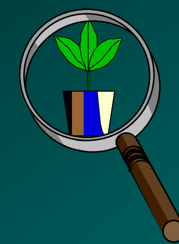
# Getting Physical with Potting Mixes!

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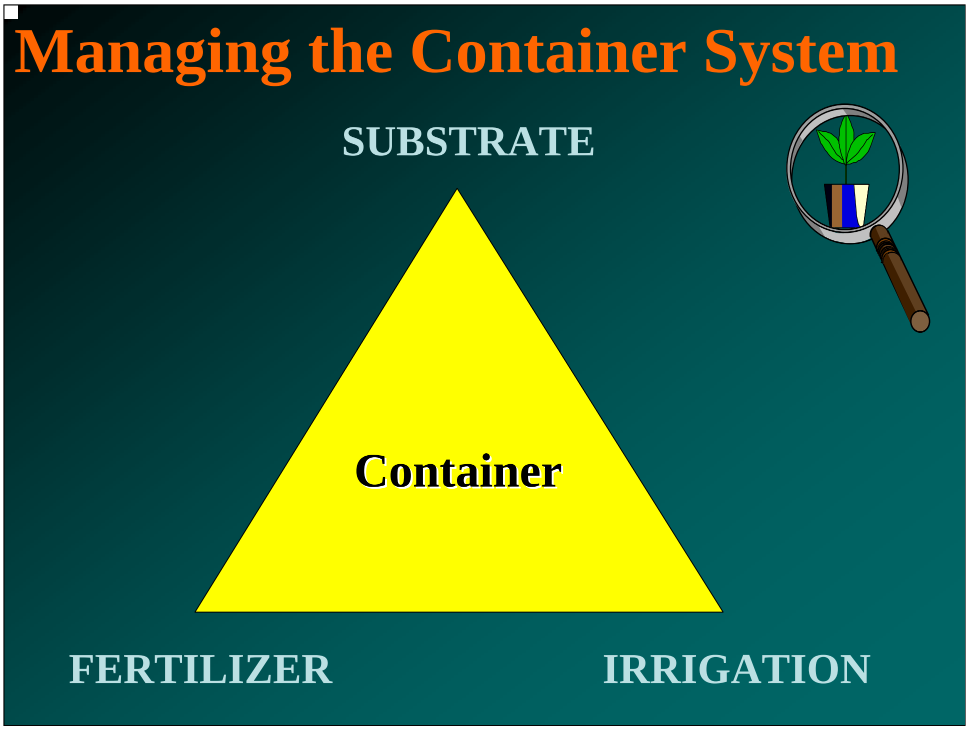
This presentation introduces considerations related to components used in formulating container substrates, methods used for evaluation of physical properties of container substrates and other considerations used for engineering stable uniform potting substrates used by the horticultural industry.

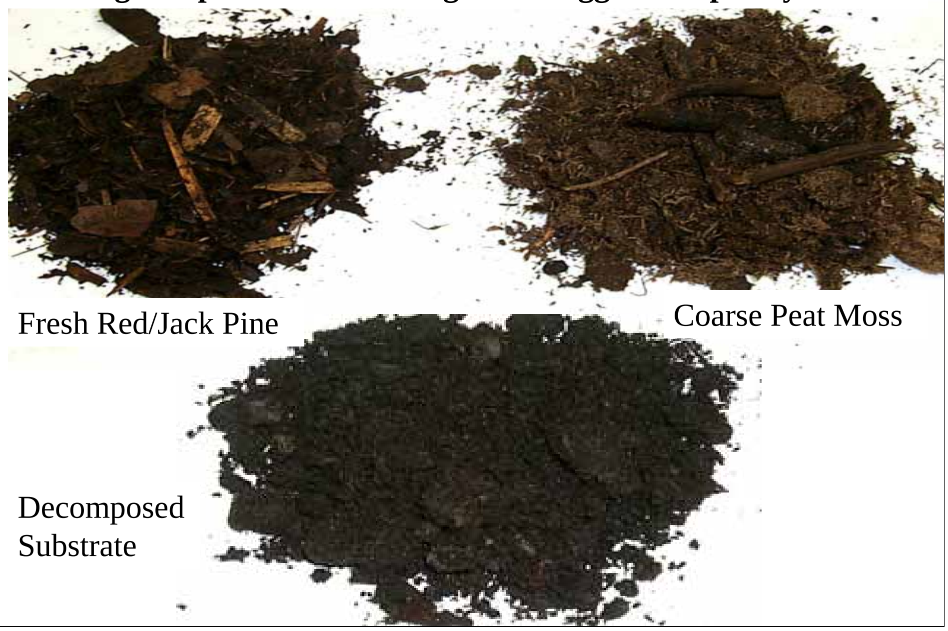



The container substrate is the reservoir and source for root adsorption of water and nutrients. Fertilizer application and irrigation practices also effect these resources. However, the amount of air, water and nutrients available for plant use after irrigation are largely due to the volume of these resources retained by the substrate.


Container substrates used in production of horticultural crops are predominantly organic components such as bark or peat moss blended with other organic or mineral components. Composts for potting substrates have been widely tested using a variety of materials including municipal wastes such as yard waste, garbage wastes, and biosolids/sludge; agricultural wastes such as rice hulls, cotton gin trash, peanut hulls; and animal and industrial wastes such as kitchen wastes, fly ash, and animal processing plant wastes. Many of these organic composts in addition to hypnum or reed-sedge peats, and sphagnum peat moss hold moisture within the particles similar to a sponge. Furthermore, composted materials often lack the coarse, large particles necessary for adequate aeration and therefore are not used in amounts greater than 50% of the volume for most container substrates

