PROCEDURES FOR DETERMINING PHYSICAL PROPERTIES OF HORTICULTURAL SUBSTRATES USING THE NCSU POROMETER

HORTICULTURAL SUBSTRATES LABORATORY

NCSU

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Horticultural Substrates Laboratory

Introduction

All horticultural producers are faced with problems of water quality, water conservation, and the reduction of water runoff from their respective agricultural industries. At the same time, solid waste management issues, reduction in landfill sites, and waste product utilization problems are reaching not only our producers but far beyond horticulture to affect the whole of society. Here at N.C. State, the Department of Horticultural Science is addressing these issues with a new research group, the Horticultural Substrates Laboratory.

The Horticultural Substrates Laboratory is a consortium of four research scientists, technical staff, graduate students, and research facilities, housed in the Department of Horticultural Science at NCSU. This core of researchers banded together, integrating the strengths of each program into a center of excellence for substrates research. Started in 1988, the interaction works well; sharing of facilities, sometimes labor, and a constant dialogue of shared ideas allows the group to address issues that no one member could approach alone.

Mission

The mission of the Horticultural Substrates Laboratory is to integrate research dealing with the physical and chemical properties of horticultural substrates with nutrient and watering system technologies. The goals of HSL are: 1) to increase understanding of the roles of water and nutrient retention in the rhizosphere (root zone); 2) to improve conditions in the rhizosphere for more optimal uptake of water and nutrients; 3) to develop a better understanding of nutrient problems with improved diagnostic and corrective procedures; and 4) to identify alternate, renewable components for use in horticultural substrates.

Benefits

By sharing information generated from this consortium with other, problems in many areas can be addressed. For the professional growers, benefits from this research will be improved substrates, improved crop yield, better conservation of water and nutrients, and reduction in water runoff and ground water pollution. For the retail consumer there will be better substrates and soil amendments for landscape use. Municipalities and industries will have alternative management strategies for solid waste disposal.

Approach

The combination of new and existing information with a mechanistic experimental design for physical and chemical property evaluations should provide an integrated approach to solving some of tomorrow's problems today.

This manual is a compilation of the technology and techniques used to define physical and hydraulic properties at the Horticultural Substrates Laboratory (HSL) at North Carolina State University, Raleigh NC. These techniques are the results of over 20 years of work and research. These procedures are continually evaluated and updated as new research findings are assimilated.

The authors of this manual are: Dr. William C. Fonteno, Project Director HSL and Ms. Clarissa T. Harden, Research Technician and Lab Director.

Special thanks goes to Dr. Keith Cassel, Professor of Soil Science, NCSU and Editor of the Soil Science Society of America Journal, for his guidance and assistance in the formulation of these procedures.

We have made every effort to provide an accurate and articulate presentation of our methods. We update our procedures when necessary. Check the revised date below for the last update.

Contact Information

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Explanation of Terms

Standard terminology is used for most parameters used in this manual. However, several terms will be used describing the physical and hydraulic properties of substrate components. Although most of the terms are not new, the following definitions and concepts are offered for clarification.

Substrate — Any material or combination of materials used to provide support, water retention, aeration, or nutrient retention for plant growth. This is the standard term today. Other terms that are similar are: medium (Plural=media), and mix.

Component — A single material that is combined in volumetric proportions with other components to achieve a desired air, water, nutrient ratio for plant growth. Examples are peat moss, pine bark, perlite, vermiculite, etc.

Total Porosity — The percent volume of a substrate or component that is comprised of pores, or holes. This is the volume fraction which provides the water and aeration in a substrate. The total porosity + the percent solids = 100%.

Container Capacity — The percent volume of a substrate (or component) that is filled with water after the material is saturated and allowed to drain. It is the maximum amount of water (or capacity) the material can hold. Since drainage is influenced by the height of the substrate, this property is dependent on container size. The taller the container, the more drainage it will cause, and the less capacity of the substrate to hold water.

