Effects of Container Geometry and Media Physical Properties on Air and Water Volumes in Containers[1]

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Abstract

Data derived from soil moisture retention curves of two media were combined with geometric descriptions of four containers to produce calculated values of air and water volumes for each medium-container combination. The volume air space ranged from 28% in a #1 container to 12% in a bedding plant cell (BPC). Water volume after drainage increased from 43% (#1) to 59% (BPC). The same trend occurred in these containers with the peatlite mix. These calculations were also used to mathematically model four simulated containers and to calculate the air and water contents in the resultant container-medium combinations.

Index words: container capacity, computer models

Introduction

Flower and nursery industries are using a variety of container sizes and shapes. The greenhouse industry is providing smaller pot plants as they accommodate not only full-service flower shops, but also mass market outlets. The nursery industry is producing more ground covers and perennial landscape plants in small containers, and using bigger containers for production of large landscape plants. The reduced size and volume of such containers have resulted in several problems associated with plant production which can be reduced by more accurately matching container size with media type (9). Biran and Eliassaf (2) reported that plant growth tends to be stimulated when the natural growth pattern of roots and the shape of container are matched. Keever et al., (6) found that growth was influenced by container depth and width; however, this influence varied among species depending on root growth patterns. The objective of this study is to introduce techniques which describe the air and water characteristics of specific container-media combinations.

Methods and Materials

Physical properties of selected potting media including moisture characteristic curves were determined using a pressure plate apparatus and modified procedures of Fonteno et al. (3) and Bilderback et al. (1). Regression equations were developed for semilogrithmic curves to predict moisture values at specific tensions for each medium using procedures of Milks (7).

To apply soil physics to containers, three axiomatic criteria for container models need to be considered. First, the bottom of a container acts in similar fashion to an impervious soil hard pan (4). Therefore, after drainage a "perched water table" would exist at the bottom of the container. The matrix tension in this zone would essentially be zero. Once equilibrium is reached after drainage, the tension at any location in the container (expressed as cm of water) would be equal to the gravitational force exerted by the height (in cm) of that location from the bottom of the container. For example, at equilibrium after drainage the tension exerted 5 cm (2 in) up from the bottom of the container would be 5 cm (2 in).

Second, from the moisture retention regression models (Fig. 1) the percent moisture content at any tension between 0 and 300 cm of water (0 to 118 in) can be determined. The portion of the moisture retention curves which correspond from zero to a specific height in a container (dashed section, 3 pine bark:1 sand, Fig. 1), can be used to determine the percent moisture content in the container.

Third, a range of matrix tension forces exist at equilibrium in a container, from 0 at the bottom to the height of the medium surface. Since the slopes of the moisture retention curves change rapidly in these tension ranges (Fig. 1), the prediction of percent moisture

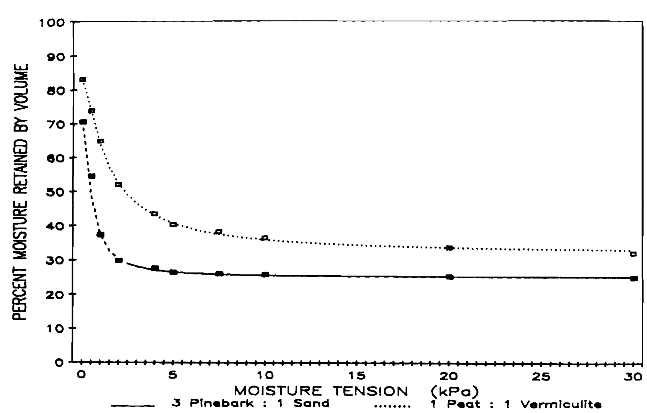

Fig. 1. Moisture retention curves for 1 peat:1 vermiculite (PV) (by vol) and 3 pine park:1 sand (BS) media. Dashed section used by calculating container capacity in Fig. 2. Regression equation for PV: Y = 50.9(1/1+2.89x)0.423))5.391+32.2. Regression equation for BS: Y = 45.6(1/(1+3x)0.886)) 2.24+25.1.