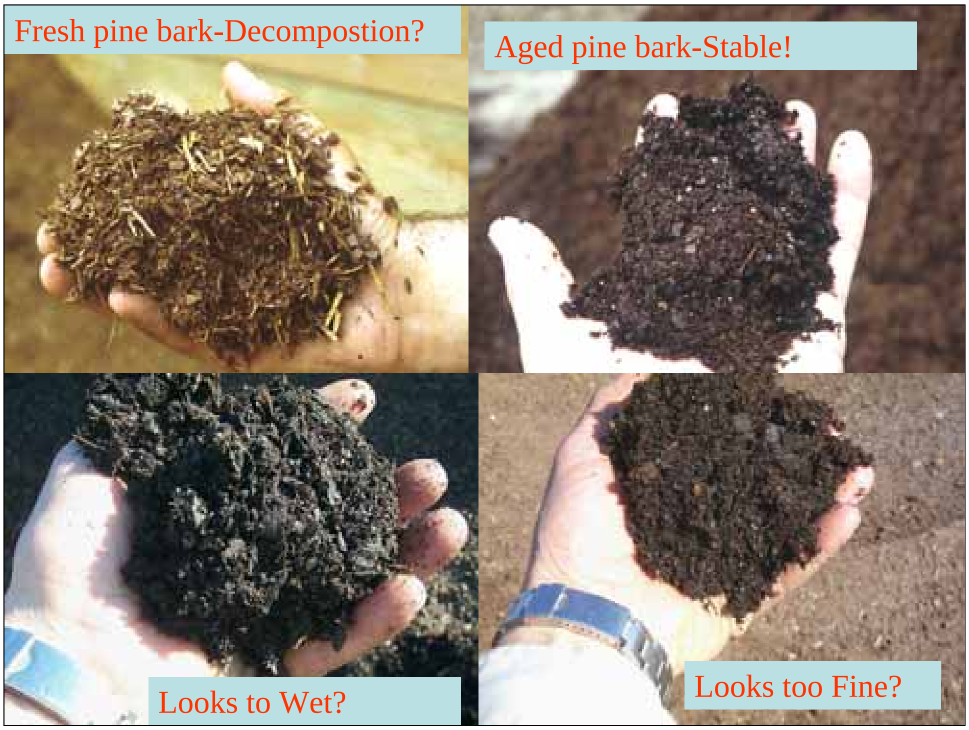

There are no distinct universally accepted standards for the physical properties of container substrates. Moisture retention characteristics of components blended into a container substrate are an average of the individual components.

**Decomposition of some organic components occurs rapidly reducing air space and becoming water logged and poorly drained**




Decomposition of organic components can create an overabundance of small particles that hold excessive amounts of water, thus creating limited air porosity. ). In contrast to composts, bark, sand, and most aggregates hold moisture between particles, therefore air and water retention characteristics are largely dependent upon how components "blend together" initially. However due to aging, decomposition and softening of particles under production conditions, most bark components over time also hold considerable moisture within particles as well.


Even when the same components are blended in identical ratios physical properties vary due to differences in particle size due to aging. Pine bark can vary from one shipment to the next.




Initial physical properties of potting mixes can be engineered for optimal characteristics. However, substrates containing predominantly organic components decompose during crop production cycles producing changes in air and water ratios. In the commercial nursery industry, crops frequently remain in containers for longer periods than one growing season (18 to 24 months). Changes in air and water retention characteristics over extended periods can have significant effect on the health and vigor of crops held in containers for a year or more.


Mineral aggregates such as perlite, pumice, coarse sand, and calcined clays do not decompose, or breakdown slowly, when used in potting substrates. Blending aggregates with organic components can decrease changes in physical properties over time by dilution of organic components and preserving large pore spaces, thus helping to maintain structural integrity

## Dry Weight of Pine Bark and Sand Substrates

| Substrate | Dry Weight (lbs / ft$^3$) |
|---|---|
| Pine Bark | 13.7 |
| 3PB:1Sand | 36.2 |
| 1PB:1Sand | 59.3 |
| 1PB:3Sand | 79.2 |
| Builders Sand | 97.3 |

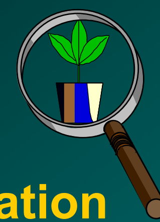
Addition of sand to pine bark is a common practice throughout the United States. Nurseries add sand to pine bark to increase the weight of containers to prevent blow-over and to slow infiltration rate of irrigation water as it moves through the container profile, particularly in fresh pine bark.). Growers use sources of sand that are available locally due to costs related to hauling. Mortar sand used in laying brick must be used cautiously in potting mixes since it has very fine particles and readily fills pores between larger bark particles reducing AS. Most growers use washed builder's sand (particle size distribution is approximately 56% of particles between 2.0 to 0.5 mm with ≤ 10% particles less than 0.2 mm by oven dry weight; which usually has a wet weight of 120 lbs/ft3 (1.9 g/cc), approximately 9% AS and 36% TP.

## Shrinkage of Pine Bark and Sand Substrates

| Substrate | Volume of Mix (cc) | % Shrinkage (Components) |
|---|---|---|
| Pine Bark | 200 | 0 |
| 3PB:1Sand | 192 | 4 |
| 1PB:1Sand | 189 | 5.5 |
| 1PB:3Sand | 194 | 3 |
| Builders Sand | 200 | 0 |

When potting materials of greatly different particle sizes, such as pine bark and fine sand, the final volume is not additive; e.g. 1 yd 3 plus 1 yd 3 (0.765 m3 / yd3) results in less than 2 yd 3, perhaps 1.5 to 1.75 yd 3. In this situation, a great increase in the Db of the substrate would be expected. An increase in bulk density results in lower TP and decreased AS. Even course builder's sand is much smaller in particle size than large pine bark particles, therefore adding sand usually increases moisture retention and AW content but reduces AS and TP when added to bark.

## Percolation Rate of Pine Bark and Sand Substrates



| Substrate | Percolation (cm /15 minutes) |
| --- | --- |
| Pine Bark | 91 |
| 3PB:1Sand | 62 |
| 1PB:1Sand | 35 |
| 1PB:3Sand | 23 |
| Builders Sand | 15 |

The slower infiltration rate promotes more thorough wetting of the substrate, compared with straight coarse pine bark particles, through which water can channel rapidly to the bottom of the container.

## Cation Exchange Capacity of Pine Bark and Sand Substrates

| Substrate | CEC ME/100g | CEC ME/100CC |
|---|---|---|
| Pine Bark | 52 | 11 |
| 3PB:1Sand | 15 | 8 |
| 1PB:1Sand | 6 | 5 |
| 1PB:3Sand | 3 | 3 |
| Builders Sand | 1 | 1 |

Characteristics of components blended into a container substrate are an average of the individual components. Sand in essentially inert, therefore additions of sand dilute CEC characteristics of pine bark. Cation exchange capacity represents an estimate of the cation nutrient holding ability of the substrate. Addition of sand dilutes the CEC of pine bark.

