Water Content of a Pine-bark Growing Substrate in a Drying Mineral Soil

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Abstract. Newly transplanted container-grown landscape plants are reported to require very frequent irrigation. However, container nurseries in the U.S. commonly use growing substrates that are mostly bark, even though the contribution of bark-based growing substrates to water relations of transplanted root balls is unknown. Therefore, a field experiment was undertaken to determine water relations of a pine-bark substrate (container removed) within a drying mineral soil over a three week period. A range of common production container sizes—3.7 L (#1), 7.5 L (#2), 21.9 L (#7), 50.6 L (#15), and 104.5 L (#25)—was used. The fraction of substrate volume that is water [total volumetric water (TVW)] within the top and middle zones of substrate was compared to TVW at corresponding depths of adjacent mineral soil. The fraction of substrate and soil volume that is plant-available water [plant-available volumetric water (PAVW)] was calculated by subtracting the fraction of substrate or soil volume below where water is unavailable to most plants (measured with pressure plates) [plant-unavailable volumetric water (PUVW)] from each TVW measurement. The pine-bark substrate had a PUVW of 0.32 compared to a PUVW of 0.06 for soil. Top sections of substrate dried to near zero PAVW 6 days after irrigation for all containers. Larger container sizes maintained higher PAVW in middle sections than smaller container sizes, and PAVW was always higher in the adjacent soil than in the embedded substrate. Overall, very little PAVW is held by the embedded pine-bark growing substrate, suggesting the need for container substrates with greater water retention once transplanted to mineral soils.

Because it can be produced in a variety of particle sizes, allowing mixtures of desirable air-filled porosity to be created (Fonteno, 1996; Handreck and Black, 1999), composted or aged bark is considered by many to be the best substrate for production of container-grown landscape plants. Pine bark, peat, and sand are the predominant substrate components used for container-grown landscape plants throughout the Southern United States (Yeager et al., 1997). In the Northern United States, hardwood bark predominates, whereas douglas-fir and redwood bark are most common in the western U.S. (Fonteno, 1996). A favorable air-filled porosity during production often results in suboptimal water holding capacity when the container is removed at transplanting (Nelms and Spomer, 1983; Spomer, 1979). Unless drainage is impeded, more frequent irrigation may be needed after transplanting because of increased drainage into the surrounding soil after elimination of the container-induced perched water table (Costello and Paul, 1975) and radial movement of water from the root

ball into the surrounding backfill-soil (Day and Skoupy, 1971). Water held at 1.5 MPa tension is considered to be unavailable for most plants (Brady, 1990; Kramer and Boyer, 1995). A larger volumetric fraction of plant-unavailable water is present in organic substrates than in mineral soil, due mostly to the increased surface area of organic particles. Plant-unavailable water has been reported to be near 27%, 25%, and 5% of substrate volume for pine bark, sphagnum peat, and mineral soil, respectively (Fonteno, 1996).

Other studies with non bark-based substrates such as peat-sand-sawdust mixtures have shown that container removal results in a drier root ball after transplanting (Costello and Paul, 1975; Day and Skoupy, 1971; Nelms and Spomer, 1983), but apparently no studies have concentrated on the availability of water within transplanted bark-based substrates. Tensiometers, used to monitor water relations in non bark-based substrates, are unreliable when a coarse substrate, such as the pine-bark substrate used in the present study become dry (Rundel and Jarrell, 1991). However, time domain reflectometry (TDR) has been successfully used to measure the fraction of substrate or soil volume occupied by water [total volumetric water (TVW)] of pine-bark substrates (Anisko et al., 1994, da Silva, 1998).

This experiment was undertaken to examine plant-water availability patterns within a pine-

bark substrate imbedded within a mineral soil. Our objective was to determine the fundamental relationship between water content of substrate and soil during a drying event, so plants were not included.

Materials and Methods

A field bed consisting of Groseclose silt loam soil (clayey, mixed, mesic Typic Hapludults; pH=6.2; bulk density=1.1 g·cm⁻³) was tilled to 20-cm depth in mid-August 2001, at the Urban Horticulture Center, near the campus of Virginia Tech, Blacksburg, Va. (USDA plant hardiness zone 6a). Fifty holes were spaced 1.2 m on center, dug to a particular container size, and filled with a mixture (volumetric 2:1) of 100% pine bark and Scott's Perennial Mix (65% to 75% pine bark, 20% to 25% sphagnum peat, and 9% to 15% perlite; The Scott's Co., Lawrenceville, Va.). This resulted in a substrate that was approximately (by volume) 85% pine bark, 10% sphagnum peat, and 5% perlite. Substrate physical properties, determined as described by Niemiera et al. (1994), were: air space = 21.5%; total porosity = 87.3%; container (water-holding) capacity = 65.8%; bulk density = 0.32 g·cm⁻³. Five container sizes were used as templates for hole sizes: 3.7 L (#1), 7.5 L (#2), 21.9 L (#7), 50.6 L (#15), and 104.5 L (#25). Ten replications of each size were arranged in a completely randomized design.

