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Where Did the Water Go?

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Summary

Particles in a substrate create a network of pathways for water to move through, with size and shape determining the efficacy of these channels. Reduced particle size diversity can lead to excessive leachate, poor substrate hydration, and an inefficient irrigation practice. This research was designed to examine the water capture characteristics of peat, coir, and pine bark using three initial moisture contents (MC) of 67%, 50%, and 33% (by weight) through subirrigation under three time-interval pulse irrigation regimens. The objective was to determine the impact of differing irrigation event durations (5, 10, 20) over a 60-min total period of time, water depth, and initial moisture on the initial water capture rate of these three substrates. Initial capture rate (ICR) was influenced by MC, irrigation water depth, and inherent substrate characteristics (hydrophobicity / hydrophilicity). Initial moisture content had the greatest impact on peat, regardless of water depth or pulsing time. Lower moisture conditions increased the hydrophobic characteristics of peat, lessening the amount of water it was able to capture in the first irrigation event with the ICR of peat never reaching 1 mL/min at 33% MC. Pine bark had a 2 mL/min decrease in initial capture rate across 67, 50, and 33% MCs, while coir's hydrophilic nature reduced any moisture content affects. At 50% MC or less, coir had the highest capture rate across all substrates, pulsing durations, and water depths. Water depth was found to increase capture 2-4 mL/min across all substrates (aside from 33% MC peat). While pulsing time produced variable results, with an

increase in pulsing time not always equaling the added volume of water from the 5 min treatment. Ultimately, these three substrates portrayed benefits to irrigation capture that further research is needed to understand. Pine bark captured more water under low moisture equal to or better than 50% and 67% MC while coir and peat exhibited higher water retention abilities (peat at higher MCs). Engineering substrates to combine or enhance these characteristics could allow growers to decrease irrigation rates and frequencies while still producing healthy, viable crops. It is believed to be feasible to select substrate components (or types) to fit the irrigation delivery method and container type of a grower to achieve maximum irrigation efficiency for different crops.

INTRODUCTION

Water use efficiency of horticultural soilless substrates represents one of the largest variables in container plant production. With nearly 21,500 acres of land devoted to greenhouse operations in the U.S., representing a 148% increase since 1998, growers specializing in container plant production need to understand how irrigation technique can impact the water use efficiency of soilless substrates (USDA, 2014). As water quality, conservation, and scarcity concerns increase, as well as operational costs, growers must adopt new strategies to maintain the sustainable use of water to confront water-climate policy (González et al., 1992; Deccache et al., 2014; Egea et al., 2017; Montesano et al., 2018). Understanding the components that make up a substrate allows a better understanding of substrate properties and their management and further increases the ability to structure substrate tendencies to production practices. Components are classified as the individual materials (peat, coir, pine bark, perlite, wood, etc.) that, when mixed together, make up the substrate.

Whether ebb-and-flow, flood-floor, capillary mat or other systems, subirrigation is a popular technique in container plant production with the ability to control the application of water, further increasing the operation efficiency (Dole et al., 1994; Uva and Weiler, 2001). The economic benefits of a subirrigation system can be a lower labor requirement (compared to traditional overhead systems) and an even application of water, leading to a more uniform crop (Elliott, 1990; Uva et al., 1998). Subirrigation systems have the ability to reduce application runoff (Klock-Moore and Broschat, 1999) further reducing water and fertilizer costs, which are a few key points in the use of this irrigation practice. Compared to overhead and surface irrigation systems, subirrigation was found to consistently reduce overall water use due to the recollection and reuse of water in the system (Davis et al., 2008, 2011; Dumroese et al., 2007; Elliott, 1990). The objective of this experiment was to understand the effect of pulsing irrigation techniques and initial moisture content on the initial water capture of peat, coir, and pine bark substrates using ebb and flood subirrigation.

MATERIALS AND METHODS

Substrate components being tested were sphagnum peatmoss (Premier Pro-Moss, Quakertown, PA), coconut coir (Densu Coir, Ontario, Canada), and pine bark (Pacific Organics, NC). Peat was removed from the compressed bale, water was added and peat was agitated by hand to allow proper water absorption. Moisture contents (MCs) were then tested in order to bring the MC up to 70% before being dried down to MCs of 67%, 50%, and 33%. Compressed bricks of coconut coir were hydrated by adding 14 L of water by hand, until the compressed brick was completely broken apart before testing moisture levels to ensure an initial MC of 70%. Four-month aged loblolly (*Pinus taeda* L.) pine bark was weighed, moisture levels tested, and further hydrated to a moisture content of 70%. Cylinders were then packed by weight, keeping all 4 reps of each substrate moisture content within 5% of each other and then packing them down to a pre-measured 10 cm of height to ensure similar bulk densities.