## pH of Pine Bark and Sand Substrates

| Substrate | pH |
|---|---|
| Pine Bark | 4.1 |
| 3PB:1Sand | 4.2 |
| 1PB:1Sand | 4.4 |
| 1PB:3Sand | 4.6 |
| Builders Sand | 5.4 |

As with CEC, addition of sand dilutes the organic acids contained in pine bark and therefore increases pH with incremental addition of the sand component.


Dry components when mixed tend to fit together tightly and increase Db of the substrate compared to when moist components are blended. Consequently air space is reduced and water may even tend to pool on the substrate surface of dry blended components.

## Laboratory Physical Property Analytical Procedures

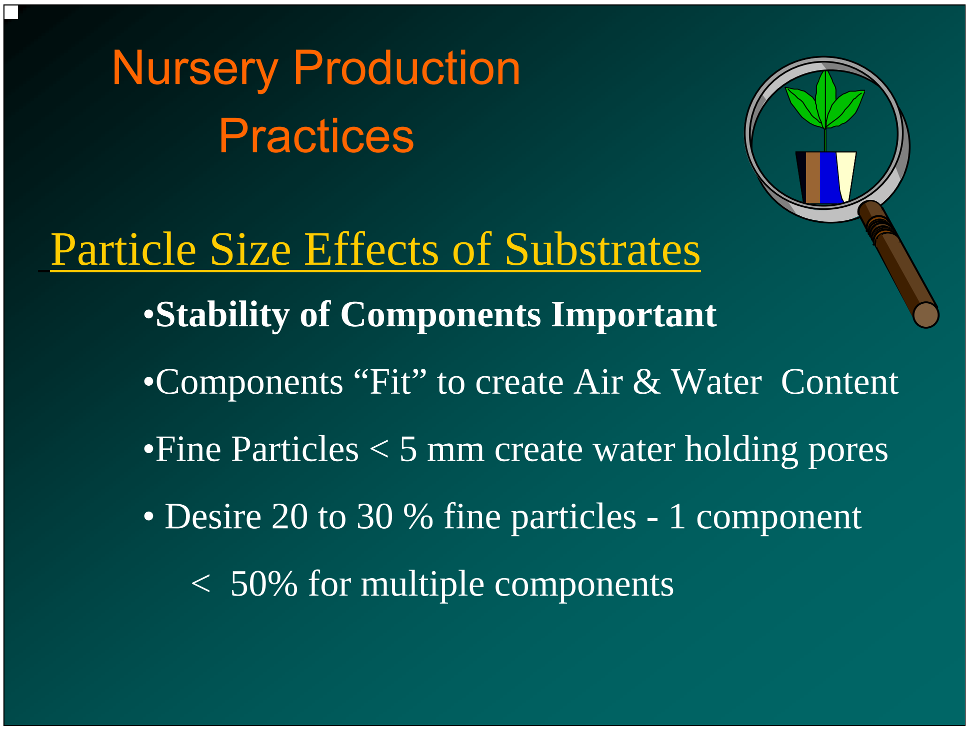
- Sample Preparation Procedures
  - Packing Cores
  - Coring Pots
  - Burying Cores
- NCSU Porometer
  - Total Porosity , Air Space. Container Capacity
- 15 Bar Extractor
  - Unavailable Water, Available Water Content
- Ro-Tap Shaker and Sieves
  - Particle Size Distribution

The NCSU Horticulture Substrates Laboratory specializes in conducting studies that characterize physical properties of container substrates. Three methods of preparing samples may be used to analyze substrates. Initial study samples or industry samples may be analyzed by laboratory procedures where cores are packed in a 3 ring column and the middle core selected for analysis. Substrate samples in containers may be cored using a sharp bevelled ring and a 3 inch sampling core to extract substrate from the container. An alternative for sampling substrate from containers, used to determine changes in substrates during a production season is performed by burying cores in containers at pot up of the study, then extracting cores from containers after several weeks to months under production conditions.

The NCSU porometer is used to analyze air space and water retention characteristics of test substrates.

The 15 Bar Extractor is used to determine unavailable content and to calculate container capacity substrate content.

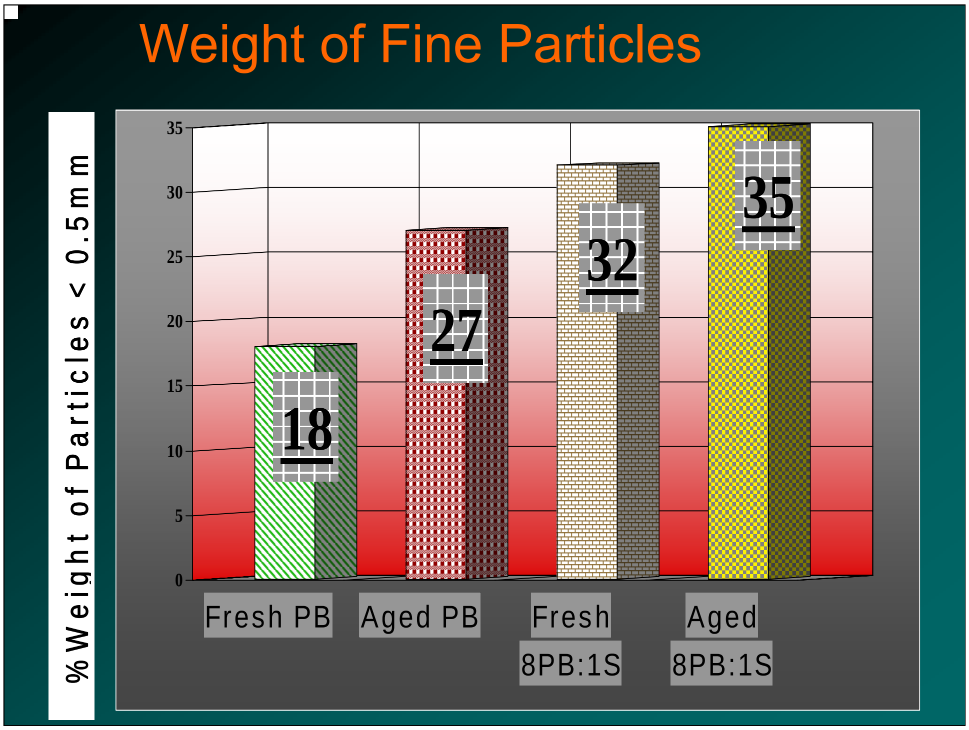
A Ro-Tap Shaker and selected sieves are used to classify particle size distribution of container substrates.




