	0.980	6	0.887			6	0.100	6	0.350		

[z] irri=irrigation.

[y] subs=substrate.

[x] fert=fertilizer.

species were larger when grown in PM2 (Table 3). Initial moisture content was not measured in either substrate prior to potting and wetting agents were not added; therefore, it is possible that neither substrate reached container capacity during the experiment due to low hydration efficiency of unamended pine bark (Fields et al. 2014). The AS40 substrate may have been at a particular disadvantage of not providing a saturated substrate because of the combined low irrigation volume, large airspace, and preferential channeling of water as it moves through drier substrates (Hoskins et al. 2014b). Nevertheless, PM2 likely retained more pore water with mineral nutrients compared to AS40 in both irrigation treatments and would act similarly in

Table 3. Dry weight 18 weeks after potting for rose and hydrangea cultivars grown in two soilless substrates or receiving three different fertilization methods[z].

	Rosa 'BAIneon'	*Hydrangea macrophylla* 'PIIHM-II'
Main Effect	Mean (g) ± SE	Mean (g) ± SE
Substrate[y]		
AS40	91.0 ± 2.4a	86.4 ± 3.2a
PM2	98.3 ± 2.7b	101.9 ± 3.9b
Fertilizer[x]		
TD	101.3 ± 2.7a	101.9 ± 3.7a
IT	97.3 ± 3.4a	111.4 ± 3.3a
TH	85.5 ± 2.7b	69.1 ± 2.8b

[z] Means followed by a different lowercase letter are significantly different ($P<0.05$), within a main effect, using Tukey's honestly significant difference.

[y] *Aeration+* Potting Mix (AS40) and *All-purpose* Potting Mix (PM2) substrates averaged over low and high irrigation levels and three fertilizer treatments.

[x] 1.0x rate top dressed (TD), 1.0x rate incorporated throughout the container (IT), and 0.75x rate incorporated in the top half only (TH) averaged over low and high irrigation rates and two substrates with differing physical properties.

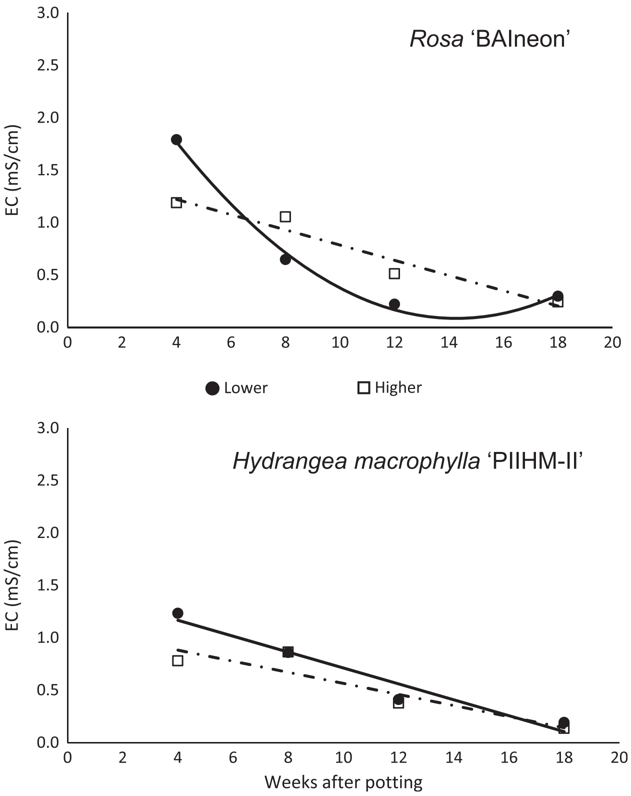

Fig. 1. Electrical conductivity (EC) (mS/cm) of *Rosa* 'BAIneon' at lower (filled circle) ($EC= 3.33-0.46WAP+0.02WAP^2$ $P=0.07$, $R^2=0.99$; solid line) and higher irrigation (unfilled square) ($EC= 1.51-0.07WAP$, $P=0.03$; $R^2=0.94$, dashed line) and *Hydrangea macrophylla* 'PIIHM-II' at lower ($EC= 1.47-0.08WAP$, $P=0.03$, $R^2=0.95$; solid line) and higher irrigation ($EC= 1.09-0.05WAP$, $P=0.07$, $R^2=0.86$; dashed line) at 4, 8, 12, and 18 weeks after potting (WAP). Data points are means averaged over two substrates with differing physical properties, three fertilizer treatments, and four replications (n=24).