The equipment used follows the same procedure as Schulker (2020), and consisted of a transparent cylinder, 5 cm i.d. x 15 $cm \cdot h^{-1}$, with a mesh screen (mesh size 18 x 16; New York Wire, York, PA), attached to one end, using rubber pressure plate rings (Fig. 1B). The subirrigation method used to simulate capillary rise uses an Ebb and Flood irrigation unit (Hawthorn Hydroponics, Vancouver WA) 2ft wide by 4ft in length (Fig. 1A).

Pulsing in this context means time of exposure to water based on a total time of 60 minutes. The hydration events tested were 5min exposure - 12 events, 10min exposure – 6 events, and 20min exposure – 3 events. All of which were tested at water heights of 2mm, 20mm, and 35mm above the sample base. Once placed on the mesh screen, the unit was filled with water. Water was allowed to fill until water poured into the copper piping fitted to the desired water level. At that time, water flow input equaled output, allowing constant flow of water without a change in water level. The substrates were held at a constant water level for the allotted event time (between 5 min and 20 min), once finished, water was drained from the unit for one timed minute before each cylinder was weighed. The difference between final and initial weights was the amount of water captured by the substrate during hydration. This procedure was repeated based on specified time-allotted events (12, 6, and 3 irrigation event(s)).

Initial capture rate. Initial capture rate (ICR) was calculated using a version of the flow rate formula to account for variables in this experiment, the equation was written as

$$\mathrm{ICR} = \frac{\mathrm{C_i} - \mathrm{C_p}}{\mathrm{t}} \qquad (1)$$

where ICR is the amount of water captured by the substrate after the first irrigation per unit time (in mL/min), C_i (initial capture) is the weight (g) of the substrate after the present irrigation event (minus the weight of the cylinder), C_p (previous capture) is equal to the pack weight of the cylinder (minus the weight of the cylinder), t is the amount of time per irrigation (minutes).

