Managing water and oxygen for optimum rooting©

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INTRODUCTION

Propagation of unrooted cuttings requires high humidity and frequent irrigation events through mist emitters to hydrate cuttings. Container substrate is maintained at a high moisture level, which increases the risk of low oxygen availability and root pathogens such as *Pythium* (Chérif et al., 1997). Oxygen is essential to plants for healthy root growth and nutrient uptake. Oxygen can be supplied to roots through either air-filled pores in container substrate or through dissolved oxygen (DO) in irrigation water. The diffusion of oxygen gas is approximately 10,000 times greater in air compared to in water and oxygen solubility in water decreases as temperature increases. There are limited data on the use of oxygen injecting technology to increase the dissolved oxygen levels in irrigation water for use in greenhouse production. The objective was to measure the effect of ambient "tap" or oxygenated water on DO in irrigation water, root substrate, and on root growth during propagation and finished plant production.

METHODS

The experiments were carried out at the University of Florida Environmental Horticulture Research Greenhouse Complex in Gainesville, Florida. The water source in all experiments was greenhouse tap water. The main water types were ambient "tap" water which was either not oxygenated (6 to 7 mg L^{-1}) or oxygenated water (25 to 30 mg L^{-1}). Oxygenated water was injected (Mazzei) with pure oxygen as water flowed at 1.8 GPM or 7 LPM that increased DO three times above saturation. Dissolved oxygen was measured in water and substrate with an optical oxygen sensor (NeoFox, Ocean Optics). Data were analyzed in SAS (SAS Version 9.4; SAS Institute, Cary, North Carolina) using ANOVA with Tukey's Honestly Significant Difference (HSD) at p=0.05 for mean separation.

Propagation plant trial

The propagation plant trial ran for two weeks during late March to April 2016. There were two factors of water type (oxygenated or ambient water) and plant species (*Calibrachoa* × *hybrida* 'Aloha Kona Dark Red' and *Lobelia erinus* 'Bella Aqua') in a factorial design. The water types were pumped through propagation nozzles (Coolnet Pro Fogger, Netafim, droplet size of 69 microns) to separate sections on a bench. Calibrachoa and lobelia unrooted cuttings were transplanted in 102-count trays (20.3 mL $cell^{-1}$). Trays were filled with a 60:40 peat:perlite substrate. Irrigation frequency was high for the first three days and gradually decreased. The average day temperature was 22.5°C and average percent relative humidity was 72%. Root length, root and shoot dry mass were measured on day 7 and 14.

Persistence of supersaturated DO in water over time

Dissolved oxygen was measured over time to study the effect of water type (ambient tap or oxygenated water) and water movement (not stirred or stirred at 100 gal h^{-1} or 378.5 L h^{-1}) on DO persistence in water. The water type was held in an unpressurized 5-gal or 18.9-L container. There were three replicate containers for each combination of water type and water movement. Dissolved oxygen was measured in water at 4-cm depth from the surface over time (0, 30, 90, 150, 210, and 270 min.).

Dissolved oxygen measured for the irrigation system

Dissolved oxygen was measured in tap water or oxygenated water at three delivery points. The water delivery points consisted of (1) an initial "source tank", (2) "bench no

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nozzle" where water was pumped from the source tank through an irrigation line to an open container, and (3) a "bench with nozzle" point where water was pumped from the source tank through an irrigation line and then a propagation nozzle.

Plant trial in pots

Calibrachoa, *Lobelia* and *Pelargonium* 'Patriot Red' (geranium) rooted cuttings were transplanted into pots (4-in diameter containers). Plants were irrigated when the average of 6 pots dried to 45% of container capacity allowing for wet-dry cycles. Tap water with soluble fertilizer (17-4-17 at 150 ppm) was supplied without oxygenation ("ambient") or was passed through the oxygen injector ("oxygenated"). Water was delivered through top watering or subirrigation (180 mL). The average day temperature was 25.3°C. A sub-group of geranium plants were grown to measure the effect of water type (oxygenated or ambient water) and substrate moisture level (medium of 45% or high at 80% of CC) on plant growth. Total root length, root, and shoot dry mass were measured after 4 weeks of growth.

Substrate-oxygen levels measured in pots

The objective was to measure the effect of water type (oxygenated or ambient water) and applied water volume at two depths (2 and 4 cm) on substrate-DO without plants. Substrate (60:40 by volume peat:perlite) was filled in pots. The pots were subirrigated overnight and drained to container capacity. The applied water volume to substrate was based on percent container volume from 0 (0 mL, 0% CC), 25 (106 mL, 44% CC), 50 (212 mL, 87% CC), 100 (425 mL, 175% CC), and 200% (850 mL, 350% CC) also shown was the actual water added and reference to percent container capacity. A toothpick was used to indent the substrate prior to inserting the oxygen sensor. Oxygen sensor and temperature probe was allowed to equilibrate for 40 to 120 s before recording a measurement.

