GREENHOUSE AND INDOOR PRODUCTION OF HORTICULTURAL CROPS

Understanding the Pores of a Soilless Substrate

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EXPERT REVIEWED

The growth and quality of plants in soilless substrates is largely determined by the substrate's physical characteristics including pore space (porosity), air space, water-holding capacity, and composition of pores. This publication, describes in detail these substrate characteristics and several others. It also provides research-based information about them as a reference to guide growers.

Pore Spaces Serve Valuable Functions

Did you know that you are mostly paying for pore space when you buy a bag of soilless substrate? This is because, unlike mineral soils, nearly three-fourths of the volume of soilless substrates is pore space.

I like to refer to pore space as the "functional" component of a substrate. By definition, pore space is the volume available for air and water in a substrate — the substrate volume minus solids. In other words, a substrate with 75 percent pore space contains 25 percent solids. Wide pores are good because they provide spaces for air exchange. Narrow pores are good because they hold water.

Ideally, a substrate should have 20-25 percent air space for proper root growth. Therefore, it is important to understand pore space and maintain a balance between air and water space in a substrate.

Porosity: Measuring Pore Space

Pore space is expressed in terms of porosity, which is the percentage of pore space volume for a given substrate volume. You can determine the porosity, air space, and water space in your substrate by following the five steps below.

1. Determine the volume of the pot used to grow plants. You can usually obtain this from the manufacturer.
2. Add a water-tight liner (such as a polyethylene wrap) to the outer bottom of the pot. Tape the liner to the pot to prevent any material from draining through the holes.
3. Pour the substrate to the top of the pot. Make sure to compact the substrate as you would normally do during production. At this point, the substrate volume is equal to the volume of pot.
4. Add water to the top of the substrate, and carefully monitor how much you add. You want to add water until you completely saturate the substrate — that is, when you start to see a shiny layer of water over the substrate. Cover the pot with a lid and keep it aside for an hour. After one hour, check if you need to add a little more water to saturate the substrate. The total volume of water that you added to saturate the substrate is equivalent to the total pore space volume.

Use this equation to determine porosity:

$$\text{Porosity (\%)} = 100 \times \frac{\text{Volume of water added}}{\text{Volume of the pot}}$$

Next, place the pot in a water-tight container and make holes at the bottom of the liner you added in step one. Your goal is to drain the water and collect it in the container. Let the pot drain for 10 to 15 minutes so the water can completely drain out. Then, measure the drained volume of water. This volume is equivalent to the air space volume in the substrate.

Use this equation to determine air space:

$$\text{Air space (\%)} = 100 \times \frac{\text{Volume of water drained}}{\text{Volume of the pot}}$$

The water that is left in the substrate after it drains is the water space (also called maximum water-holding capacity or container capacity). Once you've determined air space, you can determine water space with this equation:

$$\text{Water space (\%)} = 100 - \text{air space (\%)}$$

Table 1. The following table provides information about the fractional volume of pore space, air space, and water space in two soilless substrates:

Component	Peat + Bark + Perlite + Vermiculite (P-B-P-V)	Peat + Perlite (P-P)
Solids (%)	40.9	38.6
Porosity (%)	59.1	61.4
Water space (as % total pore space)	72	62
Air space (as % total pore space)	28	38

Pores Are Dynamic

Pore space is not a constant characteristic. Pore space can change when:

- Organic components (like peat) expand and contract during watering and drying
- Organic matter decomposes, which changes the particle size of the substrate and changes pore size
- Overhead irrigation or root growth compacts the substrate, which interlocks substrate particles or increases bulk density (reduces pore space).

For these reasons, use your pore space measurements of a fresh substrate with caution. The approach described above can be also used to measure the dynamic changes in pore space during crop growth as well.

Maximum Water-holding or Container Capacity

Water space (%) (also called maximum water-holding capacity or container capacity) is the percentage of total pore space that water occupies after excess water has been drained from the substrate (after air occupies pore space). After draining the excess water, air fills the space the drained water once occupied. A substrate can hold water inside the narrow pores against gravity by capillary forces. Water inside large pores drains because the force of gravity is greater than the capillary force in these pores. The amount of water the substrate can hold is its water-holding capacity.

A substrate's water-holding capacity is not same as the volume of water required to saturate the substrate. That's because, at water holding capacity, both water and air space is at maximum in the substrate. Whereas at saturation, all pores are occupied by water only (not a good situation as air is needed for root growth).

Total pore space affects water-holding capacity, so water-holding capacity is considered a dynamic property of a substrate. It can change because of substrate type, compaction, and root growth.

