Impact of wood fiber substrate additions on water capture through surface and subsurface irrigation

B.A. Schulker and B.E. Jackson

Department of Horticultural Science, North Carolina State University, North Carolina, USA.

Abstract

The effectiveness of a horticultural substrate to imbibe water through irrigation can be part of a sustainable plant production program. A reduction in substrate wettability can lead to lower water capture, excessive leachate, and poor plant growth. The movement toward new soilless substrate materials in plant production is necessary for a sustainable future in plant production. To better understand the impact of these materials on water imbibition, Canadian sphagnum peat moss was amended with a hammermilled pine tree substrate (PTS) at ratios of 20, 40, and 60% before undergoing both surface and subsurface irrigation evaluations to study the impact of PTS additions on substrate water capture. Using both an ebb and flood subirrigaton unit and the NCSU overhead wettability method, we investigated the capillary capture intensity and gravitational capture intensity by using volumetric water content curves to identify the plateau where water uptake was maximized under 50% moisture contents. Under surface irrigation, the increasing wood content increased the amount of water imbibed by the substrate over 10 irrigation events, while also increasing the speed at which water was captured. Through subsurface irrigation, there was less of an impact on total imbibition. Water content within the substrate increased at the first irrigation event as wood ratio increased, showing that the wood content aided in reducing the hydrophobicity of peat. By the 10th irrigation event, the differences were insignificant, all capturing similar amounts of water. This shows that under greenhouse irrigation conditions, the increase of PTS in sphagnum peat moss does not decrease the amount of water captured but does increase the flow of water through the substrate, allowing more water to be captured over multiple events.

Keywords: capillary, water capture, soilless media, irrigation, sphagnum peat

INTRODUCTION

The continued push within the horticultural industry to increase our international focus on sustainability has brought forth the introduction of new, alternative materials for use as soilless media in containers. Worldwide, peat moss has been the commonly used base component in greenhouse plant production, however substrate manufacturers and growers are looking for ways to decrease peat moss use and use cost-effective and possibly more sustainable materials. Recently, substrate research has pivoted toward the use of substitute materials like wood fiber (Jackson et al., 2008; Jackson and Wright, 2009; Fields et al., 2014; Owen et al., 2016, 2017, 2020; Durand et al., 2021) to further increase the use of alternative materials in container media by reducing the amount of peat and perlite needed in production.

This research has been vital to the insurgence of wood-based products being used in the horticultural industry, however to the previous work has not evaluated the effect of wood fiber on substrate water capture and efficiency. Durand et al. (2021) described that using wood in peat-based substrates can decrease the hydrophobic nature of peat moss, while Schulker et al. (2020) showed the benefits of surface irrigation to mitigate those hydrophobic tendencies. Michel et al. (2021) analyzed the rehydration efficiency between two base substrate components consisting of a commercial wood fiber and milled white peat, showing the hydrophilic characteristics of wood fiber. However, few have studied irrigation delivery method on the ability of substrates to imbibe water or rehydrate over multiple irrigations.

Wood fiber is a manufactured product, allowing the shape, size, and texture to be

Acta Hortic. 1377. ISHS 2023. DOI 10.17660/ActaHortic.2023.1377.74
XXXI IHC – Proc. Int. Symp. on Innovative Technol. and Prod. Strategies for Sustainable Controlled Environ. Hortic.
Eds.: Y. Rouphael and J.-C. Michel

determined by the process by which it is produced before selection as an amendment with substrates. Some of the processes used to make wood products include hammer-milling, screw-extrusion, and disc-refining; with each providing a very different textured material for use in conjunction with other materials such as sphagnum peat moss and coconut coir.

In soilless systems, water distribution can rely heavily on the physical characteristics (texture/particle size/bulk density), irrigation method, and the inherent hydrophobicity of the material. The confluence of these factors combines to play a pivotal role in the effectiveness of water uptake in specific combinations of irrigation method and substrate components. Irrigating from below can require a micro-pore abundant, finer textured substrate to effectively take up water through capillary action (Biernbaum, 1993). Contrariwise, greater pore size diversity and air space favors surface irrigation methods. The objective of this study was to understand the impact of wood fiber in combination with peat moss on the effectiveness of water imbibition and retention through two irrigation techniques under two initial moisture contents (MC).