The initial particle size distribution of organic components nest uniquely with additional components blended as part of the substrate. Aged pine bark is a more stable component than fresh pine bark and aged pine bark contains more fine particles than fresh pine bark, therefore the aged pine bark and fresh pine bark differ in how particles fit when components are blended. Components with many fine particles fill more large pore spaces than when components have similar particle size ranges. Particle sizes less than 0.5 mm (dust sized particles) greatly influence the ratio of air space and moisture held in the substrate. Too many fine particles (20% to 30% fine particles in pine bark and 50% fine particles of multiple components) tend to be upper limits for optimal air and water retention characteristics.

Samples are oven dried,sieved and particle weight on each sieve recorded

Particle size distribution of substrates are analyzed using multiple sieves placed in a Ro-Tap shaker.  Oven dried 100 g substrate samples are sieved for 5 minutes at 150 taps per minute. Weights of particles collected on each sieve are recorded to develop a description of the particles making up.




Data in this figure are representative of the type of information gained from a particle size distribution analysis. Rather than presenting data from all sieves, this figure focuses on the % weight of the particles which were ≤ 0.5 mm. These small particles most directly effect the air and water ratio and substrate moisture retention characteristics. Particle size analyses provide explanation for physical property data. Fresh pine contained only 18% fine particles (by weight) compared to aged pine bark which had 27% fine particles. The optimal range for pine bark used as a lone potting substrate component is 20% to 30% fine particles. When sand was added to fresh pine bark in a 8:1 ratio (11% by volume), the two component substrate was found to have 32% fine particles (by wt) compared to 35% fine particles when sand was added at the same ratio to aged pine bark. Expectations would be that the fresh pine bark with only 18% fine particles would have characteristics of high air space and limited container capacity and available water content. Likewise, it would be expected that the Aged 8PB:1S substrate would have the highest container capacity and available water content when compared to the other 3 substrates. The physical property results are presented after discussion of the NCSU Porometer (8 slides ahead).

3 Sampling Methods for Substrates

Packing using 3 stack cores

Burying a Core and extracting several weeks to months after potting

Using a Sharpened (Beveled) Core to extract undisturbed potting substrate

Laboratory analyses of initial physical properties at potting can be compared to end of the production cycle physical properties. However comparisons are usually not conducted under laboratory conditions since changes in Db of the substrate that occurred over time are difficult to reproduce by packing sample cores for porometer laboratory analyses. Rather than packing cores in the lab, there are two procedures that can be used to compare substrate physical characteristics over a period of time. One alternative is to bury sample cores in fallow containers, place containers containing cores under production conditions, then remove cores and analyze the physical after nine weeks compared to removing cores after one year in containers. This procedure is not frequently done since very few researchers have equipment for physical property analysis and laboratory sample cores are tied up for long periods of time. A second alternative is to conduct initial laboratory analyses by packing cores for porometer analyses, then samples for end of production analysis are created by filling fallow containers with the substrate and placing the fallow containers under nursery production conditions for a determined length of time. Core samples can then be collected from fallow containers by driving a sharpened beveled ring attached to a sampling core into the substrate and extracting the sample for porometer analysis. It can be difficult to obtain intact samples using this procedure if large particles such as coarse pine bark are a component in the substrate.

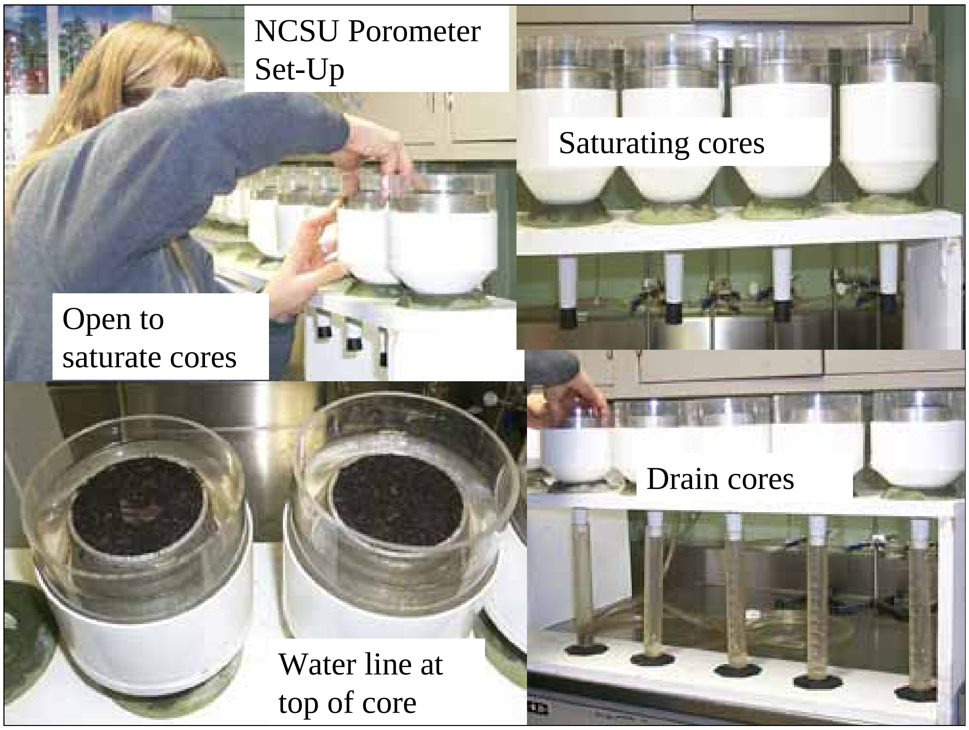
The NCSU porometer for measuring physical properties uses standard 7.5 cm soil cores that snap into base plates which rotate to open or close the holes allowing cores to be saturated and drained.

The main parts of the NCSU porometer consist of a base plate with 8 holes that rotate to open or close the holes. A standard 3 inch (7.6 cm) core containing the substrate sample is placed in the base plate. The sample can be opened and closed for saturation, closed to remove excess water from porometer funnels (see next slide) and then opened to collect the drained water volume (drained pore space equals air space).