Container height is another characteristic that influences water-holding capacity. For a given diameter of container, a substrate's water-holding capacity will decrease as the container gets taller. That's caused by increased effect of gravity on the water column. For a given height, water-holding capacity increases with diameter of the container.

And, in spite of drainage holes, some amount of substrate at the bottom of a container never drains. This is due to relatively lower influence that gravity has on the substrate water in this zone. This zone is called perched water zone, which has virtually no air space. The perched water zone is a larger portion of the total volume as you decrease container height (Figure 1). This is one reason why it is challenging to grow uniform quality seedlings in small plug cells.

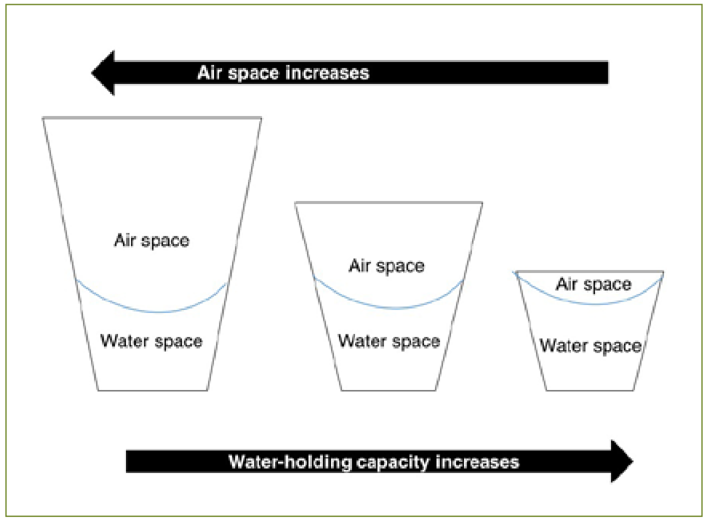

Figure 1. The perched water zone in a container increases in proportion as the container decreases in height.

Pore Sizes

There are two basic types of substrate pores:

- Inter-aggregate pores (or macropores) are wide pores that allow water infiltration and aeration. Most of the water in inter-aggregate pores usually drains out, which lowers the substrate water status from saturation to water-holding capacity.
- Intra-aggregate pores (or mesopores or micropores) are narrow pores that allow a substrate to retain water. Intra-aggregate pores usually retain the water that is easily available for plants.

The Soil Science Society of America (SSSA) created a pore size classification system based on pore diameter (Kay and Angers, 2001). In their system:

- Macropores have a radius greater than 0.0075 centimeter
- Mesopores have a radius of 0.003 to 0.0075 centimeter
- Micropores have a radius 0.003 to 0.0003 centimeter
- Ultra-micropores have a radius less than 0.0003 centimeter

The water ultra-micropores hold is usually unavailable to plants. Table 2 provides information about the fractional volume of different pore sizes in a Peat + Perlite (P-P) substrate and a Peat + Bark + Perlite + Vermiculite (P-B-P-V) substrate. Note that there are significantly more ultra-micropores in a P-P substrate than in a P-B-P-V substrate. This is likely because the P-P substrate contains more peat, and peat fibers contain narrow pores that increase ultra-micropore space.

Table 2. This table shows the fractional volume of different pore sizes in a Peat + Perlite (P-P) substrate and a Peat + Bark + Perlite + Vermiculite (P-B-P-V) substrate.

Component	Peat + Bark + Perlite + Vermiculite (P-B-P-V)	Peat + Perlite (P-P)
Solids	40.8	38.7
Macropores	10.9	12.0
Mesopores	8.5	8.2
Micropores	17.6	13.4
Ultra-micropores	22.1	27.8
Total	100	100

Water Availability

Not all water in substrate pores is available to plants. The water held in mesopores and micropores is generally available, but water held in ultra-micropores is held so tightly that it is difficult for roots to extract it. Inside the pores, two forces hold together water molecules: cohesive force (water-water) and adhesive force (water-solids). To extract the water, root hairs must exert sufficient pressure to break these forces. To do this, a gradient in pressure between the soil solution and roots must develop for water to move along the pressure gradient — that is, from high water pressure (substrate solution) to low water pressure (roots).

Roots maintain a negative pressure relative to the substrate solution as water moves up from the roots and is lost in transpiration. When necessary, roots can maintain even more negative pressure by synthesizing complex carbohydrates produced in photosynthesis. However, this process comes at a cost to plants.