Air Space — The percent volume of a substrate or component that is filled with air after the material is saturated and allowed to drain. It is the minimum amount of air the material will have. It is affected by container height in reverse fashion to container capacity; i.e., the taller the container, the more drainage and therefore more air space. For a given density and moisture content, Total Porosity = Container Capacity + Air Space.

Bulk Density	The ratio of the mass of dry solids to the bulk volume of the substrate. The bulk volume includes the volume of solids and pore space. The mass is determined after drying to constant weight at 105°C, and volume is that of the sample in the cylinders. Values expressed as g/cc.
Unavailable Water (PWP)	The percent volume of a substrate or component that contains water which is unavailable to the plant. This is also called the permanent wilting percentage (PWP). This is defined as the amount of water remaining at 1.5 MPa (approximately 15 atmospheres). This property is a measure of the inefficiency of the substrate to provide water to the plant.
Moisture Content	The percent moisture found in a sample on a wet mass basis. This is calculated by: [(Wet weight - Dry weight)/Wet weight] X 100. This is the common format for most data. It denotes how much of a particular sample is comprised of water.
Mass Wetness	The water content of a sample on a dry mass basis. This is calculated by: (wet weight - dry weight)/dry weight. This measure more precisely depicts how much water is added to a dry sample.

Sample Preparation:
Moisture Content & Bulk Density

Introduction

This test was designed to determine properties of STRUCTURE for components and mixes. There is NO structure in the bag or bale of product. Structure is always created at the point of use.

All of following physical properties are based on a percent volume basis. During the testing procedure, it is critical for the substrate to have a structure that does not change. Swelling of substrates during saturation or shrinking during drainage causes erroneous readings.

If your substrate is swelling or shrinking more than 3 mm above or below the top of the aluminum cylinder during the test, the numbers are not valid.

Fortunately, controlling shrink/swell can be accomplished by using proper moisture content and packing to target bulk densities.

At the Horticultural Substrates Laboratory, we have tested thousands of samples including peats, barks, professional and consumer mixes. We have also evaluated many materials as perspective components. In all of our tests we try to evaluate structure as the plant would see it.

Procedure:

1. Determine mass wetness (moisture content) of sample by drying. This can be accomplished with conventional drying oven, forced-air drying oven, microwave oven, or moisture determining balance. This can take from 15 minutes to 24 hours, depending on sample and technique used.

2. Calculate the target mass wetness, add moisture, blend in, seal in plastic bag and let equilibrate over-night. This is a critical step. If we try to pack our sample right after moisture addition, the substrate may be “tacky” or sticky. If we

equilibrate it over night, this tackiness is gone.

3. Pack sample to target bulk density. If we have run test on the product before, we match mass wetness and bulk density for comparison.

Common Values for Moisture Content and Bulk Density of Selected Substrates

Substrate	**Mass Wetness**	**Moisture Content**	**Bulk Density**
	(g water/g substrate)	*(% wt.)*	*(g/cc)*
Sphagnum peat	3.0 - 5.0	75 - 82.5	0.06 - 0.10
Pine bark	1.5	60	0.2
Pine bark fines	1.5	60	0.25
Coconut fiber (Coir)	4.0 - 5.0	80 - 85	0.08
Professional Mixes (all)	1.5 - 2.75	60 - 75	0.10 - 0.16
Mixes: Peatlite	2.5 - 2.75	70 - 75	0.10 - 0.14
Mixes: Coir	2.5 - 3.5	70 - 78	0.09 - 0.14
Retail Mixes	1.0 - 2.5	50 - 70	0.10 - 0.40

This table is offered as a guide. Your actual numbers may vary, according to your materials.

Testing Freshly Manufactured Products

While it is desirable to test pH and EC directly on freshly run product, it is not desirable to test structure that way. However, once you have established a proper test as described above, you can develop a quick, ON-LINE test for porosity, using samples directly from the production line. These numbers will not necessarily be the same as a proper Porometer test, but can be repeatable and provide useful information.