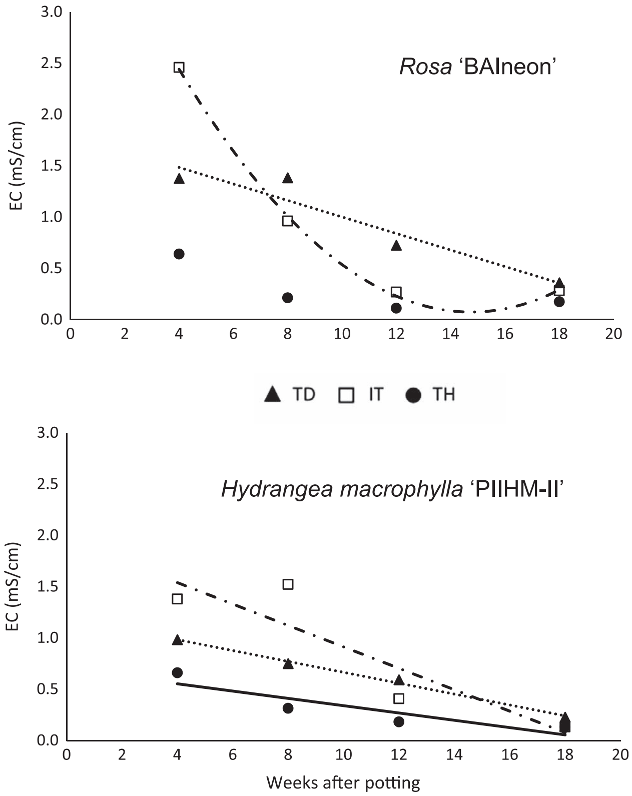

Fig. 2. Electrical conductivity (EC) (mS/cm) for *Rosa* 'BAIneon' (Top graph) and *Hydrangea macrophylla* 'PIIHM-II' (Bottom graph), respectively, for fertilizer treatments 1.0x rate top dressed (TD) (filled triangles) (EC=1.81-0.08WAP, P=0.05, R^2=0.91 and EC= 1.18-0.05WAP, P=0.01, R^2=0.97, dotted line), 1.0x rate incorporated throughout (IT) (unfilled squares) (EC= 4.53-0.60WAP+0.02WAP^2, P=0.04, R^2=0.99 and EC= 1.96-0.10WAP, P=0.10, R^2=0.80; dashed line), and 0.75x incorporated in the top half only (TH) (filled circles) (not significant and EC=0.70 -0.04WAP, P=0.11, R^2=0.80) at 4, 8, 12, and 18 weeks after potting (WAP). Data points are means averaged over lower and high irrigation rates, two substrates with differing physical properties, and four replications (n=16).

container culture in the green industry given similar conditions.

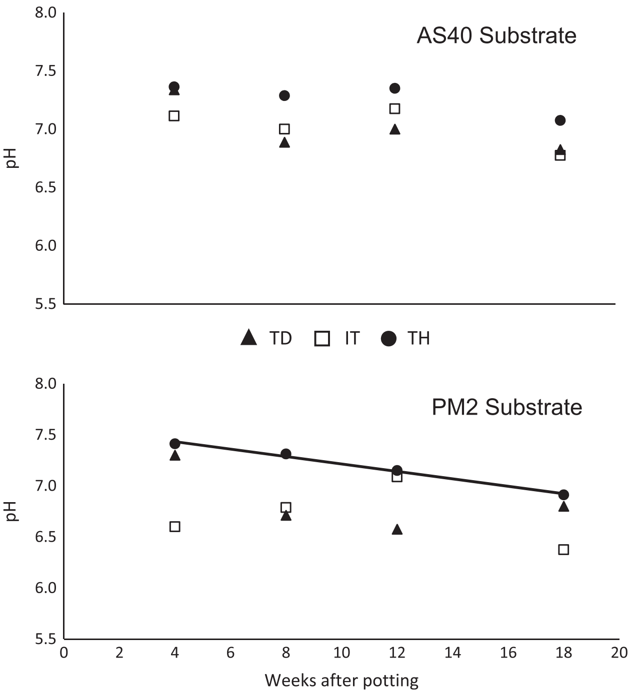

Fig. 3. Average pH for treatment combinations in containers of *Rosa* 'BAIneon': *Aeration+* Potting Mix (AS40) (Top graph) and 1.0x rate top dressed (TD) (filled triangles) (not significant); AS40 with 1.0x rate incorporated throughout the container (IT) (unfilled squares) (not significant); AS40 with 0.75x incorporated in the top half of the container (TH) (filled circles) (not significant); *All-purpose* Potting Mix (PM2) (Bottom graph) with TD (filled triangles) (not significant); PM2 with IT (unfilled squares) (not significant); and PM2 with TH (filled circles) (pH=7.58-0.04WAP, P=0.01, R^2=0.99, solid line) at 4, 8, 12, and 18 weeks after potting (WAP). Data points are means over lower and higher irrigation levels and four replications (n=8).