Cohesive forces (water-water attraction) are easier to break than adhesive forces (water-substrate attraction). Generally, adhesive forces dominate inside the ultra-micropores because of the narrow pore size and thin water columns. Sometimes it can be difficult for roots to develop enough negative pressure to break these adhesive forces and extract water from ultra-micropores.

For this reason, when a substrate contains a large number of ultra-micropores, it can increase the amount of unavailable water. Compacting a substrate not only reduces air space, it also increases the proportion of unavailable water in the substrate by increasing ultra-micropores. Bigelow et al. (2000) reported that pure peat moss has large volume of unavailable water due to the large fraction of ultra-micropores it contains. This is why you should lightly compact peat-based substrates to avoid increasing the number of ultra-micropores.

You can estimate available water by comparing the difference in water volume at container capacity and wilting point. Generally, substrate moisture retention curves help determine characteristics like plant available water. When the pressure with which water held inside the pores falls to less than -1500 kilopascals (kPa), then the water is assumed to be unavailable to plants. At this pressure, plants start to show wilting signs. Figure 2 shows the moisture retention curves for a peat-perlite substrate (P-P) and peat-bark-perlite-vermiculite (P-B-P-V) substrate. These curves indicate the water content in the substrate at different pressures inside the pores. Note that most of the water in the two soilless substrates is held at pressures less than -500 kPa. This means that roots can easily extract most of the water in the pores; however, the fact that most of the water is within a short range (0 to -500 kPa) means that roots can rapidly shift from a no-stress situation to a moderate water stress situation as water dries in the substrate.

It's also important to note about the graph that nearly 20 percent of the water in the P-P substrate and 10 percent of the water in the P-B-P-V substrate, is held at pressures less than -1,500 kPa (or in ultra-micropores). At these pressures, the water volumes are likely unavailable to roots.

These curves require complicated equipment for measurement. However, here is a simpler method to measure the volume of available water in the substrate:

1. Select four to six containers with plants and weigh the container at maximum water holding capacity (W1, grams). The procedure to determined water holding capacity (or water space) is explained at the beginning of this article. Make sure to irrigate the substrate uniformly and slowly from the top until it is close to saturation. Allow sufficient time for drainage before weighing.
2. Stop watering plants in the selected containers after weighing them, and allow the substrate to dry for a few days until you observe mild wilting signs on leaves.
3. Weigh the containers again at this mild wilting stage (W2, grams).
4. Calculate the average of the W1 and W2 weights.
5. The difference between average W1 and W2 is the available water in the substrate. Convert the weight to volume by using 1,000 g of water = 1 L of water.

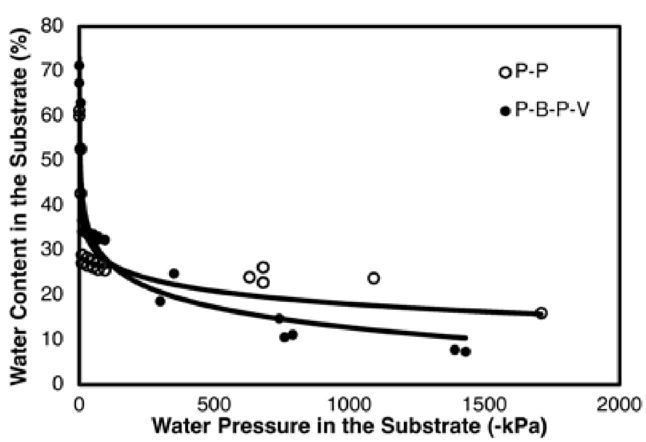

Figure 2. Moisture retention curves for a peat-perlite substrate (P-P) and peat-bark-perlite-vermiculite (P-B-P-V) substrate.

Hydraulic Conductivity

The ease with which water can move through the pores is described as hydraulic conductivity. Peat-based substrates have a sharp decline in hydraulic conductivity or increase in the resistance to water flux within a narrow range of water status in the substrate. Researchers observed a 100-fold decrease in hydraulic conductivity when water content decreased from 60 to 20 percent in peat media (da Silva et al.1993).

What this means is that, in spite of reasonable volume of water in the substrate, an increased resistance to water flux because of a drop in hydraulic conductivity will reduce water availability to plants. Therefore, you should consider hydraulic conductivity along with the water content of the substrate when you schedule irrigation.

If you allow peat-based substrates to dry out between irrigations and add a large volume of water during each irrigation, the irrigation water will simply leach out of the containers and the substrate will retain very little. This is because dry peat has a very low hydraulic conductivity. If the substrate is dry, then apply water in small volumes and allow sufficient time between irrigations to hydrate the medium and increase its hydraulic conductivity.

References

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