RESULTS AND DISCUSSION

Propagation plant trial

Oxygenation of irrigation water did not increase or decrease root growth compared with ambient water. All plants were rooted by day 7. There were no differences observed in root or plant growth when compared by species for water type on day 7 or 14 (Table 1). Species difference showed that *Calibrachoa* had greater total dry mass at day 7 and grew faster than *Lobelia* by day 14. It is likely that there were no observed effects of water type on plant growth because water that passed through fine mist emitters equaled 100% DO saturation (Figure 1).

Table 1. The propagation trial showed no effect of water type on root or shoot growth of *Calibrachoa* or *Lobelia* cuttings.

Plant species	Water type	Day 7		Day 14			
		Root length (cm)	Total dry mass (g)	Root length (cm)	Shoot dry mass (g)	Root dry mass (g)	Total dry mass (g)
Calibrachoa	Ambient	8.7	0.053	128	0.071	0.017	0.088
Calibrachoa	Oxygenated	8.8	0.051	123	0.078	0.018	0.096
Lobelia	Ambient	7.3	0.020	81	0.026	0.011	0.037
Lobelia	Oxygenated	7.3	0.019	69	0.027	0.012	0.039
Summary of ANOVA analysis							
Water type		NS	NS	NS	NS	NS	NS
Species		NS	***	***	***	***	***
Water type*species		NS	NS	NS	NS	NS	NS

NS = not significant.

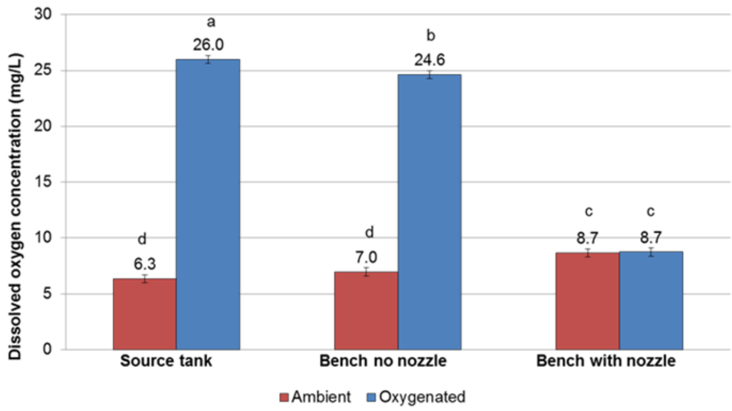

Figure 1. Water that passed through the bench with nozzle equaled 100% DO saturation regardless of water type.

Persistence of supersaturated DO in water over time

Dissolved oxygen in ambient tap water was not affected by the movement of water and the average DO was 7.1±0.05 mg L^{-1} (mean±standard error). Oxygenated water that was not stirred initial DO was 28.3 mg L^{-1} and after 4.5 h. DO was 26.5 mg L^{-1}. Dissolved oxygen in oxygenated water decreased from an initial measurement of 26.8 to 16.9 mg L^{-1} (a 37% decrease) after 4.5 h. Oxygenated water that was stirred decreased in DO because the movement of water increases the surface area of water exposed to air and supersaturated water holds more DO than water can hold at a given temperature. The DO in water held in unpressurized containers after 4.5 h. was 208 and 324% of saturation for oxygenated water that was stirred and non-stirred, respectively.

Dissolved oxygen measured for the irrigation system

At the source tank ambient tap water DO was measured at 6.3 and 26.0 mg L^{-1} for oxygenated (Figure 1). Water that was pumped from the source tank through irrigation lines and out of the bench no nozzle or hose end slightly decreased for oxygenated water compared to ambient water. Water that passed through the bench with nozzle, a fine mist emitter equaled 100% DO saturation at 8.7 mg L^{-1}, regardless of water type. Fine water droplets increases the surface area of water exposed to air (Vestergaard, 1984; Schröder, 1994; Schröder and Lieth, 2002) that resulted in an increase in DO for ambient tap water and like-wise off-gassed oxygen in supersaturated water.

Plant trial in pots

During the trial, irrigating plants with oxygenated water did not increase or decrease rooting or plant growth. All plants were healthy and grew vigorously. There was a slight but statistically significant increase in shoot and root dry mass for lobelia with ambient water (Table 2) compared to oxygenated water. Top watering increased root growth in *Calibrachoa* compared to subirrigation. There were no treatment effects on geranium growth (data not shown). In the geranium sub-group, there was greater root length and root dry mass for "high" moisture level compared to "medium" moisture level (Table 3). Although, water was delivered to pots without passing through a fine breaker and oxygenated water was shown to increase substrate-DO (Figure 2) there were no benefits of irrigating with oxygenated water. In container substrate oxygen can also be supplied to roots through air-filled pores. Peat substrate contains high air porosity even at container capacity (Argo et al., 1996; DeBoodt and Verdonck, 1971; Handreck and Black, 1994) and measured in 4-in diameter pots at 19%. In other studies, plants with adequate supply of oxygen at the root zone generally showed no growth benefits by irrigating with oxygenated water (Bonachela et al., 2005, 2010). However, corn grown under low oxygen and saturated root zone conditions observed an increase in plant growth by irrigating with oxygenated water (Lei et al., 2016).

