Water Use and Fertilizer Response of Azalea Using Several No-leach Irrigation Methods

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SUMMARY. **Although research has shown that plants grown with subirrigation systems such as ebb-and-flow and capillary mat require less water and fertilizer inputs than traditional overhead irrigation methods, similar information for capillary wick irrigation has not been available. We compared the growth and water use response of azalea (*Rhododendron* sp. 'George Tabor') grown in 6.5-inch-diameter "azalea" containers with three irrigation methods [overhead (OVR), subirrigation (SUB), and capillary wick (WCK)] and four fertilizer nitrogen (N) rates 0.5 to 2.0 lb/yard^3 supplied by an incorporated, resin-coated, controlled-release fertilizer (Nutricote 17N–3.1P–6.7K, 180 d at 77 °F). OVR volume was adjusted to deliver 100% of evapotranspiration (ET) loss. For all irrigation treatments, the lowest N rate resulting in maximum plant growth was 1.0 lb/yard^3, which was less than the label recommendation of 1.5 lb/yard^3. At the N-limiting N rate of 0.5 lb/yard^3, irrigation method had no effect ($P < 0.05$) on azalea growth. At N rates higher than 1.0 lb/yard^3, decreased growth was observed for OVR compared with SUB and WCK. This negative effect on plant growth was attributed to salt injury as indicated by excessive pour-through electrical conductivity (EC) levels in OVR containers. At the end of the experiment, substrate EC was highest in the uppermost layer of SUB and WCK containers, reflecting the upward movement of water associated with these two irrigation methods. Water use efficiency, which ranged from 1.9 to 2.8 g shoot dry weight per liter of water lost through ET, was unaffected ($P < 0.05$) by irrigation method at the N rate of 1.0 lb/yard^3. We concluded that the growth response of azalea to fertilizer N rate was similar for WCK and SUB despite periodic pour-through EC tests indicating higher substrate nutrient levels with WCK.**

Traditional greenhouse irrigation systems (e.g., sprinkler, hand-watering, drip, ebb-and-flow, and so on) require some form of decision-making to schedule irrigation. Decision-making, which ranges from grower-based judgment to more complex mechanical processes such as computer-controlled tensiometer-triggered irrigation, is based on the effect that evapotranspiration (ET) has in lowering substrate moisture levels. Because information is typically derived from sampling a small fraction of all containers, there is an inherent uncertainty that the "one-size fits all" irrigation schedule will be effective for all plants in an irrigation zone. Alternatively, irrigation systems can be designed to provide a constant and consistent supply of water at a rate driven directly by the plant's need, i.e., ET.

Constant supply irrigation systems such as capillary mat and capillary wick (WCK) irrigation have the potential to optimize plant growth and crop uniformity while maximizing irrigation efficiency. Capillary mat is an absorbent material typically underlain with impervious plastic, which when placed on top of a bench can supply water to the containers through substrate contact and capillary action (Henley, 1982; van Iersel and Nemali, 2004). The effectiveness of capillary mat irrigation can be limited by the inability of these systems to maintain consistent matting wetness without applying excessive quantities of water. Bryant and Yeager (2002) reported that more than 80% of water applied to wet capillary matting resulted in runoff. Capillary wick is an alternative irrigation system that relies on the capillary movement of water from a reservoir directly into the container substrate via an absorbent wick (Dolan and Keeney, 1971; Henley, 1997; Toth et al., 1988; Yeager and Henley, 2004). The wick maintains a constant substrate moisture level in the container so that the rate of water movement is directly related to ET loss. Bryant and Yeager (2002) found that compared with overhead irrigation, capillary wick irrigation reduced cumulative irrigation volume 86% without sacrificing plant growth.