Mass Wetness Calculations

Mass Wetness = (wet weight - dry weight) ÷ dry weight [1]

Bulk Density = dry weight ÷ volume [2]

1. Determining mass wetness of a substrate

1.1. Fill 3 beakers half full with representative samples of a substrate.

1.2. Weigh (and record as wet weight) the 3 samples and place in a drying oven for 24 hours at 105° C.

1.3. Weigh again and record as dry weight.

1.4. Average the wet and dry weights, then calculate mass wetness using the above equation.

2. **Determining the amount water to add to a substrate to obtain a specific mass wetness desired for packing**

2.1. After determining mass wetness of a substrate then select an amount sufficient for packing and record as substrate weight (SW).

2.2. Select a target mass wetness (MW^T) desired for packing. Generally a 1.5 mass wetness is sufficient for packing. However any mass wetness can be chosen and may be more suitable for some substrate.

2.3. Use the following equations to calculate the amount of water to add to the substrate:

$$SW \div (1 + \text{mass wetness}) = X \qquad [3]$$

Where X is the weight of the packing substrate

$$X \infty MW^T = Y \qquad [4]$$

Where Y would be the volume of water to add if the substrate was at oven dryness.

$$X + Y = Z \qquad [5]$$

Where Z is the target weight of the packing substrate.

$$Z - SW = \text{the amount of water to add to the medium} \qquad [6]$$

Example:

The target mass wetness for packing is a 1.5. The weighed amount of substrate to be used is 3000 grams. The mass wetness of the three representative samples was calculated as 0.86.

From [3]: $3000 \div (1+0.86) = 1613$

From [4]: $1613 \infty 1.50 = 2419$

From [5]: $1613 + 2419 = 4032$

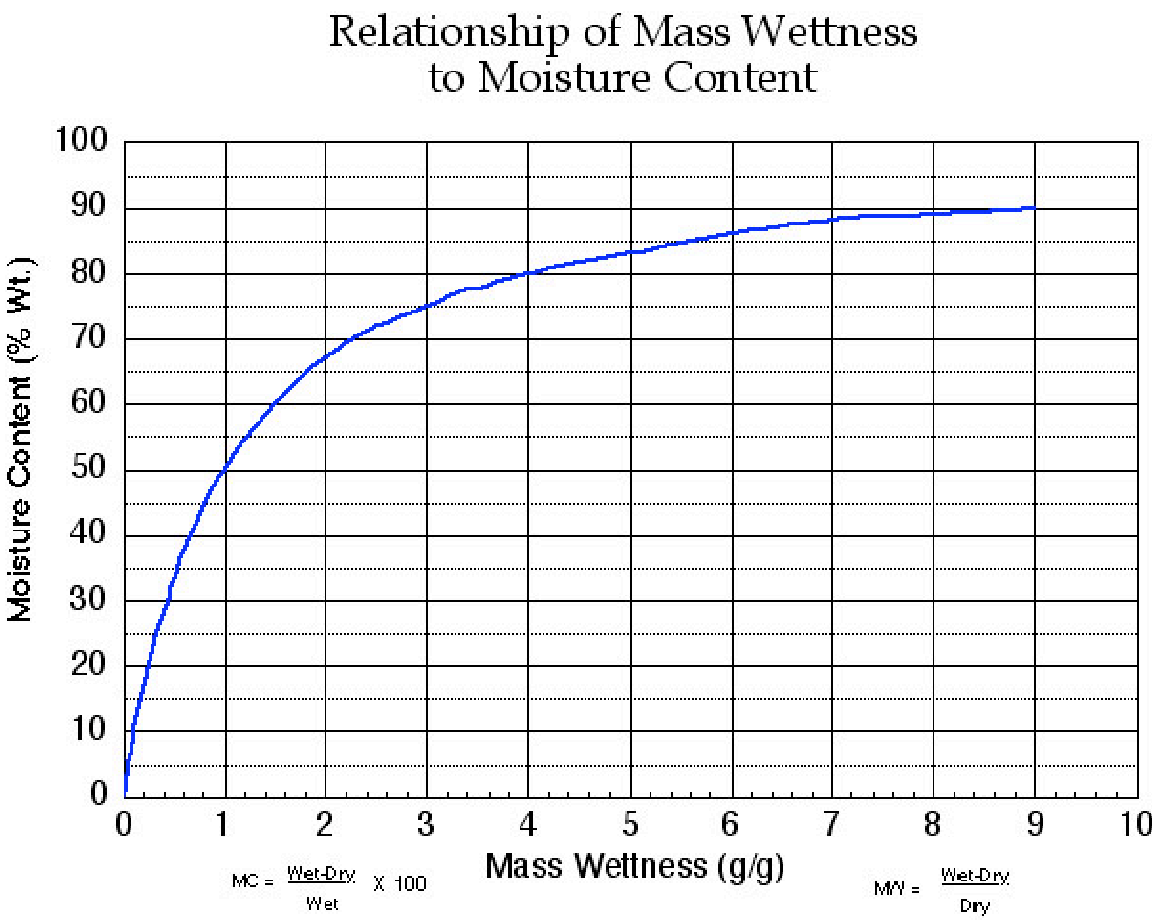
From [6]: $4032 - 3000 = 1032$ mls of water need to be added to 3000 gms of substrate to reach 1.5 mass wetness at packing.