For details on the Horticultural Substrates Laboratory, diagnostic services and substrate lab equipment and procedures see the following webpages:

http://www2.ncsu.edu/unity/lockers/project/hortsublab/

http://www2.ncsu.edu/unity/lockers/project/hortsublab/diagnostic/porometer/description.htm




Stepwise procedures include (1) placing cores in funnels;(2) placing stoppers in the funnel spouts; (3) opening the base plate and bring distilled/de-ionionized water levels to the top of the cores, adding water during saturation to maintain water levels at the top of the core; (4) closing the cores after saturation is complete; (5) removing stoppers to draining excess water from the funnel; (6) placing graduated cylinders under funnel spouts;(7) opening the base of the porometer; (8) collecting and recording volume of water drained from cores (drained pore space= air space).

For analytical procedures using the NCSU porometer see the following webpage:

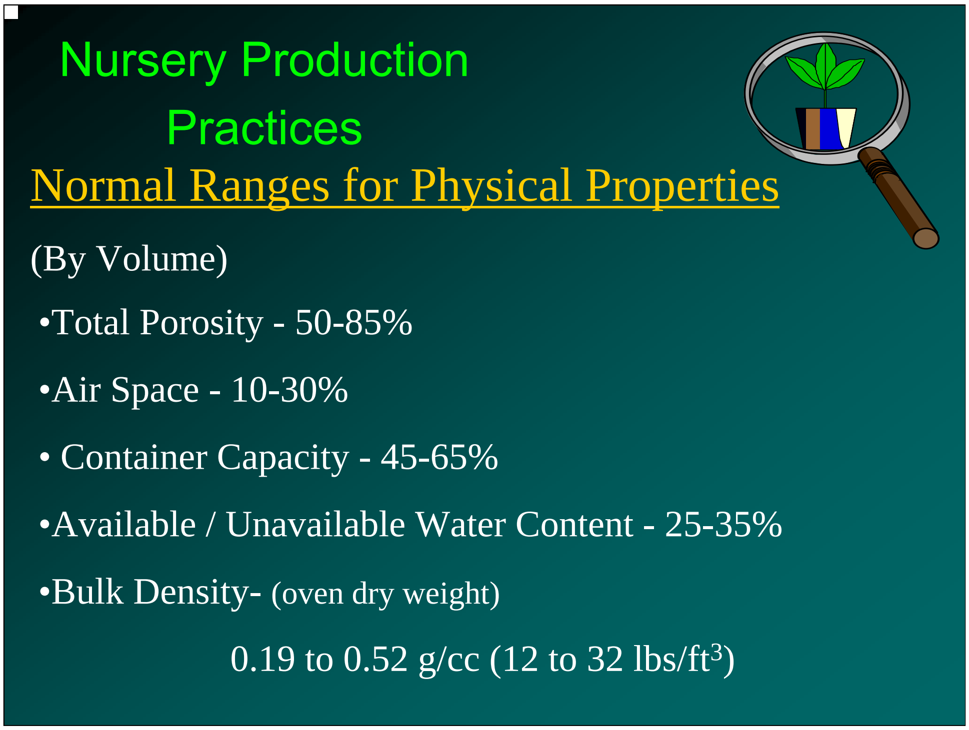
http://www2.ncsu.edu/unity/lockers/project/hortsublab/pdf/porometer_manual.pdf


After complete drainage, cores are removed from the porometer unit, weighed and placed in an oven at 105°C for 24 hours. Cores are then weighed to determine oven dry weight. A calculation of drained weight subtracted from the oven dry weight divided by the dry weight x 100 equals the % container capacity of the substrate.


To determine the moisture content held at 1.5 MPa (15 bar, 220 psi or permanent wilting point) substrates are packed in 1 inch (2.54 cm cores) placed on 15 bar plates and moistened. Plates with cores are then placed in the 15 bar extractor and incrementally pressurized to 1.5 MPa.

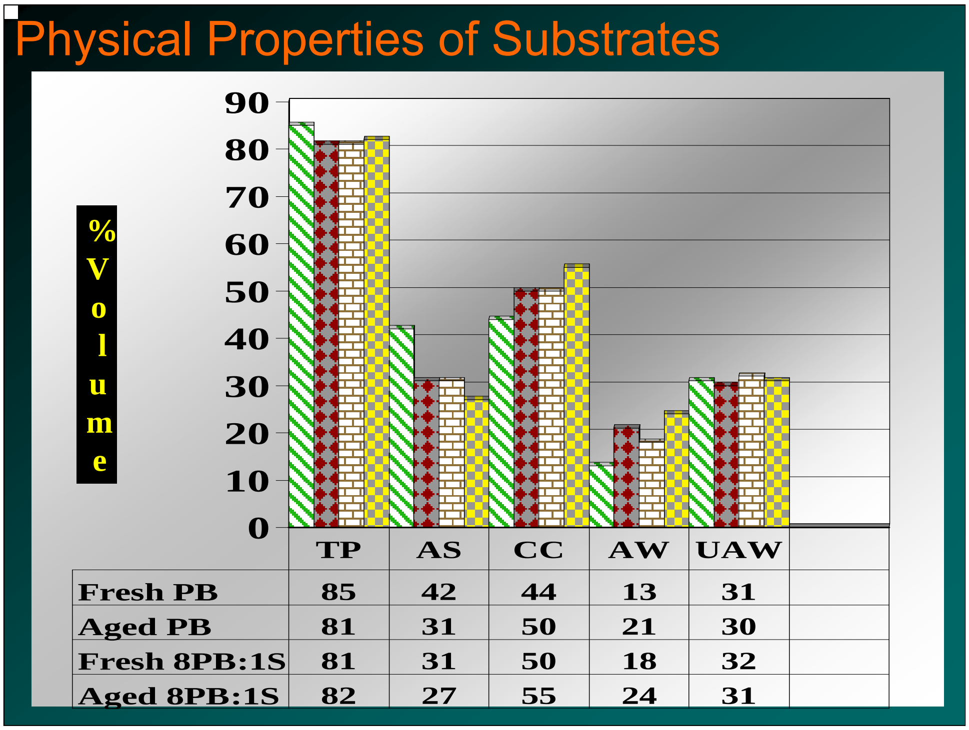

Cores are removed from the 15 bar extractor, weighed, and placed in an oven at 105ºC for 24 hours and weighed again.

The oven dried weight subtracted from the 15 bar weight divided by the dry weight x 100 equals the % unavailable water content of the substrate. The % unavailable water content subtracted from the % container capacity equals % available water content of the substrate.