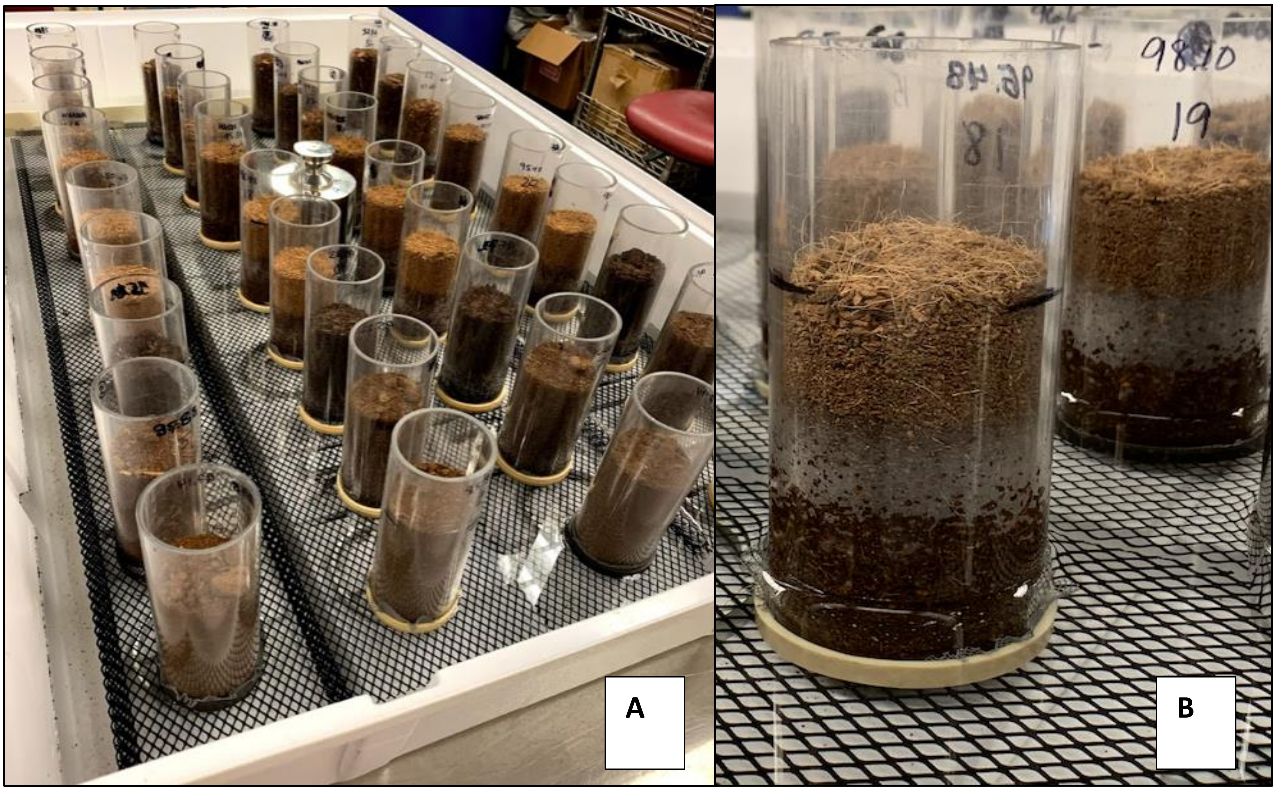

Figure 1. Ebb and flood subirrigation system. A) Fully constructed system complete with packed substrate cylinders during experimentation. B) Close up of 2mm water level during irrigation event.

RESULTS

Initial capture rate (ICR) was calculated for each pulsing time, water level, and MC of coir by the equation (1) and recorded in Table 1. Based on the formula used, the CR falls as pulsing time increases, as that would increase the t-value in the denominator of the equation. However, that does not mean the amount of water captured is any less, the water has more time to be absorbed by the substrate.

Table 1. Initial capture rate (ICR) (in mL/min) at three initial moisture contents (MC), three irrigation water levels, and at three irrigation pulse durations per water level.

ICR^{z}	Peat			Coir			Bark		
	33%IM	50%IM	67%IM	33%IM	50%IM	67%IM	33%IM	50%IM	67%IM
2mm^{x}									
5 min	0.29 c^{y}	0.71 d	3.72 d	9.66 b	9.97 c	8.77 c	6.73 bc	4.91 c	3.99 c
10 min	0.06 d	0.72 d	2.40 de	4.59 c	4.75 e	4.50 d	3.06 d	2.48 d	2.00 d
20 min	0.03 d	0.64 d	1.48 e	2.64 d	2.84 f	2.60 e	1.71 e	1.40 e	1.03 e
20mm									
5 min	0.31 b	3.25 b	7.34 b	10.83 b	12.74 b	12.29 b	8.36 b	8.62 b	7.16 b
10 min	0.18 bc	2.27 bc	4.29 cd	5.94 c	6.76 d	6.47 cd	4.24 c	4.50 c	3.87 c
20 min	0.13 c	1.64 c	2.41 de	3.48 cd	3.66 e	3.42 d	2.47 de	2.35 d	2.04 d
35mm									
5 min	0.61 a	6.04 a	9.49 a	14.27 a	15.43 a	14.02 a	10.61 a	11.26 a	9.01 a
10 min	0.34 b	3.83 b	5.34 c	7.53 bc	8.47 c	7.29 c	5.98 c	5.65 c	4.70 c
20 min	0.30 b	2.52 bc	2.97 d	4.09 c	4.34 e	3.89 d	2.74 de	2.98 d	2.45 d

^{z}ICR = the amount of water (in mL per min) that each substrate is able to capture after one irrigation per unit time. ^{y}Statistics using Tukey's honestly significant difference with alpha = 0.05 are given down individual columns at a given initial moisture content. ^{x}Water depth during irrigation event expressed in millimeters.

Coir. Initial CR was directly affected by water level and pulsing duration. Based on the formula used, it is understandable that the ICR decreases as pulsing time increases (Fig. 2), as that would increase the t-value in the denominator of the equation. However, that does not mean the amount of water captured is any less, the water simply has more time to be absorbed by the substrate. At 20mm, there is flooding (of the cylinder) involved, increasing the CR compared to 2mm which is based solely on capillary movement of water by the substrate. For coir, there is an incremental increase in water captured based on MC and water depth, with 50% MC and 5min time interval representing the highest ICR. Even at 2mm, coir is able to capture water at nearly the same rate as 20mm, exhibiting the hydrophilic nature of the material.