Traditional subirrigation systems such as ebb-and-flow and flood-floor irrigation (Barrett, 1991; Neal and Henley, 1992) are closed systems that allow for the recirculation of irrigation water. For these systems, containers are placed in trays or other confined structures that can be periodically flooded to allow irrigation water to move into the substrate through capillary movement. Because water is applied periodically, substrate moisture levels using traditional subirrigation decrease between irrigation events. Therefore, although both capillary wick and traditional subirrigation methods such as ebb-and-flow rely on the capillary movement of water into the container substrate and are considered water-conserving systems, traditional subirrigation systems result in variable substrate moisture levels, whereas capillary wick irrigation results in uniform substrate moisture levels.

Precision irrigation systems designed to minimize container leachate have the capacity to reduce fertilizer

Unit

To convert U.S. to SI, multiply by	U.S unit	SI unit	To convert SI to U.S., multiply by
0.01	%	$g \cdot g^{-1}$	100
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.5933	lb/yard^3	$kg \cdot m^{-3}$	1.6856
1	mmho/cm	$dS \cdot m^{-1}$	1
28.3495	oz	g	0.0353
7.4892	oz/gal	$g \cdot L^{-1}$	0.1335
1	ppm	$mg \cdot L^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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requirements. For example, constant-feed liquid fertilizer rates can generally be halved or greatly reduced when changing from surface to subirrigation watering (Barrett, 1991; Dole et al., 1994). Similarly, reduced controlled-release fertilizer (CRF) rates are recommended when capillary mat irrigation is used (Havis, 1982). When leaching is reduced or eliminated, buildup of fertilizer salts as indicated by elevated substrate EC levels can reduce plant growth if fertilizer rates are not adjusted properly (Haver and Schuch, 1996). Information on the fertilizer requirements of capillary wick-irrigated plants compared with other irrigation systems is needed. The purpose of this study was to compare capillary wick irrigation with overhead and subirrigation methods with regard to irrigation and fertilizer use efficiency. Our hypothesis was that capillary wick irrigation would be more efficient than the other irrigation methods owing to its favorable effect in maintaining a continuous and uniform distribution of moisture in the container substrate. To test this, we measured total water use by an azalea crop fertilized at several N rates and compared dry weight gain relative to the amounts of water and fertilizer applied. Azalea was selected because it responds well to fertilizer nutrients and is sensitive to excessive salt levels, which can result using subirrigation methods.

On 7 Dec. 2004, azalea liners (32 per standard trade 1020 tray) were planted one per 6.5-inch-diameter "azalea" container (ITML Horticultural Products, Brantford, Ont., Canada) containing 1.5 L of Metro Mix 500 (Sungro Horticulture; Bellevue, Wash.), a soilless substrate consisting of pine bark, vermiculite, sphagnum peatmoss, and processed pine bark ash. The substrate fill height was 11 cm. The substrate was amended with dolomitic limestone and contained a proprietary macronutrient and micronutrient fertilizer charge designed to supply nutrients for the first several irrigation events. One polyester absorbent wick (DBellco, New Berlin, Wis.) 24-cm long, 1.7-cm wide, and 1.5-mm thick was placed along the container wall and out one drain hole in one-third of all pots before filling with substrate. The top of the wick was 3 cm below the substrate surface and the tail extended 15 cm from the bottom of the container. A resin-coated CRF (Nutricote 17N–3.1P–6.7K, 180 d at 77 °F; Florikan, Sarasota, Fla.) was incorporated into the substrate by hand at 2.6, 5.2, 7.8, or 10.4 g/container. These CRF rates were equivalent to N application rates of 0.5, 1.0, 1.5, and 2.0 lb/yard^3, respectively. Containers were placed in a fan-and-pad-cooled glasshouse that excluded 45% of *PAR*. Minimum temperatures were maintained above 16 °C. Average daily minimum, maximum, and average temperatures in the greenhouse during the experiment were 17, 37, and 22 °C, respectively. Containers were arranged in a split-block design with four blocks, three irrigation practices as main plots, four fertilizer N rates as subplots, and three plants per treatment block (n = 12). Twice during the first week after planting and before irrigation treatments were initiated, all containers were hand-watered using a hose and breaker nozzle attachment.