MATERIALS AND METHODS

Substrate components tested included Canadian sphagnum peat moss (Premier Pro-Moss, Quakertown, PA) and North Carolina State University pine tree substrate (PTS). On March 14, 2021, sphagnum peat was removed from the bale, hydrated, and placed in a covered container to equilibrate overnight. For this process, the peat was removed from the 107.6L compressed bale and positioned in a large plastic tub, water was then added in 3 L increments after which peat was fluffed by hand to allow water absorption and full expansion. Moisture levels were measured (Ohaus MB27 soil moisture balance; Ohaus Corp., Parsippany, NJ), to determine if further water additions were needed to increase the moisture to 50% by mass. Sphagnum peat moss was blended with PTS at 20, 40, and 60% ratios (by vol.). MC was then tested and adjusted to 70% MC. The substrate materials were then placed on drying trays and moved to a dehumidification chamber and removed once half of the substrate treatments reached 50% MC and the remaining samples were removed at 33% MC.

Particle size distribution of 25 g 101.5°C oven-dried substrate samples was determined on three replications of peat and PTS with 6 sieves (6.3, 2.0, 0.71, 0.5, 0.25, 0.11 mm, plus the bottom collection pan). The sieves and pan were stacked together, and substrate samples were poured into the top sieve and placed into the RX-29 Ro-Tap sieve shaker (278 oscillations min^{-1}, 150 taps min^{-1}; W.S, Tyler, Mentor, OH). The sieves and pan were shaken for five min and the particle fractions retained on each sieve and the amount collected in the bottom pan (representing the smallest particle fractions) were weighed (Table 1).

To determine the effects of MC with surface applied irrigation, this experiment followed the procedures described by Fields et al. 2014. The equipment consisted of a transparent cylinder, 5 cm i.d. × 15 cm h^{-1}, with a mesh screen (mesh size 18×16; New York Wire, York, PA, USA), attached to one end, using rubber pressure plate rings (Soil moisture Equipment Corp., Santa Barbara, CA, USA); a 250-mL beaker; a 250-mL funnel; as well as a 10 mL plastic vial (4-cm diameter) with five evenly spaced 2.33 mm diameter holes in the base to act as a diffuser. This allowed the water dripping through the funnel to be evenly dispersed through the holes onto the substrate surface in the cylinder.

The transparent cylinders were packed with each substrate treatment to have a weight within 5% of other samples in the same treatment group. To achieve this, cylinders were filled (by weight) with substrate then raised 12 cm off a flat surface, then tapped four times to bring the top of all four replications to 10 cm from the base of the cylinder, representing 200 mL of substrate and providing similar D_b across all replications. With five substrates, at two MCs, and four replications there were a total of 40 experimental samples per irrigation technique. After the cylinders were packed, each was fitted with a diffuser and attached to the ring stand with clamps, situated just under the separatory funnel. Two hundred milliliters of water were added to the separatory funnels and allowed to drip onto the surface of the substrate at an average rate of ~40 mL min^{-1}, using a stopcock to control water flow (Schulker et al., 2020). Water was applied in 10 consecutive individual hydration events. The progression of water in this technique starts in the separatory funnel, through the diffuser and onto the surface of the substrate. Using gravity, the water was able to penetrate the surface of the substrate and percolate through the 10 cm depth. Some of the water volume was absorbed as it moved through the substrate, while the rest was collected at the bottom by a 250 mL beaker. Taking ~5 min. water flow ceased, holding the substrate at equilibrium for two minutes before measuring the effluent collected in the beaker. Water retained was calculated by subtracting the amount of water applied (200 mL) from the amount of effluent captured. With the completion of the individual event needing ~7 min, 5 min time intervals were measured out in between events to retain treatment evenness. This procedure was repeated for each of the 10 hydration events.

Table 1. Particle size distribution of two soilless substrate components.

Texture	Particle size distribution (%)[a]	
	Peat	PTS[g]
Coarse[b]	24.0 B a[e,f]	6.0 C b
Medium[c]	25.4 B b	57.5 A a
Fine[d]	50.6 A a	36.5 B b

[a] Particle size distribution calculated on a dry weight scale using means of three oven-dried samples.

[b] Coarse = particles that are greater than 2.0 mm in diameter.

[c] Medium = particles that are less than 2.0 mm but greater than 0.5 mm in diameter.

[d] Fine = particles that measure less than 0.5 mm in diameter.

[e] Values are means of percentages of the total sample.