REFERENCE

Gardner, W. 1986. Water content, p. 493-544. In: A. Klute (ed.). Methods of soil analysis, Part 1. Physical and mineralogical methods.

Mass Wetness vs Moisture Content

There is a correlation between mass wetness and moisture content. Mass wetness is calculated as the difference between pack weight and dry weight divided by the dry weight. Moisture content is calculated as the difference between pack weight and dry weight divided by the pack weight multiplied by 100. Refer to graph below.



Packing Instructions for Substrate Samples

1. Preparation

1.1. Fill out Data Sheet as per sample sheet.

1.2. Fill in CORE #, substrate descriptions, numbers and reps.

1.3. To pack to a known bulk density, continue to step 2. If not packing to a previous bulk density, go to step 3.

2. Packing to a previous bulk density.

2.1. In advance, determine the mass wetnesst (by weight) of the substrate. This is done by taking several (3 to 5) samples of the substrate at the current moisture content, recording the weights, and drying them in a forced air drying oven at 105° C for 24 hours. Mass wetness (MW) is determined as follows:

$$MW = (\text{Wet weight} - \text{Dry weight}) \div \text{Dry weight} \quad [1]$$

2.2. To determine the packing weight of the substrate needed in the core, use the following equation:

$$\text{Pack weight} = \underset{(dry)}{\text{Bulk density}} \infty \text{ Core volume} \infty (1+MW) \quad [2]$$

Where: 7.6 cm Core volume = 347.50 cc
2.54 cm Core volume = 115.83 cc

3. Packing the Sample Core.

3.1. Weigh each core and record the weight on the data sheet.

3.2. Place a petri dish with the core on the scale and tare the scale. Keep the petri dish with the core.

3.3. Place the core in the core column. The core column should contain (from bottom to the top): a 7.6 cm core with aluminum lid, the tared core for use in the analysis, and the15.2 cm packing cylinder.   Use the straps to hold the core column together.

3.4. Pour the substrate into the column to overflowing.

3.5. Level the substrate off by slowly and carefully striking across the top surface with spatula.

3.6. Drop the column 5 times from approximately 3 to 6 cm above a sturdy table. Consistency in dropping force is more important than the actual height.

4. Weighing Sample Core

4.1. Remove the top cylinder, level the substrate, and place the petri dish (tared with the core) on top of the freshly leveled surface.