If potting substrates are within the normal physical property ranges shown in the slide, irrigation and nutrient programs require less intense management. Suggested ranges for easiest management of most potting substrates utilized in commercial production of horticultural crops are within the following ranges: total porosity (TP) (50-85%), air space (AS) (10-30%), container capacity (CC) (45-65%), available water (AW) (25-35%), unavailable water (UAW) (25-35%) and bulk density (Db) (0.19-0.5 g.cm-3 dry weight) (Yeager et al.,1997).


Total porosity, unavailable water and bulk density are unique for the substrate tested and do not readily change under production conditions. However, container capacity, air space and available water content vary according to the height of the container and may vary due to decomposition over time. Therefore, low air space values as determined by the NCSU porometer test provide guidance for use in various size containers used in production. A low air space value (less than 10%) may have critically low aeration in shallow containers, which inhibit root growth and vigor. Low air space values in larger nursery sized containers such as trade gallons (6 inch height) or larger nursery containers may be of less concern.



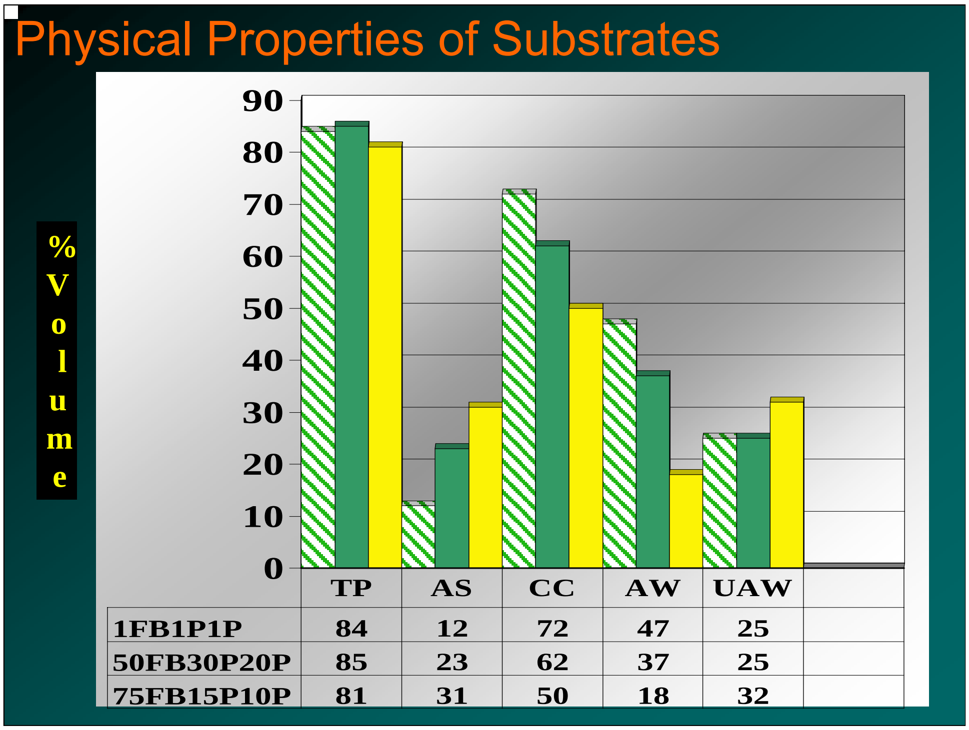

Examples of data obtained from the NCSU porometer and 15 bar extractor are shown in this slide. UAW (unavailable water content + AW (available water content) add to CC (container capacity). CC + AS (air space) = TP (total porosity). One to two percent differences are due to rounding of averages from multiple replications for each substrate.

Data in this slide show that the fresh pine bark sample had higher TP and AS than aged pine bark but lower CC and AW as expected based upon the particle size analysis. Since fresh pine bark has excessive AS and limited CC and AW, growers would need to irrigate fresh pine bark in containers more frequently (daily cycled irrigation) to produce equivalent plant growth. UAW was approximately the same for both fresh and aged pine bark, which would be expected to be approximately 30% for pine bark. Hardwood bark tends to have even higher UAW values.

When sand is added to pine bark, AS is reduced as sand fills in large pore space in the pine bark component. Likewise, CC and available water content are increased, making management similar to aged pine bark alone. Adding sand to aged pine bark further reduces AS (but is still within an optimal range of 20% to 30%) and consequently also increases CC and AW. Although these values are optimal, further decomposition during production may decrease AS to growth limiting volumes.


Aggregates such as perlite, PermaTill (concrete block particles, Carolina Statlite Company, Salisbury, NC), pea gravel, pumice, sand, screened fly ash, granite shavings, and calcined clay can be used as coarse components for potting substrates.


In this slide components are typically those used in potting substrates in Oregon. The components are fir bark: peat moss and pumice. Pumice is an aggregate used as washed builders sand would be used on the by nurseries in the Eastern half of the US. Aggregates that are used in the nursery industry tend to be locally available products since aggregates tend to be heavy and are expensive to ship long distances. Aggregates can drastically increase wear on mixing equipment and in the case of fly ash raise pH and alter chemical properties of potting substrates. Aggregates can also grind organic components reducing particle size if mixed for too long in mechanical blending equipment.




West Coast US substrates compared in this slide are fir bark, peat moss and pumice, respectively. Of interest is that substrates containing fir bark and peat moss used in Oregon have similar physical properties values as pine bark and peat based substrates used on the East Coast. The 1FB:1Peat:1Pumice substrate has a low AS value and would require careful irrigation management. Peat moss has a lower UAW content than barks, therefore substrates containing peat moss tend to have higher CC and AW content than bark substrates that do not contain peat moss.