[f] Statistics are determined down columns (denoted by an uppercase letter) and across rows (denoted by a lowercase letter) using Tukey's honestly significant difference to determine similarities and differences across all components.

[g] PTS = Pine Tree Substrate

To determine how wood product ratio, and substrate MC influences substrate water capture through subsurface irrigation, this experiment was conducted using materials and modified procedures described by Schulker et al. (2021). Using the same transparent cylinders as described in surface irrigation above were prepared the same way to account for comparisons. The subsurface irrigation method used an ebb and flood irrigation system (Hawthorn Hydroponics, Vancouver WA) 61cm wide by 122cm in length. The transparent cylinders were packed in an identical manner as those used in the surface irrigation testing. After packing, cylinders were moved and placed on an elevated mesh screen (used to optimize surface area exposure to water) before the unit was filled with water. From the moment the valve was turned on, it took approximately one minute for water to reach the bottom of the cylinders and another minute for it to reach final irrigation height of 2.54 cm. At that time, water flow input equaled output, allowing a constant flow of water without a change in water level. The substrate sampled were irrigated for 5 min for each hydration event before the unit was drained and each sample was weighed (after allowing one min of structured time). The weights were used to calculate water captured by the substrate by using the initial weight and subtracting it from the hydrated event weight. This procedure was repeated over 10 hydration events with a total irrigation time equaling 50 min.

Once the 10 hydration events were complete, container capacity (CC) was determined for each cylinder. The cylinders were again placed in the ebb and flood unit and CC was determined as described in Schulker et al. (2021). After saturating in the system for 30 min, the water was drained, for 15 min and samples were reweighed to record changes in weight (water captured and retained). Samples were then placed into a forced-air drying oven at 105°C for 48 h to dry. Then, each sample was weighed, and dry weight was used to determine total water retained and moisture content.

RESULTS AND DISCUSSION

It should be noted that the MCs for this experiment of 33 and 50% were all determined by weight (g g^{-1}). This MC is consistent with many industry practices for initial MC at the time of potting and is essential when substrate materials are tested. The hydration curves in Figures 1 and 2 were constructed by volumetric water content (VWC) to describe the amount of water captured by the substrate. With that said, the MC of 50% by weight was 12 to 15% for peat by vol. For particle size, peat represented the highest proportions of larger particle sizes, with 24% of particles larger than 2.0 mm while PTS only recorded 6% of particles in the large size class with zero larger than 6.3 mm. However, both peat and PTS recorded <70% of particles smaller than 2.0 mm, with most PTS particles recorded within the medium size class range.

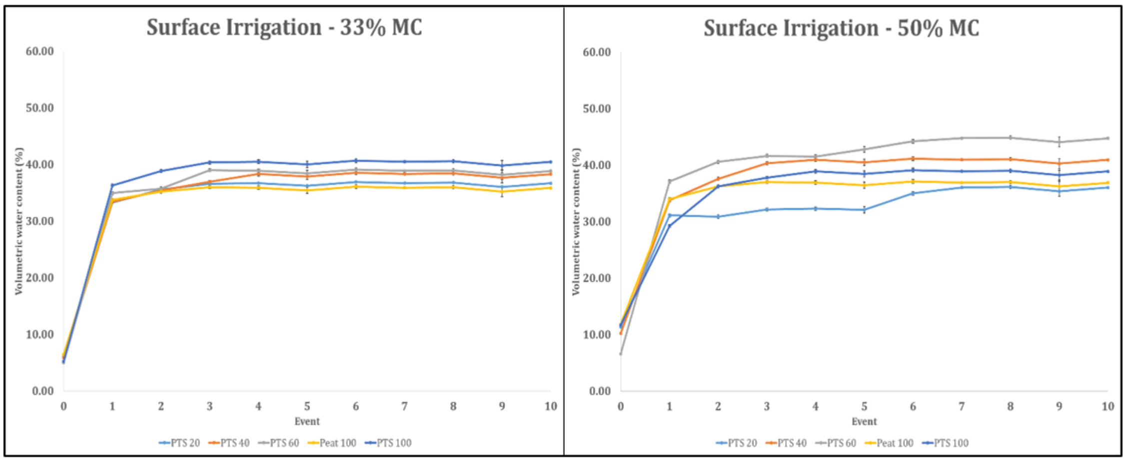

Figure 1. Substrate hydration curves for the five tested substrates over ten hydration events and two initial moisture contents through surface irrigation. Error bars signify the standard deviation from the mean of each data point.