The EC of rose and hydrangea grown in the three fertilizer treatments depended on the week after potting interaction. Therefore, the relationship of EC was regressed on WAP for each fertilizer treatment (Fig. 2). In rose, substrate EC had a linear relationship in the TD treatment, quadratic for IT, and not significant for TH (Fig. 2). In hydrangea, the three relationships were all linear, with TD and TH treatments having almost identical slopes (0.05 and 0.04, respectively), while IT had a steeper release rate (slope=0.10). In both species, substrate in the IT treatment had higher initial EC values before releasing mineral nutrients more quickly over the 18 weeks (Fig. 2). Higher initial EC values and quicker mineral release rates for incorporated treatments compared to topdress is consistent with other reports (Cabrera 1997, Warren et al. 1997). Electrical conductivity release relationships were similar for TD and TH, but EC values of TH were significantly lower. Clearly, there were not enough available nutrients in the TH treatment to produce enough biomass for sale.

For both species, the pH was affected by substrate, fertilizer, and WAP, but not irrigation application volume (Table 2). Due to numerous interactions among the main effects (Table 2), Figure 3 is used to illustrate the relationships among fertilizer application method within a substrate. For rose, substrate pH was affected by the WAP by fertilizer by substrate interaction; however, there was a linear relationship only for the PM2 TH treatment combination (Fig. 3). In hydrangea, the WAP by fertilizer interaction showed a linear relationship for TH fertilizer application (pH=6.97+0.12WAP-0.01WAP^2, P=0.04, R^2=0.99). The highest pH occurred for the TH treatment in both substrates (7.3), with the pH in the TD AS40 treatment (7.2) also being similar, which might indicate the interaction. Even though the range of pH values among treatments was only 0.5 units when averaged over 18 weeks, the overall pH depended on the substrate and fertilizer treatments in both species. The most likely justification for the observed shift in pH was altered pH buffering capacity as a function of substrate particle size and subsequent surface area, where the finer particles had less ability to buffer specifically from basic solutions or processes (Pancerz and Altland 2020). Therefore, pH in turn could potentially impact mineral nutrient availability to the crop when outside recommended acidic ranges, especially if greater variation occurred (e.g., 1.0 pH unit) at the upper or lower threshold of the desired pH.

The TH treatment applied 25% less fertilizer and produced roses 16% smaller in weight than TD and 12% smaller than IT (Table 3). Hydrangeas grown with TH were 32% smaller than TD and 38% smaller than IT (Table 3), which is consistent with previous studies showing roses can be grown at fertilizer rates lower than recommended (Cabrera et al. 1993), and that hydrangeas are less adept at water uptake in dryer substrates than other species (O'Meara et al. 2014). This indicates that roses accumulate more biomass per nutrient rate than hydrangea, especially if the available water volume containing nutrients is low. Clearly, more nutrients than 0.75x were needed to grow saleable plants with these two species. The low irrigation rate was chosen to reduce leaching and increase available mineral nutrients, but this treatment in conjunction with PM2 failed to produce saleable plants for either species when treated with 0.75X TH. When a 1.0x rate was applied as two 0.5x rates, six months apart, EC values also never reached levels that produced saleable plants (Ivy et al. 2002). Nevertheless, the combination of substrates with increased water holding capacity, lower fertilizer rates placed within the top half of the container, and with low irrigation rates is still intriguing to reduce leaching, as well as reduce use of other inputs. Air filled porosity of PM2 was 35%, which is outside the 10-30% range recommended by best management practices (Bilderback et al. 2013). Perhaps using a substrate with less airspace might retain more nutrients in a reduced fertilizer treatment, especially if amended with coir to improve water distribution and unsaturated hydraulic conductivity when applying less irrigation volume (Fields et al. 2017). Choosing the correct fertilizer and irrigation rate by species can offer advantages in cost savings without loss of quality in plants but requires more work to determine which combination of low to intermediate fertilizer rate within the top half works well with plants of similar nutrient use efficiency rates. Some of these might include lower nitrogen rate users such as *Euonymus, Heuchera,* or *Spiraea*. Additionally, amendments to substrates that increase the water holding capacity without sacrificing air space considerably would be beneficial.

Literature Cited

Altland, J.E., J.S. Owen, Jr., B.E. Jackson, and J.S. Fields. 2018. Physical and hydraulic properties of commercial pine-bark substrate products used in production of containerized crops. HortScience 53:1883–1890.