Peat. Initial CR was calculated for peat using the same formula that was used for coir (Table 1). Based on the effects MC had on the water capture of peat, the values for ICR at 33% IMC were lower than all other substrates tested. Increasing time (further increasing the value for t in the equation) did not have a major effect in the values at 33% MC. Increasing the moisture to 50% MC, in relation to 33% IMC, impacts that CR of peat. With an increase in ICR as much as 6 mL/min at a 20mm water depth. Peat, under lower moisture conditions was unable to capture water in the same manner as coir (Fig. 2). Even at 35mm, the greatest capture rate for low moisture peat did not crest 1 mL/min.

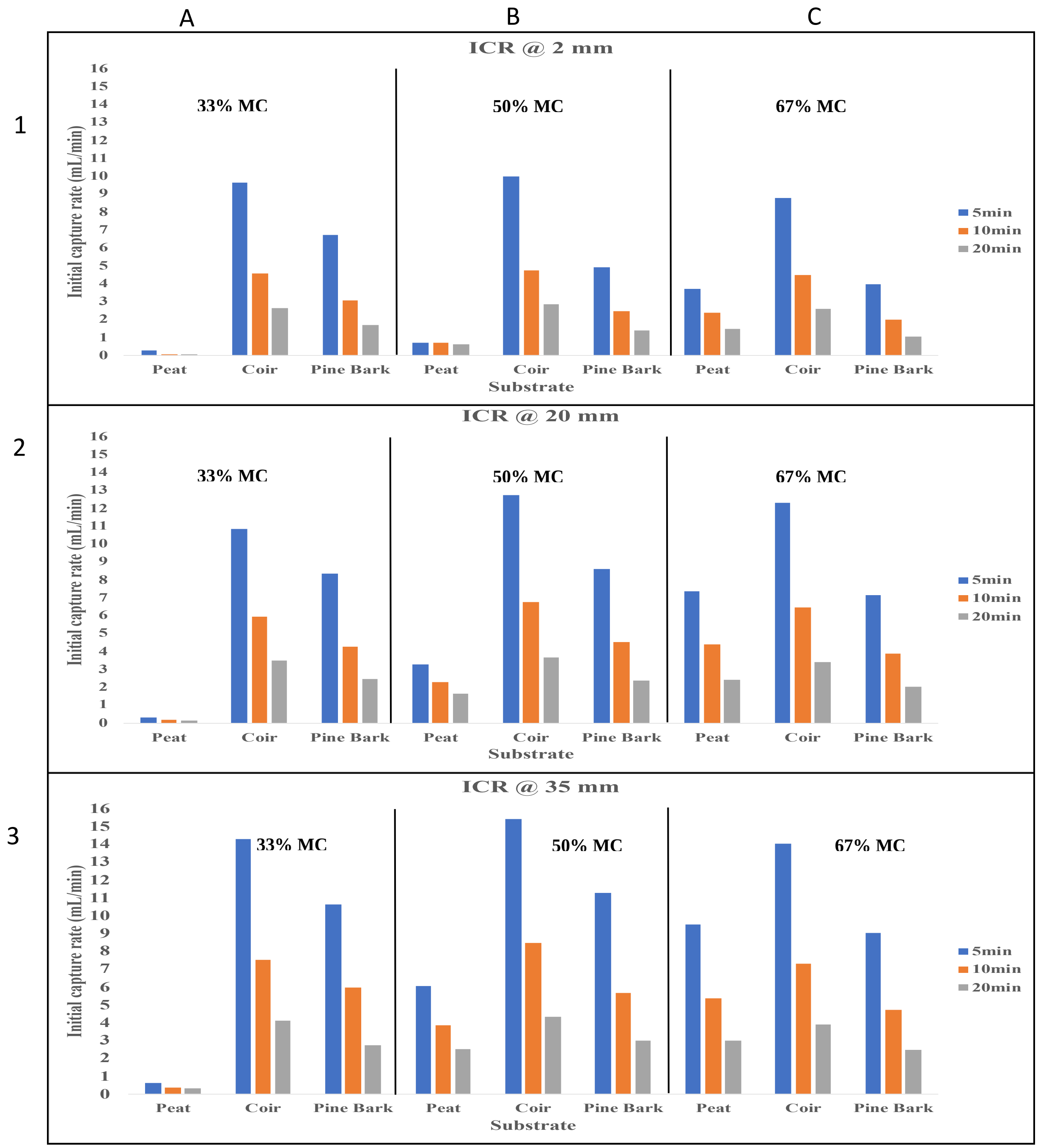

Figure 2. Substrate initial capture rate (ICR) for peat, coir, and pine bark over three initial moisture contents (MC) of 33%, 50%, and 67%, three water levels of 2mm, 20mm, and 35mm, and three pulse durations of 5min (blue), 10min (orange), and 20min (gray).