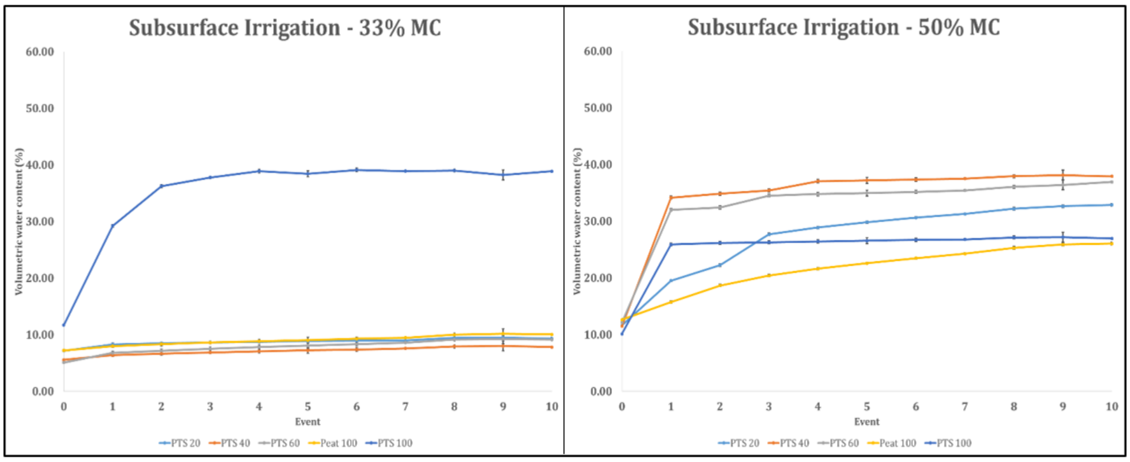

Figure 2. Substrate hydration curves for the five tested substrates over ten hydration events and two initial moisture contents through subsurface irrigation. Error bars signify the standard deviation from the mean of each data point.

The VWC curves for the peat-PTS blends (Figures 1 and 2) indicated a pattern related to MC and PTS combination ratio. Regardless of MC, the first hydration event had the most water absorbed by the substrate compared to all other irrigation events. The MC and ratio of PTS affected the amount of water absorbed in the first hydration and increased as MC increased. For surface irrigation, the differences between H1 and H10 in Table 2 are small, showing ~85% of total water captured within the first irrigation event in all treatments including MC and wood ratio, excluding PTS 100. Across all treatments, H1 increased as PTS increased in combination with peat, with 60% PTS recording 34.6 and 36.7% VWC of water captured at 33 and 50% MC, respectively. For subsurface irrigation, MC contributed to the ability of the substrates to absorb water across all 10 events, nor did any material reach a steady state or maximum absorption at any initial moisture level or PTS ratio (Table 3; Figures 2). At 50% MC, 40% PTS reached the highest final hydration value of 37.9% VWC captured. Unlike surface irrigation, increasing the ratio of wood did not equal higher water absorption values, with 40% PTS at 50% MC also recording the higher H1 value. Container capacity was impacted by MC through subsurface and surface irrigation, with as large of a difference as 50% VWC at 20% PTS through subsurface irrigation. Capture rate was calculated for each substrate, MC, and irrigation technique for PTS. Capture rate was directly affected by irrigation type and MC, with the maximum capture rate recorded at 60% PTS and 33% MC at 11.69 mL min^{-1} through surface irrigation.

Table 2. Effective water capture, first hydration (H_1), final hydration (H_{10}), and container capacity (CC), of five substrates analyzed at two moisture contents using surface irrigation.

Surface	33% MC				50% MC			
	H_1[a]	H_{10}[b]	CC[c]	S*[d]	H_1	H_{10}	CC	S*
Peat 100	32.90	35.14	46.10	L* Q*	33.10	36.90	70.32	L* Q*
PTS[e] 100	35.45	40.53	63.70	L* Q*	28.40	38.70	70.11	L* Q*
PTS 20	33.40	36.70	50.10	L*** Q*	30.84	35.94	83.24	L* Q*
PTS 40	33.01	38.23	51.74	L*** Q*	33.51	40.78	78.83	L* Q*
PTS 60	36.70	38.90	53.20	L* Q*	36.81	44.61	70.80	L* Q*

[a] H_1 = the amount (by % volume) of water that is absorbed after one irrigation event, recorded as the first hydration.