4.2. Turn column over, holding petri dish securely. Remove the bottom core and level the substrate.

4.3. Weigh core and dish on the tared balance and record as PackWt.

4.4 Sample pack weights within 5% of each other are generally acceptable as replicates.

4.5. To attain a desired weight, either lighter or heavier, the force of the drop and height of the drop in step 3.6 may have to be modified.

REFERENCE

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peatmoss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107(3): 522-525.

NCSU Porometer Procedures

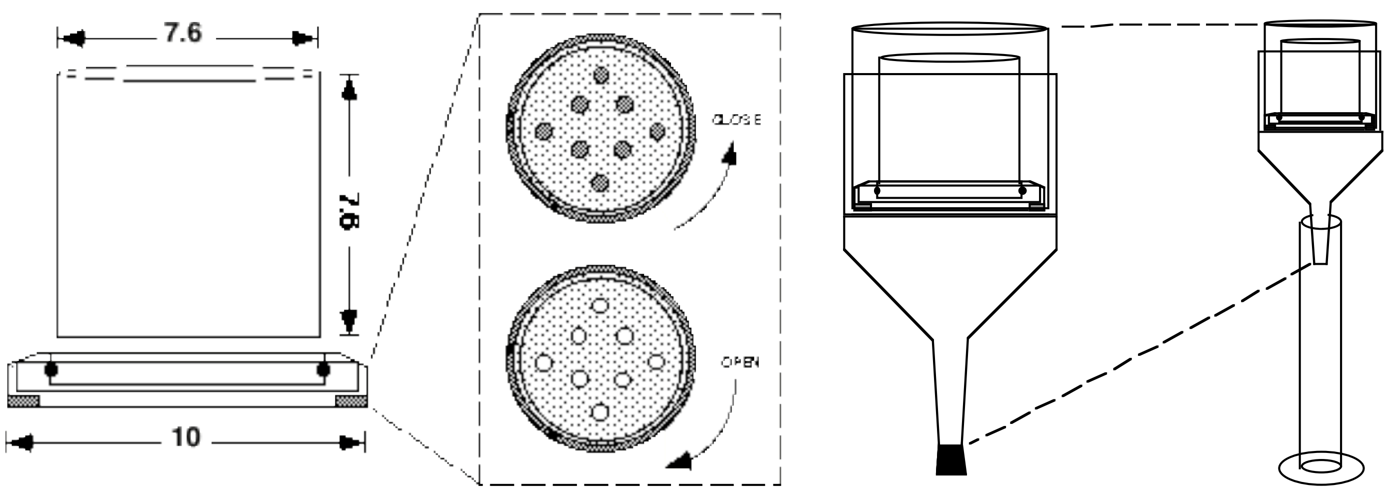
INTRODUCTION:

The Porometer consists of three parts:

- The main part is an aluminum **base plate** having an inner and outer plate with 8 holes in each. The plates fit together as one unit and can be rotated so that the holes are aligned in the **open position** to allow drainage through the plates. Also, the plates can be rotated such that the holes are covered in the **closed position** to prevent any seepage of water through the plates.

- The second part is a 3 inch aluminum core that is packed with a substrate sample and then placed onto the base plate.

- The third part is a funnel in which the base plate with the core is placed for saturation and drainage of the sample.



PROCEDURE

1. DATA SHEETS:

1.1. Refer to sample data sheet.

1.2. Prepare data sheet before packing cores.

1.3. Record core number and core weight.

2. LOADING:

2.1. Read attached packing instructions. Properly pack 3 inch (7.6 cm) cores and cover with petri dishes.

2.2. Place each core on a flat surface. Remove the top dish and carefully press the base plate onto the core without disturbing the sample.

2.3. Rotate (open and close) the base plate several times to insure a firm seal. Check to make sure all plates are in the open position.