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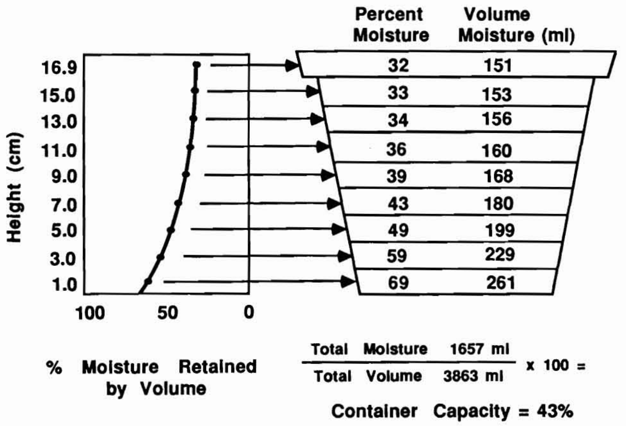


Fig. 2. Percent and volume moisture retained in 2 cm zone increments in a 3.8 l (#1) container derived from the moisture retention curve of a 3 bark:1 sand medium.

must be within a very small tension range (-1 cm or 0.38 in). To allow this, each container should be divided into zones no taller than 2 cm (0.79 in).

Height, top, bottom and lip diameters were measured for three containers: (a) 3.8 l (#1), (b) 15.3 cm (6 in) and (c) 10.2 cm (4 in) standard pot. Volumetric determinations in 2 cm (0.79 in) height increments were calculated for each container using the equation for inverted, truncated cones:

$$\text{Top radius}^2 + \text{Bottom radius}^2 + (\text{Top radius} * \text{Bottom radius})* *(\text{Height}/3)$$

where Top radius is the top radius of the zone, Bottom radius is the bottom radius of the same zone and Height is the height of the zone (in most cases = 2 cm, or 0.79 in). the lip of the container was treated separately with different top and bottom radii, effectively describing a container as two stacked frustrums.

A 5.7 cm (2.25 in) bedding plant cell (C4/8, 48 per tray) was also measured and zone volumes were calculated in a similar manner as above, using the formula for a frustrum of an inverted pyramid (8).

Tension values of 1, 3, 5, 7, etc. (which correspond to the center of each 2 cm (0.79 in) zone) were used to predict percent moisture in each zone.

By combining moisture retention data with volumes of incremental 2 cm (0.75 in) zones, actual moisture volumes can be determined for each zone (5). These volumes can be summed to the height of the medium surface and percent moisture volume of the entire container at container capacity determined (Fig. 2). Subtracting container capacity from total porosity results in percent air space. Air space for each zone can also be determined in the same manner as container capacity.

In the first experiment, regression models of two media, aged pine bark:concrete grade sand (3:1 by vol) and Canadian sphagnum peat moss:horticultural grade vermiculite (1:1 by vol) were combined with mathematical descriptions of the above four containers. Computer-generated simulation models were developed to predict air and water values for each medium-container combination.

In experiment 2, a mathematical description of a container with 15 cm (6 in) top diameter, 10.6 cm (4 in) bottom diameter and 14.4 cm (5.5 in) height with no lip was altered to produce four simulated containers of equal height: (a) normal taper, (b) straight sides (top and bottom diameters = 15 cm (6 in), (c) double taper (top diameter = 30 cm (10 in); bottom = 10.6 cm (4 in) and (d) inverted normal taper (top = 10.6 c, (4 in); bottom = 15 cm (6 in). These were combined with the above media regression models, and air and water values were predicted for the new container-media combinations. Medium surface level was considered to be 2 cm (0.79 in) from the top rim of the containers.

Two assumptions were made in the use of these models in both experiments: A) the bulk density and total porosity of the media in containers were equal to the bulk density and total porosity of the samples in the moisture retention curves; (B) since the moisture retention curves were desorbtion curves, all simulated irrigation was applied to the medium surface.

Results and Discussion

Regression models of moisture retention curves for BS and PV media are found in Fig. 1. The BS medium contained 72% moisture (by vol) at saturation while the PV medium held 83%. Both media drain rapidly, hold the majority of their available moisture between 0 and 4.89 kPa (1.7 log kPa or 0.7 lbs/in²) and provide approximately parallel moisture release patterns.

Simulation models for bark:sand in the four containers in experiment 1 are shown in Fig. 3. The 3.8 l (#1) and 15.3 cm (6 in) standard plastic containers provided 28 and 26% air space, respectively and varied by only 2% in water held (by vol) after irrigation was applied and the containers were allowed to drain. However, because the 3.8 l (#1) container was approximately twice the volume of a standard 15.3 cm (6 in) container, the corresponding air and water volumes in the two containers differ by a factor of 2. As container height decreased in the 10.2 cm (4 in) pot and bedding plant cell, percent aeration dropped to 19 and 12, while percent moisture increased to 52 and 59, respectively.