Pine Bark. Initial CR for each treatment showed just how consistent pine bark was. Reversing the equation, by re-multiplying by the number of events away from 5min, showed that pine bark captured water at nearly the same rate across all pulsing times within the same MC. Compared to both peat and coir, pine bark captured the majority of water within the first 5min irrigation pulse (Fig. 2). the ICR for pine bark did not increase with MC, in most cases it actually decreased. With 33% MC representing the highest ICR for most pine bark treatments

DISCUSSION

From the values shown in Table 1, it appears that initial MC prior to the first irrigation event and depth had the greatest effect on the ICR of peat, coir, and pine bark.

Across all initial MCs and water depths, coir was able to capture and retain the most water comparatively. However, MC played a role in determining just how fast it was able to do so. At 5min and 2mm, there was very little difference in the ICR based on MC, and that holds true for all pulsing times at that water level. Abad et al. (2005) characterizes coir as having a sponge-like ability to soak up water and be able to retain it within the pores of the substrates, and this is evident in table 1. As water level increases, the ICR increases. Showing that the increase in irrigation water depth truly plays the biggest role in the amount of water coir captures in the first irrigation event. Increasing by 5 mL/min from 2mm to 35mm.

It is evident from the data in Table 1, that initial MC had the greatest impact on the ability of peat to capture water, regardless of pulsing time or water depth. As moisture levels increased in peat, the substrates ability to capture water increased, in a nearly linear fashion. Peat is known to have hydrophobic characteristics which could come from inherent characteristics of a substrate at lower moisture levels (Michel et al., 2001) or from material drying processes in the production of these substrates. At 33% MC, peat exhibited difficulty in capturing any water whether it was a 5min pulse at 2mm or a 20min pulse at 35mm. The hydrophobic tendencies truly hindered the ability of peat to rewet, taking more water and time to wet the substrate. The main result shown is that the ICR of peat is nearly 10 mL/min less under lower moisture conditions, representing the largest difference of the three substrates.

Pine bark was comparably unaffected by pulse time and observed an increase in ICR as water depth increased from 2mm to 35mm. Similar to both peat and coir, the higher the initial MC and water depth, the greater the capture. Generally speaking, pine bark is known to have larger particle sizes than both peat and coir. The larger pore sizes created by these larger particles tend to have difficulty holding water after saturation (Drzal et al., 1999). However, these larger pore sizes aided in pine bark to capture water at lower MCs, with 33% moisture exhibiting the highest ICR at 2mm, and within 1 mL/min for 50% MC and 67% MC (Table 1).

CONCLUSION

Initial CR was designed to be able to understand the first irrigation characteristics of these substrates, and how different variables such as water depth and pulsing time can affect the amount of water captured by the substrate. The results of this study showed that initial MC had the biggest role to play in the ability of materials to take up water, with peat showing the greatest difference in water capture. Coconut coir captured and retained water in a sponge-like manner regardless of treatment while pine bark showed little variation based on MC. Overall, these three substrates represented differing abilities in water capture through water level, initial MC, and pulsing time. With each of the three substrates being tested representing different particle size distributions, if we could manipulate the particle size fractions and/or percentages in these substrates it could fundamentally change the initial capture rate, making irrigations more efficient while conserving more water. In doing so, continued research on engineering and formulating substrates with the goal of increasing the water capture efficiency of substrates is of potential great significance to the future of precision growing of plants in container systems. For example, blending different substrate components (at varying percentages) with different water capturing abilities to enable maximum container substrate hydration with the fewest irrigations as possible could reduce the inconsistences of container crop irrigation scheduling and practices. It is believed to be feasible to select substrate components/types to fit the container and irrigation delivery method of a grower to achieve maximum irrigation efficiency for different crops.

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