2.4. Carefully place the entire unit (core with attached base plate) in the funnel. The notches in the base plate should fit securely over the bolt heads in the bottom of the funnel.

3. SATURATION:

3.1. Place rubber stoppers in the bottom of each funnel.

3.2. Next the funnels are filled with distilled water in a step-wise fashion to prevent air entrapment. First fill all funnels up to the height just above the top of the baseplate. Next fill all funnels to 1/3 the height of the core. Then fill all funnels to 2/3 the height of the core. Then fill again to within 1/4 inch from the top of the core. Fill once again to almost the top of the core. At this point, using the water surface as a guide, level all units. Finally fill to the top being careful not to spill into the core. (Exact increments in filling is not critical.)

3.3. Wait 15 minutes for complete saturation. Then close the base plate by carefully rotating the unit with the finger tips of your hand. Do not disturb the contents in the core.

Check to make sure the base plate is in the *closed position* before draining the funnels.

4. DRAINAGE:

4.1. Place receptacle under funnels to collect water. Remove rubber stoppers and drain water from funnels.

4.2. Discard removed water.

4.3. Place a graduated cylinder under each funnel. Open each base plate and drain sample for 60 minutes. Record the drainage on the data sheet.

5. WEIGHING AND DRYING:

5.1. Record shrinkage before removing sample for weighing. If shrinkage occurred, measure the distance from the substrate surface to the top of the core and record under "shrink" on the data sheet. If shrinkage is "negative" (substrate surface extends above the top of the core) indicate so on the data sheet. This step is optional. Proper moisture content at packing will prevent shrinkage of sample.

5.2. Rotate baseplate to the closed position. Cover the core with an aluminum lid and record lid weight. Remove the entire unit from the funnel. When handling the core try not to disturb the core sample.

5.3. Remove the baseplate from the core by inserting the core lid side down through the hole in the extraction device. Gently pull core off of the baseplate. (While securely holding the aluminum lid, turn the core upside down and put through the hole in the top of the core extraction box. While holding the core and lid, gently pull and push it away from your body.

While rotating the core in 180° increments, continue a pulling-pushing movement until the core is loosened from the baseplate.) See diagram for extraction device at the end of this section.

5.4. After removing the core covered with the aluminum lid, weigh the sample and record wet weight.

5.5. Place sample in a drying oven at **105° C for 24 hours**. Some samples (particularly samples with high peat moss content) may require 48 hours to dry. Weigh and record dry weight. Place baseplate in a tub of plain water.

6. CLEANING:

6.1. Remove sample from core. Wash all equipment in plain water. A teflon coated sponge is helpful in cleaning the core.

6.2. The baseplate unit can be wiped with a wet sponge or towel. If the plate seems to leak or have grit between the plates then it needs to be separated for cleaning.

6.3 Separate the inner and outer plates, remove grease and wipe clean. Re-grease the plates by applying a thin layer of silicon vacuum grease evenly, spreading on both surfaces.

7. CALCULATIONS

7.1 Total Porosity. Determined by summing all of the water in the sample.

$$[(\text{Wet weight} - \text{Dry weight} + \text{Drainage}) \div 347.5] \times 100 \qquad [1]$$

where values determined in steps 5.4, 5.5, and 4.3, respectively. Values are in % Volume. (347.5 = volume of cylinder)

7.2 Container Capacity. The total amount of water the sample can hold after saturation and drainage.

$$[(\text{Wet weight} - \text{Dry weight}) \div 347.5] \times 100 \qquad [2]$$

7.3 Air Space. The volume of drainable pore space in the sample.

$$(\text{Drainage} \div 347.5) \times 100 \qquad [3]$$

or

$$\text{Total Porosity - Container Capacity} \qquad [4]$$

7.4 Bulk density. Subtract weights of all container used in “dry weight” measurements to get a true dry weight of substrate sample (DWS).