The PV medium showed even greater trends of decreased aeration and increased moisture retention as container height decreased (Fig. 4). Air space decreased over 50% in the PV mix from the 3.8 l (#1) container to

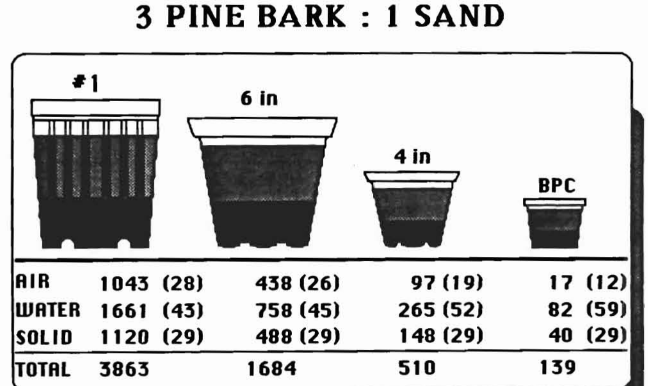
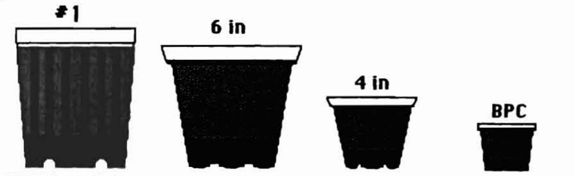


Fig. 3. Air, water and solid fractions in actual volume and as percent of total volume of 3 pine bark:1 sand (by vol) from simulation models for 4 plastic containers.

1 PEAT : 1 VERMICULITE



	#1	6 in	4 in	BPC
AIR	657 (17)	253 (15)	46 (9)	7 (5)
WATER	2549 (66)	1145 (68)	377 (74)	108 (78)
SOLID	657 (17)	286 (17)	87 (17)	24 (17)
TOTAL	3863	1684	510	139

Fig. 4. Air, water and solid fractions in actual volume and as percent of total volume of 1 peat:1 vermiculite (by vol) from simulation models for 4 plastic containers.

the bedding plant cell; whereas, air space dropped only 33% in the bark mix.

Air and water values of BS in the artificial containers from Experiment 2 are found in Fig. 5. These simulation models show that changing the container design from a normal taper did not appreciably change the percent air and water values. There were substantial changes in the actual volumes of air and water due to the resultant changes in overall container volumes, with one exception. There was no change in actual volume from the normal taper to the inverted normal container. However, changing the container configuration to a smaller taper at the top provided less drainable pore space than in the normal taper.

Similar results occurred in the PV medium in the four simulated containers (Fig. 6). The differences in air and water values between the bark and peat-based mixes in these simulated containers were due to the differences in moisture retention curves of the two media (Fig. 1).

Brian and Eliassaf (2) and Keever et al. (6) concluded that matching container shape to natural growth habit of species is likely to improve overall growth response. These conclusions are based on both the genetic capacities of plant species and the physical properties in the containers. Our data show that media type and container combinations can greatly alter air and water values. Air and water volumes can be calculated for almost any medium/container combination by knowing the medium moisture characteristics and container dimensions.

Significance to the Nursery Industry

Plant growth response in production may be improved by first selecting the appropriate medium/container combination and then matching the resulting physical properties to the needs of specific plant root characteristics. The air and water holding capacities of a medium are dependent upon the container depth and width and not solely to the medium. The same medium in various container sizes can produce different air and water contents for plant growth. Growers need to consider a medium/container combination as an integral unit, and not as two independent factors. When water restrictions become necessary, these procedures are basic to calculating and planning irrigation requirements.

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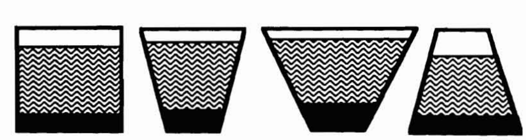
CONTAINER DESIGNS

AIR	611 (24)	486 (26)	1505 (30)	412 (22)
WATER	1196 (47)	842 (45)	2056 (41)	916 (49)
SOLID	738 (29)	543 (29)	1454 (29)	543 (29)
TOTAL	2545	1871	5015	1871

3 PINE BARK : 1 SAND

Fig. 5. Air, water and solid fractions in actual volume and as percent of total volume of 3 pine bark:1 sand (by vol) in simulated straight sided, normal tapered, double tapered and inverted normal tapered 15.3 cm (6 in) container.

CONTAINER DESIGNS



AIR	356 (14)	281 (15)	903 (18)	223 (12)
WATER	1756 (69)	1272 (68)	3259 (65)	1328 (71)
SOLID	433 (17)	318 (17)	853 (17)	318 (17)
TOTAL	2545	1871	5015	1871

1 PEAT : 1 VERMICULITE

Fig. 6. Air, water and solid fractions in actual volume and as percent of total volume of 1 peat:1 vermiculite (by vol) in simulated straight sided, normal tapered, double tapered and inverted normal tapered 15.3 cm (6 in) container.