[b] H_{10} = the amount (by % volume) of water that is absorbed after ten irrigation events, recorded as the final hydration.

[c] CC = maximum volumetric moisture content attained by sample.

[d] Significance (S*): linear (L) and quadratic (Q) regression significance test, ***$P \leq 0.001$, **$P \leq 0.01$, * $P \leq 0.05$ across each row of all materials for each moisture content.

[e] PTS = Pine Tree Substrate.

Each material used was tested on its own in a 100% treatment consisting of peat and PTS. These treatments were used to see the impact of combining the wood with peat and understanding how that changes the hydration dynamics of peat. At 33% MC, PTS was able to absorb the most water as compared to peat under both irrigation techniques, increasing capture ~5% over that of peat. As the moisture level increased to 50%, the low hydrophobicity values in wood fiber were outperformed by the now reduced hydrophobic nature of peat, with peat capturing more water at H1 than PTS. Through subsurface irrigation (Table 3), very little water was absorbed by peat at 33% MC with still minimal increases at 50%, ~10% less than what was captured by PTS. From the data in Figure 2, it appears that initial moisture content prior to the first irrigation event had the greatest overall effect of the water capture and retention of peat-based wood blend substrates under subsurface irrigation techniques. Surface irrigation nullified the impacts of MC on the water capture and retention of all materials, with only a ~5% difference volumetrically at its highest. However, CC was highly impacted by MC even under surface irrigation, showing that even though the substrates captured very similar amounts of water at both MCs, the total amount of water that can be captured is reduced under lower moisture conditions. Surface irrigation provided the highest water capture in the first hydration across nearly all substrates and MCs, with the most water captured through any irrigation being 60% PTS at 50% MC through surface irrigation.

Table 3. Effective water capture, first hydration (H_1), final hydration (H_{10}), and container capacity (CC), of five substrates analyzed at two moisture contents using surface irrigation.

Subsurface	33% MC				50% MC			
	H_1[a]	H_{10}[b]	CC[c]	S*[d]	H_1	H_{10}	CC	S*
Peat 100	7.86	10.13	46.51	L** Q*	15.64	26.21	77.54	L* Q*
PTS[e] 100	21.32	24.58	59.61	L* Q*	25.92	27.10	65.21	L* Q*
PTS 20	8.31	9.32	23.50	L* Q*	19.52	32.89	81.30	L** Q*
PTS 40	6.40	7.81	45.70	L** Q*	34.16	37.94	80.12	L* Q*
PTS 60	6.81	9.17	42.61	L** Q*	32.05	36.94	75.60	L* Q*

[a] H_1 = the amount (by volume) of water that is absorbed after one irrigation event, recorded as the first hydration.

[b] H_{10} = the amount (by volume) of water that is absorbed after ten irrigation events, recorded as the final hydration.

[c] CC = maximum volumetric moisture content attained by sample.

[d] Significance (S*): linear (L) and quadratic (Q) regression significance test, ***$P\leq0.001$, **$P\leq0.01$, * $P\leq0.05$ across each row of all materials for each moisture content.

[e] PTS = Pine tree substrate.

Through surface irrigation, there is the additional potential of gravity to draw water through the substrate, allowing droplets to travel a path of least resistance. This allows water to move through macro and mesopores to hydrate the substrate. From the data in Table 2, there is evidence to see that increasing the ratio of wood in a peat-based substrate does not negatively impact the amount of water captured by the substrate through irrigation. Gravity fed surface irrigation nearly nullified the impacts of moisture level on water absorption by all treatments, with minimal increases in recorded water capture as MC increased.

Through subsurface irrigation, the data in Table 3 shows evidence that MC had the greatest impact on peat's ability to capture water at all water levels and irrigation times. As MCs increased, the substrate's ability to capture water increased, in a nearly linear fashion. Peat is known to express hydrophobic intensity at lower moisture levels (Michel et al., 2001) or from the material drying processes in the production of these substrates. As is well documented, intensity of hydrophobicity of peat increases at lower substrate moisture contents. The evidence of peat impacting the capillary potential of these substrates is shown in Table 3 with PTS alone capturing more water than any peat-based blend at 33% MC. The data in Table 3 also shows a plateau of water absorption at 40% PTS amended to peat, with 60% PTs exhibiting a slight decline in the amount of water captured at 50% VWC. This effect was nullified at 33% MC with higher PTS rates possibly counteracting the hydrophobic characteristics of peat in low moisture conditions.