TVW was measured with a theta meter (θ -Probe, Type HH1; Dynamax, Inc., Houston, Texas). The θ -Probe uses TDR technology (Anisko et al., 1994; Rundel and Jarrell, 1991) by using microwave signals to measure the average TVW in the substrate surrounding the length (6 cm) of the wave guides. Access to center sections of substrate and to the corresponding depth in adjacent soil was through a hole that was held intact by polyvinyl chloride (PVC) pipe sections. A hole was made into the center of each replication, and another was inserted into the surrounding soil, $\approx$ 20 cm from the edge of the substrate (Fig. 1). All substrate within the pipes was removed so that hollow access tubes remained. The top of each pipe extended three cm above the surface of the substrate to allow for covering with aluminum foil. Surface (top sections) measurements of TVW with the θ -Probe are integrated along the top 6 cm, and below-surface measurements (middle sections) for the #1, #2, #7, #15, and #25 container sizes and the surrounding soil are integrated along $\approx$ 9 to 15, 12 to 18, 14 to 20, 19 to 25, and 23 to 29 cm depths, respectively.

The θ -Probe is factory-calibrated to read TVW for mineral and organic soil, but not pine-bark substrate. We calibrated the TVW to the pine-bark substrate by comparing uncalibrated readings (organic soil setting) for TVW of 15 substrate-filled containers in various degrees of drying, with TVW calculated by weighing samples before and after drying to a constant weight at 70 °C. The volume of water contained within each container was calculated by converting grams of water lost by drying to cm³ (1 g = 1 cm³). Containers (for calibration only) were fashioned from PVC pipe sections (5 cm

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Fig. 1. Diagram of pine-bark substrate installed in holes in mineral soil. Holes were made from templates of various container sizes. Hollow access tubes denote access and stars denote insertion points for θ -Probe measurements. Experimental units were arranged in a completely random statistical design. $n = 10$.

in diameter and 10 cm long). The bottom of each container was covered with four layers of cheese cloth, held to the container bottom with a rubber band, to contain the substrate. Wave guides of the θ -Probe were inserted into substrate through the top of the containers. Calibration revealed that the actual was related to the measured TVW of the pine-bark substrate by the following equation: $\text{actual} = 0.0706 + 1.1102 \times \text{measured}$ ($R^2 = 0.99$). θ -Probe readings were adjusted accordingly.

All replications of embedded substrate were lightly tamped, and 5 cm water was applied over the experimental field on 16 Aug. with overhead sprinklers. θ -Probe measurements were taken 24 h later. No further irrigation was applied during the experiment. Substrate settled ≈ 2 cm vertically after tamping and irrigation. An on-site weather station (DYNAMET; Dynamax, Houston, Texas) recorded weather variables, from which potential evapotranspiration (van Bavel, 1966) was calculated (Fig. 2). A 2.6-

Fig. 2. Potential evapotranspiration (left axis) and maximum daily air temperature (right axis) during experiment.

cm rainfall occurred on the night of 23 Aug. θ -Probe measurements were taken on 16, 17, 21, 23, and 27 Aug. and 4, 6, and 7 Sept. The 23 Aug. θ -Probe measurements were taken before the rainfall that night. Measurements were taken at four locations in each replication for each sampling date as follows.

- 1) Middle section of container (inserting the θ -Probe down the hollow PVC pipe and into the container substrate; no part of wave guides exposed to air; see above for exact depths).
- 2) Top section of container.
- 3) In soil at the approximate depths of middle section of container (inserting the θ -Probe down the hollow PVC pipe in the soil).
- 4) Top section of soil (about 20 cm from the edge of the embedded substrate) (Fig. 1).

Samples were collected from the top 10 cm of soil and substrate, and the water fraction of substrate or soil volume at which water becomes unavailable to plants [plant-unavailable volumetric water (PUVW)] was determined using a pressure membrane apparatus (eight subsamples) at a constant pressure of 1.5 MPa applied for 2 weeks (Klute, 1998). Water held at tensions >1.5 MPa is generally considered unavailable to most plants (Brady, 1990; Kramer and Boyer, 1995). Pine-bark substrate may actually hold very little PAVW at tensions as low as 1.0 MPa (Murray et al., 2001). PUVW was subtracted from calibrated TVW measurements to determine the fraction of substrate or soil volume that was water available for plant use [plant-available volumetric water (PAVW)]. Data were analyzed using the repeated measures analysis of variance within the GLM procedure of SAS (SAS, version 8.02, SAS Institute, Cary, N.C.).

Results and Discussion

For θ -Probe measurements, repeated measures analysis of variance revealed that there was an overall time effect ($P < 0.0001$), a time $\times$ container size effect ($P = 0.0002$), a time $\times$ depth of measurement effect ($P < 0.0001$) and a time $\times$ container size $\times$ depth of measurement effect ($P = 0.0013$). Data were therefore graphed to illustrate patterns of change in TVW and PAVW for substrate and surrounding soil at two depths over time for each container size (Fig. 3). Data for 3.7-L (#1) embedded substrate are similar to that for 7.5-L (#2) embedded substrate and are not shown.