Bulk density is the substrate dry weight / core volume, or:

$$D_b \text{ (g/cc)} = \text{DWS} \div 347.5 \qquad [5]$$

$$\text{Db (lbs/cu ft)} = (\text{DWS} \div 347.5) \infty 62.427961$$

REFERENCE

Fonteno, W.C. and T.E. Bilderback. 1993. Impact of hydrogel on physical properties of coarse-structured horticultural substrates. J. Amer. Soc. Hort. Sci. 118(2): 217-222.

Drying Oven Procedures

1. General hazards of operation

1.1. Contact with hot interior oven surfaces and contents.

1.2. Possible fire hazard with: a) flammable or combustible substances placed in oven, b) contents improperly arranged in oven, c) when oven temperature is incorrectly set too high.

1.3. Electrical problems - check cord and plug regularly. Replace if damaged.

2. Do NOT put the following in ovens:

2.1. Enclosed containers such as sealed jars, cans, bottles.

2.2. Flammable solvents of any kind.

2.3. Explosive or easily ignited combustible materials

2.4. Open containers, boxes, bags, which will permit dust or powdered material to escape and circulate in the oven.

2.5. Wet or moist samples in plastic bags.

3. Temperature Changes

3.1 NEVER change the temperature. If the temperature needs to be changed, the lab management will make the changes.

3.2 For safety and to prevent accidental overheating of samples or glass and plastic ware, a note will be posted on the oven stating any temperature changes.

3.3 Note that plastic ware will melt at 80°C or higher.

3.4. The ovens for 21-D are set at 105°C for drying substrate samples. Never set temperature above 105°C.

3.5 Notify lab management if oven is not working properly. Do not readjust settings.

4. Loading Ovens

4.1. Do NOT over-fill ovens, as this may cause overheating and fire.

4.2 Proper airflow in ovens is necessary for proper drying and to avoid overheating conditions.

4.3 If you can't see the back of the oven or below when it's fully loaded, then it's too full.

4.4 Remove enough material to correct the problem.

5. Storing Dried Materials

5.1. Ovens are not to be used as heated storage space.

5.2 When your samples or glassware are dried, please remove them promptly.

5.3 Turn the oven off when empty.

REFERENCE

Gardner, W. 1986. Water content, p. 493-544. In: A. Klute (ed.). Methods of soil analysis, Part 1. Physical and mineralogical methods.

Technical Support

For more information and the latest updates, visit the Horticultural Substrates Laboratory Website: www.substrateslab.com

Types of information:

- HSL Diagnostic Service
- HSL Publications (includes updates to Porometer Manual)
- Virtual Classroom "lectures" on soils & substrates
- Links to NCSU Floriculture and the NCSU Horticultural Science Dept.

Any questions or suggestions are always welcome.

Please direct any comments to:

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Appendix

Porometer Data Normal Values

Porometer Stand

Sample Data Sheets

Porometer Data

Substrate	Total Porosity (% vol.)	TP Max/Min	Air Space (% vol.)	AS Max/Min	Bulk Density (g/cc)	Mass Wetness (g/g)
Grower Mixes (Peat-lite)	85-88	92-84	9-10	13/9	0.14	2.5
Grower Mixes (Coir)	82-85	90-80	9-12	13/9	0.14 - 0.15	2.5
Peat: Vermiculite (1:1, v/v)	88	90-82	9-10	13/6	0.14	2.0 - 3.0
Peat: Perlite (1:1)	78	82/76	15-18	27/14	0.12	1.5 - 2.5
Coir	92-95	95-88	11-14	18/5	0.07 - 0.08	4.5 - 6.0
Pine Bark (<0.5”)	75 - 80	83/73	19 - 24	41/6	0.2	1.5
Peat (Canadian Sphagnum)	89 - 94	97 - 87	12 - 20	27/6	0.06 - 0.10	3.0 - 5.0
Perlite	68	82/65	28 - 32	46/14	0.15 - 0.17	1.0
Vermiculite (Hort. grade, #2 US)	78 - 80	85/74	6 - 10	26/4	0.16 - 0.18	1.5 - 2.0

*This is a compilation of over 2,000 samples tested in our laboratory using the NCSU Porometer. These data are offered as guidelines, NOT STANDARDS for these substrates. There are no standards; and it is our position that standards for these materials are inappropriate. However, it is useful to have numbers as guides. The values for total porosity, air space, bulk density, and mass wetness are not averages but those that we expect to see from that particular substrate. The Max/Min values are the total range we have found for that material - not “acceptable” ranges.