Starting 1 week after planting, plants were grown under one of three irrigation treatments: periodic overhead (OVR) watering, periodic subirrigation (SUB), and continuous wick. Both OVR and SUB containers were irrigated every 1 to 4 d depending on demand. Demand was indicated when SUB containers in one indicator block lost 0.2 to 0.3 L of water through ET. For OVR, each container was weighed to the nearest gram and the loss in weight from the previous irrigation was considered ET loss. This amount (1 g = 1 mL) was then poured over the substrate surface so that OVR resulted in zero or minimal leachate. After 30 min, OVR containers were weighed again and this value was considered the weight after irrigation. To account for changes in plant weight and substrate moisture retention properties, every ≈4 weeks, OVR containers were brought to container capacity by applying water in increments of 25 mL until leachate drainage was observed. These new container capacity weights were used for making subsequent determinations of irrigation application volumes for OVR containers. For SUB, four containers (one per block-N rate) were weighed before and after each subirrigation event to determine both the ET loss from the previous irrigation and the amount of water applied. SUB was accomplished by placing each container in a 1-gal plastic tub containing 1 L of water (3-cm depth). After 20 min, each container was lifted out of its tub and placed on a perforated plastic plate set on top of the tub to allow drainage to fall back into the tub. For capillary wick, each container was placed on top of a water-filled, 1-L plastic reservoir with the wick tail extending downward through a 0.75-inch-diameter hole drilled in the lid of the reservoir (Fig. 1). The container remained on top of the reservoir so that the wick supplied water continuously through capillary action into the substrate. On days we irrigated OVR and SUB containers, four (one per block-N rate) WCK container-and-reservoir assemblies were weighed, refilled with water, and then weighed again. Weight loss from the previous irrigation was calculated as ET loss. The water used for irrigation was from a municipal source and contained <0.03 mg·L^{-1} of nitrate-N, <0.02 mg·L^{-1} of orthophosphate-P, and <1.2 mg·L^{-1} of K.

Starting on week 3 and once every 3 weeks afterward, we conducted a pour-through (PT) substrate test 2 h after irrigation. We applied enough deionized water to collect 50 mL of leachate from each of three containers per treatment and determined the EC of the filtered leachate.

The experiment was ended on 31 Mar. 2005, 16 weeks after planting. Shoot size index [(shoot height + shoot width)/2] was determined. Shoot height was the distance from the substrate surface to the top of the canopy. Shoot width was the average of two perpendicular measurements with one measurement being the widest shoot width. After the final irrigation, plant shoots were cut at the substrate surface, dried at 70 °C for 48 h, and weighed. The root balls of four containers per treatment were removed from the container and divided into three 3.5-cm horizontal layers. Substrate was sampled from each layer and water content and EC (1 soil:2 water by volume) determined. Water use efficiency was calculated as grams of shoot dry weight per cumulative liters of water lost through ET and was determined only for containers for which ET was measured (n = 4). Analysis of variance of the split-plot design was performed using the PROC GLM procedure of

Fig. 1. The wick irrigation assembly consisted of a 6.5-inch-diameter (16.51 cm) "azalea" container placed over a water-filled, 1-L (0.26-gal) plastic reservoir with a 0.75-inch-diameter (1.91-cm) hole cut in the lid. An absorbent wick positioned along the inner wall and out a drain hole of the container extended into the reservoir through the hole in the lid to allow for continuous capillary wetting of the container substrate.

SAS (version 8.0; SAS Institute, Cary, N.C.) with mean separation by least significant difference at the $P < 0.05$ confidence level.