Pressure plate measurements indicated PUVW (SE mean in parentheses) to be 0.32 (0.005) and 0.06 (0.001) for the pine-bark substrate and soil, respectively. PUVW was subtracted from TVW measurements in Fig. A, C, and D to show PAVW (Fig. 3B, D, F, and H). The middle zones of all volumes of embedded substrate maintained the highest mean TVW throughout the experiment (Figs. 3A, C, E, and G). However, when presented as PAVW (Figs. 3B, D, F, and H), substrate at both depths had lower PAVW than adjacent soil for #2 (Fig. 3B) and #7 (Fig. 3D) volumes. Middle substrate sections had similar PAVW as top sections of adjacent soil for #15 (Fig. 3F) and #25 (Fig. 3H) volumes for most of the experiment. Top sections of substrate PAVW

Fig. 3. Fraction of substrate and soil volume that is water (total volumetric water, TVW) at surface and middle of embedded 7.5-L (#2), 21.9-L (#7), 50.6-L (#15), and 104.5-L (#25) pine-bark substrate and at corresponding depths of adjacent soil (A, C, E, G) and fraction of substrate and soil volume that is plant-available water (plant-available volumetric water, PAVW) at the same locations (B, D, F, H). Data for 3.7-L (#1) substrate are not shown. Bars represent SE mean. $n = 10$.

were never >0 after 23 Aug., even after the 2.6-cm rain. Lack of response to the rain may be partly due to a hydrophobic condition that has been reported to develop when TVW drops below 0.35 in pine-bark substrate (Airhart et al., 1978). The same trend for top-of-the-substrate measurements for #2, #5, #15, and #25 sizes is evident. Low plant-available water for the top

sections of embedded substrate was likely due to evaporation, so it is not surprising that trends were similar for the different sizes. Evaporation in actual landscape situations may be slowed by mulch (Smith and Rakow, 1992). In addition, lateral movement of water in soil may have occurred after the rainfall of the night of 23 Aug., since top sections of soil adjacent to all

substrate-filled holes increased (Fig. 3).

Substrate and soil TVW at similar measurement depths showed the same general drying and rewetting patterns for #2 and #7 sizes (Fig. 3A and C), suggesting that little water moved laterally between the coarse substrate and finer textured soil (Hillel, 1982). The middle-of-substrate measurements for #15 and

#25 sizes (Fig. 3E and G) show a somewhat increased TVW compared to adjacent soil after the 23 August rain, probably due to increased infiltration depth for these sizes. PAVW in the middle sections of substrate for all volumes were recharged from the 23 Aug. rain (Fig. 3B, 3D, 3F, and 3H), and PAVW increased with container size.

PAVW within all embedded substrate was consistently below PAVW in surrounding field soil at corresponding depths (Fig. 3B, D, F, and H). Although soil has a more favorable PAVW than modern bark substrate, the air-filled porosity of soil during production in containers is generally unfavorable, especially in periods of frequent rainfall and slow plant growth (Handreck and Black, 1999). Container substrates that work well in production, such as the pine-bark substrate in our experiment, become drier when embedded in well drained soil. For example, a peat:sand mixture was reported to lose 53% of total water held at container capacity when embedding into soil with the container removed, and the embedded substrate had a lower water content than the surrounding soil after irrigation (Nelms and Spomer, 1983). Costello and Paul (1975) found that root balls of transplanted sweet gum (*Liquidambar styraciflua* L.) trees (grown in sand-peat-sawdust mix) were drier than the surrounding soil and contained root balls. Substrates that work well for container production but retain more plant-available water after transplanting are needed.

A high plant-unavailable water fraction in pine bark has been demonstrated by others (Beardsell et al., 1979; da Silva et al., 1998). da Silva et al. (1998) explained that much of the water in pine-bark substrates are tightly bound to organic compounds, mineral crystals, or embedded in occluded pores. Our data indicate that once embedded, the pine-bark substrate retains very little plant-available water in the top 6 cm and middle sections (9 to 15, 12 to 18, 14 to 20, 19 to 25, and 23 to 29 cm depths for #1, #2, #7, #15, and #25 container sizes, respectively), even immediately after irrigation, and that embedded substrate from larger containers retains more water during a

dry-down period than substrate from smaller containers. Transpiring plants will reduce the already low available water very quickly until roots grow into the backfill-soil. Actual water withdrawal rate will vary according to species, size and growth rate (Witmer, 2000). Rapid root growth beyond the original container root ball is therefore critical, especially if irrigation or rainfall is negligible. Our experiment was conducted in typical summer weather with high evapotranspiration potential (Fig. 1). Rate of drying and magnitudes of differences between substrate and soil will likely differ somewhat as weather changes. For example, the substrate and soil will probably dry more slowly in cooler conditions as is common in spring and fall. However, it is unlikely that basic relationships illustrated by our data, such as relatively low PAVW of the embedded pine-bark substrate and increasing PAVW in middle sections as container size increases will differ considerably between seasons.

As noted by Day and Skoupy (1971) for container-grown forest seedlings, retention of water within root balls after transplanting will likely increase post-transplant survival. Water conservation measures such as mulching and use of water-conserving plants (Smith and Rakow, 1992) will also increase transplant success.

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