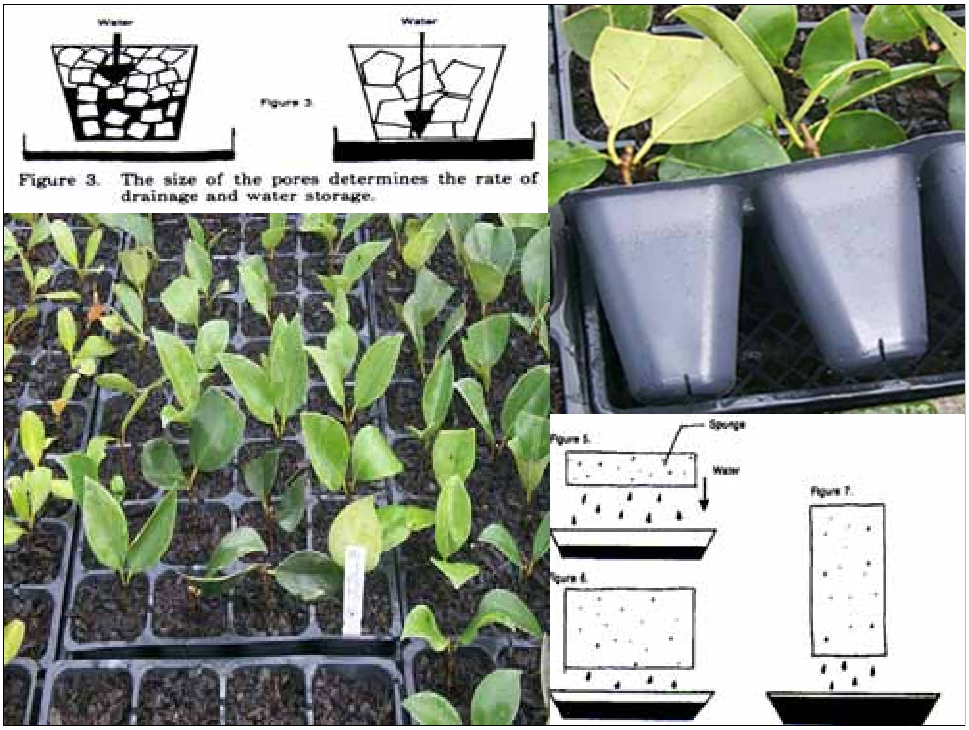


Figure 3. The size of the pores determines the rate of drainage and water storage.

Container capacity and air space ratio’s vary by container height. The illustration in the lower right of the slide demonstrates the effect of container height on the air and water characteristics of substrates in containers. A sponge laid flat and allowed to drain retains more water and has less AS than a sponge laid on edge. When the flat sponge is turn on edge more water drains out of the sponge. Likewise, when the sponge is turned on end, more water drains. Increase drainage as the height is increased is an effect of gravitational forces. The significance for container production is that substrates with low AS values in shallow containers require careful irrigation management to avoid waterlogging.

# How Do You Manage Fresh Versus Aged Pine Bark?

Tiffany Harrelson, Stu Warren and Ted Bilderback

In a study conducted by Harrelson et al.(2004), physical properties of fresh pine bark and aged pine bark (aged for 1 year in an unprotected location) were compared at initial potting and after one year in production .

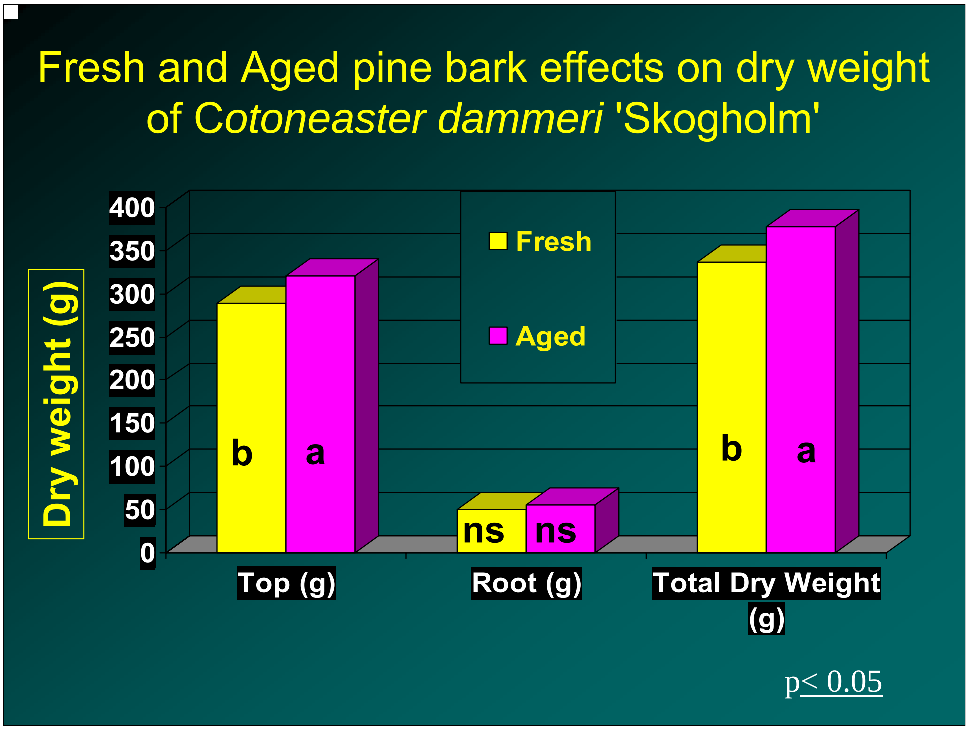
Table 2. Effect of age of bark on physical properties of an 8 pine bark : 1 sand substrate.

| Bark | Total Porosity (%) | Air Space (%) | Container Capacity (%) | Available water (%) | Unavailable water (%) | Bulk density (g/cm3) |
|---|---|---|---|---|---|---|
| Pine Bark at treatment initiation | | | | | | |
| Aged | 87.3 a | 25.2 b | 61.1 a | 26.3 a | 35.8 b | 0.19 a |
| Fresh | 88.3 a | 39.3 a | 49.0 b | 9.8 b | 39.2 a | 0.17 b |
| Pine Bark : Sand (8:1 ) at 56 days after treatment initiation | | | | | | |
| Aged | 82.8 b | 25.9 b | 56.9 a | 22.7 a | 34.3 a | 0.32 a |
| Fresh | 85.4 a | 36.3 a | 49.1 b | 15.8 b | 33.3 a | 0.32 a |
| Pine Bark : Sand (8:1) at 336 days after treatment initiation | | | | | | |
| Aged | 74.9 b | 17.0 b | 57.9 a | 30.0 a | 27.9 b | 0.35 a |
| Fresh | 80.1 a | 24.9 a | 55.2 b | 22.3 b | 32.6 a | 0.35 a |