Porometer™ Stand

This is a diagram of the stand used at HSL. Adjust the length for the number of Porometers™ available.

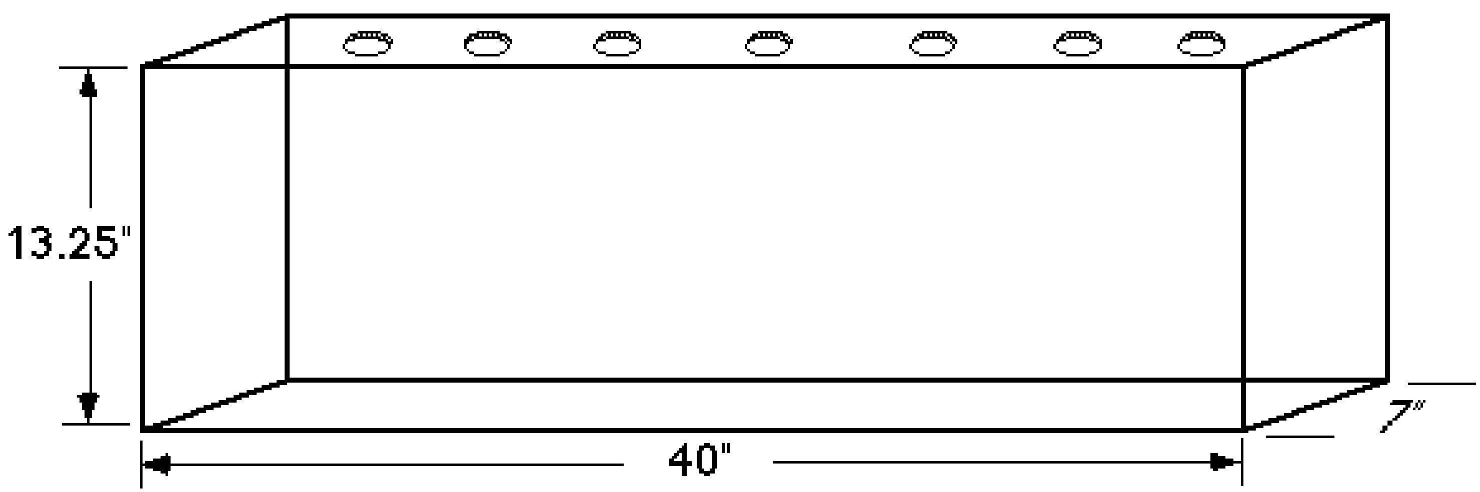
1 piece: 40" X 7" X 0.75"

2 pieces: 12.5" X 7" X 0.75"

1 piece: 38.5" X 7" X 0.75"

Holes: 2" dia. , 5.88" centers

6 L Braces, Wood screws



Porometer Data Sheet

Title:

Date:

Description:	Rep	Pack Wt.	Drain	Wet Wt.	Dry Wt.	Lid Wt.	Core #	Core Wt.	Shrink	Remarks
	1									
	2									
	3									
	1									
	2									
	3									
	1									
	2									
	3									
	1									
	2									
	3									
	1									
	2									
	3									
	1									
	2									
	3									
	1									
	2									
	3									
	1									
	2									
	3									

Mass Wetness Data Sheet

Description	Rep	Cup #	Cup Wt.	Wet Weight	Dry Weight
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				