Results and discussion

The growth response of azalea to fertilizer N rate depended ($P < 0.05$) on the irrigation method (Table 1). For all three irrigation methods, maximum shoot dry weight and shoot size index were observed at the N rate of 1.0 lb/yard³. The fact that this N rate was less than the CRF label recommendation for azalea of 1.5 lb/yard³ was likely the result of the non-leaching irrigation methods used. There was no difference ($P < 0.05$) in shoot dry weight or shoot size index resulting from the irrigation method at the N-limiting N rate of 0.5 lb/yard³. The interaction ($P < 0.05$) between N rate and irrigation method was the result of differences in azalea growth response to irrigation method at the N rates of 1.5 lb/yard³ and 2.0 lb/yard³. At N rates of 1.5 lb/yard³ and 2.0 lb/yard³, shoot dry weight was reduced with OVR, but not SUB and WCK. Under the zero-leach conditions of this experiment, OVR in

Table 1. Influence of irrigation method and fertilizer rate on the growth and water use of azalea grown in 6.5-inch-diameter (16.51-cm) containers.[z]

Irrigation method	Fertilizer N rate (lb/yard³)[y]	Shoot dry wt (g/plant)[x]	Shoot ht (cm)[w]	Shoot width (cm)	Shoot size index[v] (cm)	ET (L/container)[u]	WUE ($g \cdot L^{-1}$)[t]
Overhead	0.5	23.9	32.1	48.1	40.1	9.5	2.53
	1.0	27.1	33.0	49.0	41.0	9.5	2.80
	1.5	24.2	29.5	47.1	38.3	11.0	2.24
	2.0	22.9	29.1	45.3	37.2	10.1	2.29
Subirrigation	0.5	22.1	32.4	43.4	37.9	10.7	2.03
	1.0	28.7	34.7	52.0	43.5	10.6	2.65
	1.5	30.0	34.0	50.5	42.3	10.5	2.82
	2.0	30.3	31.7	49.7	40.7	11.0	2.62
Capillary wick	0.5	25.9	31.8	48.5	40.1	12.5	1.92
	1.0	29.1	38.3	48.5	43.4	12.6	2.47
	1.5	28.1	33.2	50.0	41.5	11.6	2.59
	2.0	27.7	29.8	50.1	39.9	11.7	2.46
$LSD_{0.05}$ within irrigation		3.1	3.5	4.4	2.5	1.3	0.53
$LSD_{0.05}$ between irrigation		4.7	4.0	4.7	2.9	1.9	0.59
Source				*Significance* ($P < F$)			
Irrigation method (I)		0.177	0.085	0.280	0.044	0.641	0.046
N rate (N)		0.0001	0.0001	0.025	0.0001	0.017	0.953
I × N		0.0001	0.170	0.005	0.032	0.015	0.007

[z]Resin-coated, controlled-release fertilizer [Nutricote 17N–3.1P–6.7K, 180 d at 77 °F (25.0 °C); Florikan, Sarasota, Fla.] was incorporated into the peat-bark-based substrate (Metro Mix 500; Sungro Horticulture, Bellevue, Wash.). Overhead irrigation volume was 100% of evapotranspiration (ET) between irrigations (zero leaching). Water use efficiency (WUE) was calculated as grams of shoot dry weight per liter of water lost through ET. Mean separation by least significant difference at the $P = 0.05$ level ($LSD_{0.05}$); n = 12 (n = 4 for ET and WUE).

[y]1 lb/yard³ = 0.5933 $kg \cdot m^{-3}$.

[x]1 g = 0.0353 oz.

[w]1 cm = 0.3937 inch.

[v]Shoot size index = (shoot height + shoot width)/2.

[u]1 L = 0.2642 gal.

[t]1 $g \cdot L^{-1}$ = 0.1335 oz/gal.

combination with N rates of 1.5 lb/yard^3 or higher resulted in PT substrate EC levels higher than 4 $dS \cdot m^{-1}$ during most of the experiment (Fig. 2). Because PT EC levels higher than 2 $dS \cdot m^{-1}$ may cause salt injury to sensitive plants (Haver and Schuch, 1996), the high N rates likely reduced plant growth of zero-leach, OVR plants through this phytotoxic effect.