Altland, J.E., J.S. Owen, Jr., and M.Z. Gabriel. 2011. Influence of pumice and plant roots on substrate physical properties over time. HortTechnology 21:554–557.

Bilderback, T., C. Boyer, M. Chappell, G. Fain, D. Fare, C. Gilliam, B.E. Jackson, J. Lea-Cox, A.V. LeBude, A. Niemiera, J. Owen, J. Ruter, K. Tilt, S. Warren, S. White, T. Whitewell, R. Wright, and T. Yeager. 2013. Best management practices: Guide for producing nursery crops. South. Nur. Assoc., Acworth, GA. 176 p.

Cabrera, R.I. 1997. Comparative evaluation of nitrogen release patterns from controlled-release fertilizers by nitrogen leaching analysis. HortScience 32:669–673.

Cabrera, R.I., R. Evan, and J. Paul. 1993. Leaching losses of N from container-grown roses. Scientia Horticulturae 53:333–345.

Cox, D.A. 1993. Reducing nitrogen leaching losses from containerized plants: The effectiveness of controlled release fertilizers. J. Plant Nutr. 16:533–545.

Fields, J.S., J.S. Owen, Jr., and H.L. Scoggins. 2015. Exploring the influence of particle size on plant water availability in pine bark substrates. Proc. 60th Ann. Rpt. South. Nur. Assoc. 60:19–27.

Fields, J.S., W.C. Fonteno, and B.E. Jackson. 2014. Hydration efficiency of traditional and alternative greenhouse substrate components. HortScience 49:336–342.

Fonteno, W.C. and C.T. Harden. 2010. North Carolina State University Horticultural substrates lab manual. North Carolina State University, Raleigh, NC. 27 p.

Hoskins, T.C., J.S. Owen, Jr., J.S. Fields, J.E. Altland, Z.M. Easton, and A.X. Niemiera. 2014. Solute transport through a pine bark-based substrate under saturated and unsaturated conditions. J. Amer. Soc. Hort. Sci. 139:634–641.

Hoskins, T.C., J.S. Owen, Jr., and A.X. Niemiera. 2014a. Controlled-release fertilizer placement affects the leaching pattern of nutrients from nursery containers during irrigation. HortScience 49:1341–1345.

Hoskins, T.C., J.S. Owen, Jr., and A.X. Niemiera. 2014b. Water movement through a pine-bark substrate during irrigation. HortScience 49:1432–1436.

Ivy, R.L., T.E. Bilderback, and S.L. Warren. 2002. Date of potting and fertilization affects plant growth, mineral nutrient content, and substrate electrical conductivity. J. Environ. Hort. 20:104–109.

Jackson, B.E. and R.D. Wright. 2009. Changes in chemical and physical properties of pine tree substrate and pine bark during long-term nursery crop production. HortScience 44:791–799.

Lea-Cox, J.D. and I.E. Smith. 1997. The interaction of air-filled porosity and irrigation regime on the growth of three woody perennial (citrus) species in pine bark substrates. Proc.42nd Ann. Rpt. South. Nur. Assn. 42:169–174.

LeBude, A.V. and T.E. Bilderback. 2009. The pour-through extraction procedure: a nutrient management tool for nursery crops. NC Cooperative Extension AG-717-W. 8 pp.

Majsztrik, J., E. Lichtenberg, and M. Saavoss. 2013. Ornamental grower perceptions of wireless irrigation sensor networks: results from a national survey. HortTechnology 23:775–782.

O'Meara, L., M.R. Chappell, and M.W. van Iersel. 2014. Water use of *Hydrangea macrophylla* and *Gardenia jasminoides* in response to a gradually drying substrate. HortScience 49:493–498.

Owen, Jr., J.S. 2007. Clay amended soilless substrates: Increasing water and nutrient efficiency in containerized crop production. Ph.D. Diss. NC State Univ. Raleigh. 259 p.

Owen, Jr., J.S., A.V. LeBude, M. Chappell, and T. Hoskins. 2016. Advanced irrigation management for container-grown ornamental crop production. Virginia Cooperative Extension Publication HORT-218P. 18 p.

Pancerz, M. and J.E. Altland. 2020. pH buffering in pine bark substrates as a function of particle size. HortScience 55:1817–1821,

Warren, S.L., T.E. Bilderback, and H.H. Tyler. 1997. Does method of fertilizer application (surface or incorporation) affect nutrient losses of controlled release fertilizers? Proc. 42nd Ann. Rpt. South. Nur. Assoc. 42:141–143.