Low moisture conditions severely impacted the water absorption of all peat-based substrates tested through subirrigation, with nearly 20% more water absorbed through surface irrigation under the same conditions. Most notably, the results showed that there is very little impact on the amount of water held by each substrate through either irrigation technique based on the amount of wood amended. Thus, wood fiber type and ratio amended to sphagnum peat moss does not negatively impact irrigation water retention.

Literature cited

Biernbaum, J.A. (1993). Subirrigation could make environmental and economical sense for your greenhouse. Prof. Plant Grow. Assn. Nwsl *24*, 2–14.

Durand, S., Jackson, B.E., Fonteno, W.C., Bartley, P.A., III, and Michel, J.C. (2021). New tools for particle shape analysis of substrate components: initial results and future prospects. Acta Hortic. *1317*, 335–342 https://doi.org/10.17660/ActaHortic.2021.1317.39.

Fields, J.S., Fonteno, W.C., Jackson, B.E., Heitman, J.L., and Owen, J.S., Jr. (2014). Hydrological properties, moisture retention, and draining profiles of wood and traditional components for greenhouse substrates. HortScience *49* (*6*), 827–832 https://doi.org/10.21273/HORTSCI.49.6.827.

Jackson, B.E., and Wright, R.D. (2009). Pine tree substrate: an alternative and renewable growing media for horticulture crop production. Acta Hortic. *819*, 265–272 https://doi.org/10.17660/ActaHortic.2009.819.30.

Jackson, B.E., Wright, R.D., and Barnes, M.C. (2008). Pine tree substrate, nitrogen rate, particle size, and peat amendment affects poinsettia growth and substrate physical properties. HortScience *43* (*7*), 2155–2161 https://doi.org/10.21273/HORTSCI.43.7.2155.

Michel, J.C., Riviere, L.M., and Bellon-Fontaine, M.N. (2001). Measurement of wettability of organic materials in relation to water content by the capillary rise method. Eur. J. Soil Sci. *52* (*3*), 459–467 https://doi.org/10.1046/j.1365-2389.2001.00392.x.

Michel, J.C., Durand, S., Jackson, B.E., and Fonteno, W.C. (2021). Analyzing rehydration efficiency of hydrophilic (wood fiber) vs potentially hydrophobic (peat) substrates using different irrigation methods. Acta Hortic. *1317*, 343–350 https://doi.org/10.17660/ActaHortic.2021.1317.40.

Owen, W.G., Jackson, B.E., Whipker, B.E., and Fonteno, W.C. (2016). Pine wood chips as an alternative to perlite in greenhouse substrates: nitrogen requirements. Horttechnology *26* (*2*), 199–205 https://doi.org/10.21273/HORTTECH.26.2.199.

Owen, W.G., Jackson, B.E., and Fonteno, W.C. (2017). Pine wood chip aggregates for greenhouse substrates: effect of age on plant growth. Acta Hortic. *1168*, 269–275 https://doi.org/10.17660/ActaHortic.2017.1168.35.

Owen, W.G., Jackson, B.E., Whipker, B.E., and Fonteno, W.C. (2020). Liming requirements of greenhouse peat-based substrates amended with pine wood chips as a perlite alternative. Horttechnology *30* (*2*), 219–230 https://doi.org/10.21273/HORTTECH04506-19.

Schulker, B.A., Jackson, B.E., Fonteno, W.C., Heitman, J.L., and Albano, J.P. (2020). Comparison of water capture efficiency through two irrigation techniques of three common greenhouse soilless substrate components. Agronomy (Basel) *10* (*9*), 1389 https://doi.org/10.3390/agronomy10091389.

Schulker, B.A., Jackson, B.E., Fonteno, W.C., Heitman, J.L., and Albano, J.P. (2021). Exploring substrate water capture in common greenhouse substrates through preconditioning and irrigation pulsing techniques. Agronomy (Basel) *11* (*7*), 1355 https://doi.org/10.3390/agronomy11071355.

Schulker, B.A., Jackson, B.E., and Fonteno, W.C. (2021). A practical method for determining substrate capillary water sorption. Acta Hortic. *1317*, 327–334 https://doi.org/10.17660/ActaHortic.2021.1317.38.