At the optimal N rate of 1.0 lb/yard^3, WCK method increased ET loss 33% (12.6 vs. 9.5 L/container) and 19% (12.6 vs. 10.6 L/container) compared with OVR and SUB, respectively (Table 1). We attributed this effect to greater substrate evaporation losses that accompany a continuous supply of water to the substrate with the WCK method. Water use efficiency for all treatments ranged from 1.9 to 2.8 $g \cdot L^{-1}$. At the N rate of 1.0 lb/yard^3, water use efficiency was unaffected ($P < 0.05$) by irrigation method and averaged 2.6 $g \cdot L^{-1}$. The decrease in water use efficiency values for OVR at the high N rates reflected reduced shoot growth associated with these treatments.

Pour-through EC measurements provided some insight on the release of nutrients from the CRF under the different irrigation methods (Fig. 2). Much higher PT EC levels were observed with OVR than for WCK and SUB methods. One would expect that with typical overhead irrigation, in which the water application volumes are adjusted to provide a significant leaching fraction (e.g., 20%), that PT EC levels would not be as high as they were in this zero-leach experiment (Lang and Pannkuk, 1998). Considerably lower PT EC values were observed for SUB than for OVR and WCK throughout the experiment, even at high N rates. The low PT EC values for SUB may have been in part the result of the uneven distribution of substrate EC in the container (Table 2). For both WCK and SUB, highest substrate EC levels at the end of the experiment were observed in the uppermost third of the substrate reflecting the upward movement of water and salts associated with these irrigation methods. Because of this uneven distribution of substrate EC, it is possible that the PT technique reflected the substrate EC status of lower rather than the upper substrate depths. In contrast to SUB and WCK, substrate EC in OVR containers was uniformly distributed and PT EC values reflected the higher EC levels observed for the lower substrate depth. These results suggest that some protection against salt injury resulting from high CRF application rates was provided by SUB and WCK as a result of localization of high salt concentrations.

Substrate water content after the final irrigation was higher for WCK than for OVR and SUB at all three sampled depths (Table 2). Fertilizer rate had no effect ($P < 0.05$) on substrate moisture content and therefore means were averaged over N rates. Capillary wick irrigation supplied water continuously during production and thus the substrate remained fully hydrated and hydrophobic properties were minimized. Because substrate dried out periodically with OVR and SUB, a certain degree of hydrophobic character was likely sustained resulting in lower water contents after irrigation than observed for WCK. The lower water content of OVR container substrate at the middle and bottom depths may have contributed to the higher PT EC

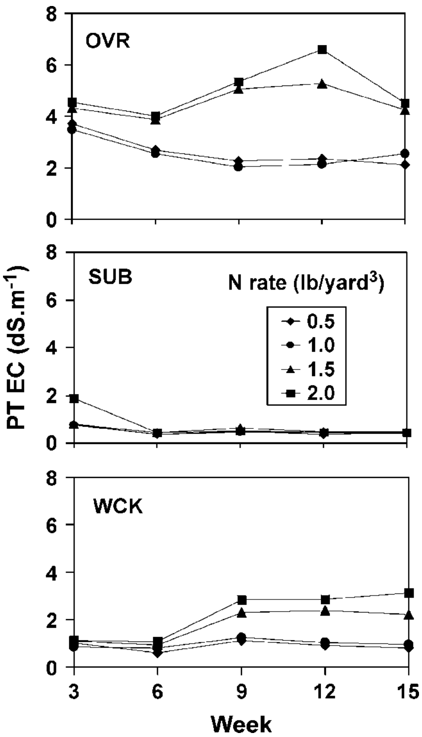

Fig. 2. Effect of fertilizer N rate and irrigation method on periodic pour-through (PT) substrate EC during greenhouse production of azalea in 6.5-inch-diameter (16.51-cm) containers. Resin-coated, controlled-release fertilizer [Nutricote 17N–3.1P–6.7K, 180 d at 77 °F (25.0 °C); Florikan, Sarasota, Fla.] was incorporated into the peat–bark-based substrate (Metro Mix 500; Sungro Horticulture, Bellevue, Wash.). The three irrigation methods were overhead (OVR), subirrigation (SUB), and capillary wick (WCK). OVR irrigation volume was adjusted to deliver 100% of evapotranspiration. Effects of fertilizer rate and irrigation method were significant for each test date with a significant ($P < 0.05$) interaction between the two factors observed for weeks 9, 12, and 15 (n = 3); 1 lb/yard^3 = 0.5933 $kg \cdot m^{-3}$, 1 $dS \cdot m^{-2}$ = 1 mmho/cm.