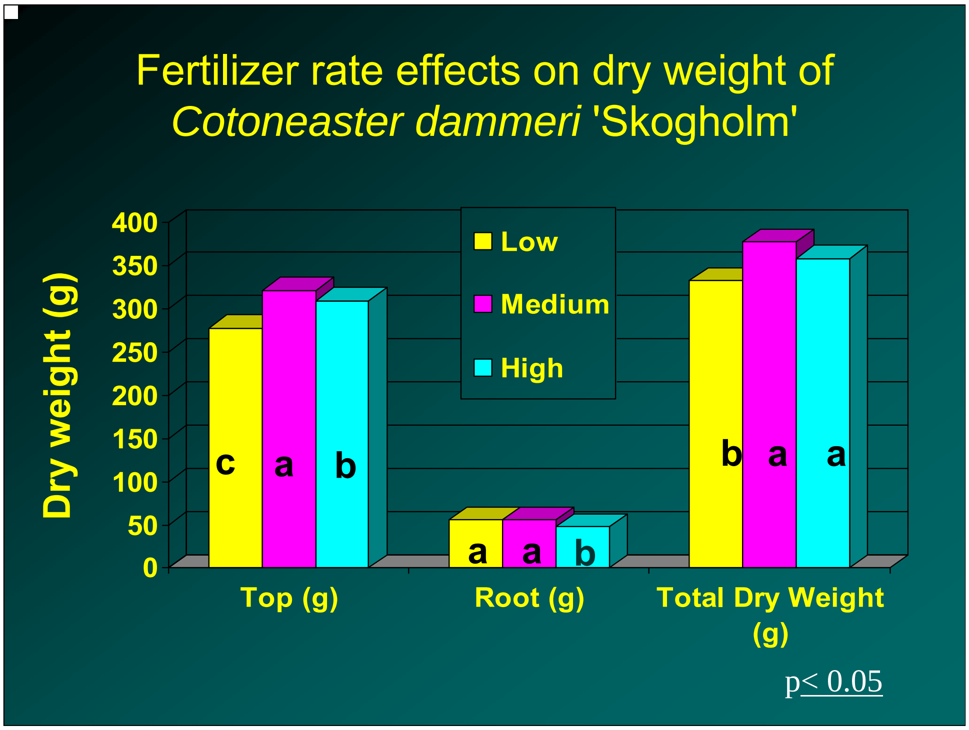
yMeans within columns and weeks after treatment initiation followed by the same letter are not significantly different as determined by Fisher's protected LSD, $P = 0.05$.

Total porosity of both fresh and aged pine bark sources were similar at potting, however AS, CC, AW, UAW, and Db were very different. The aged pine bark had 25.2% AS compared to 39.3% AS for fresh pine bark. The suggested range for pine bark as a single component is 20% to 30% air space (by vol), therefore the 39.3% AS for fresh pine bark had few micropores to hold moisture. This observation was supported by the difference in CC as the fresh pine bark had only 49.0% CC compared to 61.1% CC for aged pine bark. Available water content in fresh pine bark was 9.8% compared to 26.3% for aged pine bark. Aged pine bark as a single component substrate initially possessed the physical properties that met all the required criteria for vigorous crop growth under typical nutrient and irrigation programs. In contrast, fresh pine bark had very low AW and excessive AS. These physical properties would demand a change in traditional irrigation management.

Harrelson et al. (2004) compared physical properties after 56 and 336 days of fresh and aged pine bark sources blended with coarse builders sand (8 pine bark: 1 sand, 11% sand by vol). Container capacity and AW in the aged pine bark:sand substrate were significantly greater than fresh pine bark 56 and 336 days after treatment initiation. This was also reflected in the volume of irrigation required to maintain a 0.2 leaching fraction in each substrate. Aged pine bark with a higher AW capacity required a greater volume of water. This supports a conclusion that it was difficult to maintain adequate water in the fresh pine bark:sand substrate and growth was limited by AW content. The authors concluded that fresh pine bark:sand substrate would require frequent irrigation with small quantities of water due to limited AW content.




These substrates were also used in a 160 day plant growth study. Total dry weight of *Cotoneaster dammeri* 'Skogholm' (cotoneaster) grown in the aged 8:1 pine barksand was 12% larger than cotoneaster grown in fresh 8:1 pine bark:sand substrate.




Additional N did not increase growth in the fresh pine bark:sand substrate, therefore the authors speculated that the growth differences were due to differences in physical properties.


Pine bark, peat moss, composts and all organic potting components continue to decompose over time, even though these components were aged, composted and stabilized before use. In pine bark, large particles break down to finer particles. Hard impervious particles soften and begin adsorbing water. Early in production these changes may be advantageous. However, the substrates eventually reach conditions where air space becomes a limiting factor for vigorous root growth. Under conditions of low aeration, new active growing root tips decrease causing reduction of adsorption of essential nutrients such as iron and calcium. Foliar chlorosis is usually a symptom of poor root growth. Disease and insect problems also increase in stressed crops. All of these factors increase production costs. Therefore, targeting a 12 to 18 month widow for production followed by sale or shifting to larger containers with new resources is a good economic goal.

## Home Remedies for Physical Property Measurements

Look at potting mix- Does it look OK?

Is the Particle Size same as usual?

- Develop a Standard-
  - Fill 10 pots to the top- tap 3 times
  - Hand irrigate pots thoroughly and allow to drain 30 minutes
  - Weigh all pots and calculate the average weight
  - Use this average in comparing uniformity of new canning of same sized containers during the growing season.

Most nurseries only keep enough potting inventory for immediate use and frequently re-order potting supplies during busy potting seasons. Commercial potting substrate vendors may have aged pine bark supplies that they have turned and managed early in the growing season, however as supplies are shipped, less aged materials are available. Therefore, nurseries receive bark with less aging and variable particle size and physical properties. In most instances, changes in potting supplies can be integrated into the nursery production practices, but only if growers realize air and moisture retention characteristics are different. The information in this slide provides a method for growers to evaluate changes in potting substrates on site.


Although conducting “home remedy” analyses of physical property results will not be as precise as laboratory analyses, these procedures can be used to investigate changes between initial and end of production physical properties of container substrates. Simply weighing fallow substrate filled containers after potting and comparing them to end of production container weight could be useful in understanding changes in physical properties over time. To obtain useful data, overfill 10 containers with potting substrate, tap the bottom of the containers three times on a surface to settle the substrate, then level the substrate with the top of the container. Containers are then irrigated, drained for 2 h and wet weight recorded. At the end of the production cycle containers are irrigated, drained for 2 h and weighed. The shrinkage of the substrate from the top of the container could be measured to determine an approximate final volume and wet Dd. by dividing the final weight of the container by the adjusted volume of the container. Changes in wet Dd can then be compared between initial and final samples.

Times Up!