Table 2. Effect of water type and delivery method on plant growth for *Calibrachoa* and *Lobelia* grown in pots and analyzed by species.

Plant species	Water type	Water delivery	Root length (cm)	Shoot dry mass (g)	Root dry mass (g)
Calibrachoa	Ambient	Top watered	2277	2.98	0.22
Calibrachoa	Oxygenated	Top watered	2320	3.08	0.21
Calibrachoa	Ambient	Subirrigated	1896	2.47	0.16
Calibrachoa	Oxygenated	Subirrigated	1923	2.84	0.19
Summary of ANOVA analysis for *Calibrachoa*					
Water type			NS	NS	NS
Water delivery			*	NS	*
Water type*water delivery			NS	NS	NS
Lobelia	Ambient	Top watered	2917	2.14	0.30
Lobelia	Oxygenated	Top watered	2685	1.90	0.26
Lobelia	Ambient	Subirrigated	2748	1.99	0.28
Lobelia	Oxygenated	Subirrigated	2361	1.91	0.23
Summary of ANOVA analysis for *Lobelia*					
Water type			NS	*	*
Water delivery			NS	NS	NS
Water type*water delivery			NS	NS	NS

NS = no significance, * = significant at p=0.05 level.

Table 3. Effect of water type and substrate moisture level on plant growth of *Pelargonium* 'Patriot Red' (geranium).

Plant species	Water type	Moisture level	Root length (cm)	Shoot dry mass (g)	Root dry mass (g)
Geranium	Ambient	Medium	1273	4.97	0.41
Geranium	Oxygenated	Medium	1236	4.91	0.42
Geranium	Ambient	High	1608	6.03	0.50
Geranium	Oxygenated	High	1566	5.12	0.45
Summary of ANOVA analysis					
Water type			NS	NS	NS
Moisture level			**	NS	*
Water type*moisture level			NS	NS	NS

NS = no significance, * = significant at p=0.05 level.

Substrate-oxygen levels measured in pots

When a large volume of oxygenated water was applied an increase in substrate-DO was observed. The application of ambient water did not change the substrate-DO and the average DO was 8.5 mg L^{-1} at 2-cm depth (Figure 2). The substrate-DO was generally lower at the deeper depth by 1.8 mg L^{-1} measured from 2 cm compared to 4 cm (data not shown). The addition of oxygenated water resulted in an increase in substrate-oxygen from 8.6 to 14.5 mg L^{-1} (a 68% increase) with increasing water applied (from 0 to 200% container volume) at 2-cm depth. To provide a practical point of reference, 100% of container volume represented 14 oz (425 mL) of water for a 4-in diameter pot which is more water than normally applied in a typical irrigation.

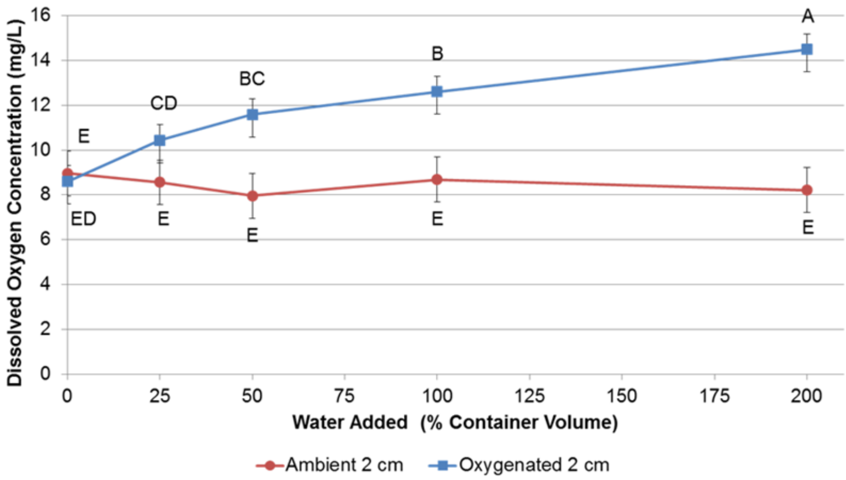

Figure 2. There was a positive increase in substrate-DO as the applied volume for oxygenated water increased compared to ambient water.

CONCLUSIONS

In the propagation trial, there were no differences in root or plant growth with mist propagation of oxygenated or ambient tap water. Oxygenated water held in unpressurized containers remained supersaturated after 4.5 h. Water that passed through fine mist emitters equaled 100% DO saturation regardless of water type by increasing the droplet surface area.

Continued growth of transplants in 4-in pots showed that irrigating with oxygenated nutrient supplemented water did not enhance root or plant growth of three bedding plants. Slight differences were measured with *Calibrachoa, Lobelia* and geranium, however those differences were not of practical significance for plant growth. Oxygenated water increased the substrate-DO by 68% when water was applied from 0 to 200% of container volume. Adding oxygenated water to an already saturated container substrate is not a recommended approach to irrigation management. Drying down the substrate is more likely to be effective by allowing pores to fill with air (oxygen). Container substrate with high porosity and irrigation management are essential to roots and healthy plant growth.

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