Table 2. Effect of irrigation method on electrical conductivity (EC) and water content of substrate sampled at three depths in 6.5-inch-diameter (16.51-cm) azalea containers at the end of the experiment.[z]

	Irrigation method		
Sample depth[y]	Overhead	Subirrigation	Capillary wick
		Substrate EC ($dS \cdot m^{-1}$)[x]	
Top (0–3.5 cm)	1.10[w]	1.96	1.03
Middle (3.5–7 cm)	1.06	0.35	0.54
Bottom (7–10.5 cm)	0.96	0.27	0.56
		Gravimetric substrate water content ($g \cdot g^{-1}$)[v]	
Top (0–3.5 cm)	3.18[u]	3.20	3.99
Middle (3.5–7 cm)	3.24	3.87	4.55
Bottom (7–10.5 cm)	3.50	4.24	5.06

[z]Substrate EC was determined in a 1 soil:2 water (by volume) filtered extract. Substrate water content was determined after irrigation. Overhead irrigation volume was 100% of evapotranspiration loss between irrigations (zero leaching) and was applied at the same time as subirrigation; capillary wick irrigation was designed to provide a constant supply of water to containers. Means were averaged over four controlled-release fertilizer N rates [0.5, 1.0, 1.5, and 2.0 lb/yard^3 (0.30, 0.59, 0.89, and 1.19 $kg \cdot m^{-3}$)] as fertilizer rate had no effect ($P < 0.05$) on the substrate depth distribution of substrate EC or substrate water content. Least significant difference at the $P = 0.05$ confidence level ($LSD_{0.05}$) was used to compare means within and between irrigation methods (n = 12).

[y]1 cm = 0.3937 inch.

[x]1 $dS \cdot m^{-1}$ = 1 mmho/cm.

[w]$LSD_{0.05}$ (within irrigation method) = 0.36, $LSD_{0.05}$ (between irrigation method) = 0.58.

[v]1 $g \cdot g^{-1}$ = 100%.

[u]$LSD_{0.05}$ (within irrigation method) = 0.15, $LSD_{0.05}$ (between irrigation method) = 0.26.

values observed in these regions through a concentrating effect on fertilizer salts. Higher substrate water content at the uppermost depth was evidence that water movement to the surface during WCK irrigation is appreciable (Table 2). One concern with WCK irrigation was the possibility of creating excessively wet substrate conditions that can increase the incidence of root rot pathogens (Benson, 1986). The fact that we did not observe this problem despite obtaining higher substrate moisture contents with WCK suggests that the saturation of capillary pore spaces in the substrate did not come at the expense of lowering adequate substrate aeration.

Currently, capillary wick irrigation is used primarily for maintenance irrigation of interior plants and the technology has not been developed for large-scale commercial plant production. However, our results suggest it has the potential to be an effective zero-leach irrigation method producing quality azaleas, a crop that can be sensitive to excessively wet substrates. We hypothesized that WCK, by providing consistent substrate moisture levels, may improve fertilizer N efficiency compared with SUB. However, this was not the case as azalea growth response to N was similar for both SUB and WCK, although periodic PT EC levels were higher for WCK compared with SUB. We concluded that growth of azalea, which is sensitive to fertilizer salt and excessive water contents, can be grown successfully with capillary wick irrigation and at fertilizer rates comparable to subirrigation, generally regarded as a fertilizer efficient irrigation method.

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