Understanding pH management and plant nutrition
Part 4: Substrates

Bill Argo, Ph.D.
Blackmore Company, Tel: 800-874-8660, Int'l 734-483-8661, E-mail: bargo@blackmoreco.com
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A wide range of substrates are available on the market to grow orchids, or many other plants. Some people are using substrates manufactured by large companies for the production of container grown crops other than orchids. Other people are using substrates manufactured primarily for growing orchids. Still others are blending their own substrates from individual components.

The choice of substrates will affect the effectiveness of your fertilizer program. Substrates can differ substantially in both their physical properties and chemical properties. In part 4 or this series, we will discuss key aspects of physical and chemical properties, and also leaching, and how these factors affect plant nutrition.

Physical properties

Physical properties deal with the ratio of air:water:solid in a substrate. Container substrates should be thought of as a sponge. A sponge is made up of the material used to make the sponge (solid space) and holes (pore spaces). If a material has a high bulk density (high weight per unit volume), then a sponge of this material would have a lot of solid space with little pore space. Examples of high bulk density materials are sand, clays, or field soils. In comparison, a sponge made from materials that have a low bulk density (low weight per unit volume) would have little solid space but lots of pore spaces. Examples of low bulk density materials are peat, coir, bark, vermiculite, things commonly found in container substrates.

Pore space can be filled with either air or water. The ratio of air to water in a given substrate will depend on size and distribution of the pores. During an irrigation, small pores (called micropores) tend to fill completely with water, while large pores (called macropores) tend to drain, which allows air to get back into the substrate. It has been said that after an irrigation, the ideal container substrate would have 25% of its volume taken up with pores filled with air, 60% of its volume taken up with pores filled with water, and the remaining 15% taken up with solids.

To put numbers on these values, an "average" 6 inch (15-cm) azalea pot has a volume of about 1.6 liters. The volume of air, water, and solid occupied by the "ideal" substrate in this pot would be 0.4 liters of air space, 0.96 liters of water, and 0.24 liters of solid. In general, substrates used for propagation tend to be very fine (lots of micropores) and so hold more water (on a relative basis) at the expense of air space when compared to the "ideal" substrate. Coarse substrates have lots of macropores and so have greater air space at the expense of water.

Container height also affects the ratio of air:water held in a substrate after an irrigation. In general, the shorter the height of the container, the greater the percentage of pore space that is filled with water and the lower the air space. For example, after a thorough watering, the average air and water porosity of five different commercially available root media in a 6 inch (15 cm) tall pot was 19% (air) and 64% (water), in a 4 inch (10 cm) tall pot was 13% (air) and 70% (water), in a 3 inch (8 cm) tall cell bedding flat was 7% (air) and 76% (water), and a 1 inch (2.5 cm) tall plug flat was 2% (air) and 82% (water), respectively. The percentage of solid material in the root media remained constant in the different container sizes. It was the ratio of air space to water space that changed with the different container heights. This is one reason why it is easier to overwater a small pot than it is a large pot because the air space in the small pot is lower than that found in the larger pot after an irrigation.

Finally, the ability of a substrate to absorb water will affect physical properties. Ideal physical properties are measured in a laboratory by allowing the substrate to remain submersed in water for 24 hours before allowing it to drain (the difference between the saturated weight and drained weight (in grams) is a measure of air porosity). In comparison, a typically irrigation may last for only 30 seconds or less. That means that under a typical irrigation, most substrates will not rewet to maximum saturation, resulting in more air space and less water-holding capacity than is measured in a laboratory test.

Another problem with organic substrates like peat and (especially) bark, is that they become water-repellent if allowed to dry too much. Commercial substrates will often contain a wetting agent or surfactant that aids in rewetting (increases water absorption). For long-term greenhouse crops, like hanging baskets, it is often recommended to reapply a surfactant to the substrate every month or two because the surfactant will degrade over time, resulting in a decrease in water absorption (more air space). If you want to apply a wetting agent to your orchids, choose one that is designed specifically for organic substrates and cut the rates found on the label in half to reduce the potential for phytotoxicity.

Chemical properties

Chemical properties generally refer to a substrates ability to buffer the water held in the substrate against changes in either pH or nutrition. The term most often used to describe chemical properties is cation exchange capacity or CEC. CEC refers to the ability of substrate particles (such as peat) to absorb and release positively charged cations like potassium, ammonium, calcium, or magnesium, thus buffering the substrate against sudden changes in pH or nutrient levels.

An example of how CEC affects pH and nutrient management occurs when a fertilizer solution is applied to a substrate. A fertilizer high in ammoniacal-nitrogen produces acid (H^+). The acid is absorbed by the substrate and a different cation, usually calcium, is released. Conversely, a fertilizer high in nitrate-nitrogen (usually calcium nitrate based) produces base (either OH^- or $HCO3^-$). The base causes an acid (H^+) bound by the substrate to be released, which will then react with the base to produce water (H_2O) or CO_2. In both cases, the net result is that the pH and calcium concentrations remain stable. Substrates that have high CEC (more buffered) can resist a change in pH for long periods of time, whereas pH can change very rapidly in substrates that have low CEC (less buffered).

CEC can play an important role in pH buffering when a field soil is added to a container substrate. CEC-based pH and nutrient buffering does occur with field soils because the substrate has a high bulk density (weight). In contrast to field soils, research has shown that the CEC of peat, coir, or bark-based substrates has little effect on resisting change in pH or in supplying nutrients.

This does not mean that the substrate plays no role in pH or nutritional management. Peat tends to be very acidic. Limestone is commonly added to peat-based substrates to neutralize the acidity and bring the pH up to an acceptable level for plant growth. The amount of acidity found in most acidic peats will not be neutralized very quickly by bases found in irrigation water. Using the example given in Part 2 of this series, a limestone incorporation rate of 5 pounds per cubic yard will supply approximately 100 meq of limestone per 6 inch (15-cm) pot. Applying 16 fluid ounces (0.5 liters) of water containing 250 ppm alkalinity to that 6 inch pot will supply about 2.5 meq of lime. That means that 40 irrigations are required to equal the amount of base found in 5 pounds of limestone. If you are only watering once a week, then it will take 40 weeks to bring the substrate pH up to an acceptable level. If you are using a pure water source without any alkalinity, then you may never get the pH up to an acceptable level. The presence of limestone in the substrate has also been shown to increase the buffering capacity when using acidic fertilizer solutions.

Finally, substrate degradation will affect nutrition and pH management. Degradation is the breakdown of the substrate, similar to composting. Of all the materials commonly found in container substrates, bark is the least stable, and therefore the most susceptible to degradation. The problem with degradation is that it not only absorbs all the nitrogen present (causing nitrogen starvation), but the process also tends to be very acidic. Hardwood barks tend to be the most stable. Softwood barks usually require some composting to make them stable. If a bark (any bark) contains any wood, then it is unacceptable for use in container substrates because the wood will cause will cause rapid degradation and nitrogen absorption.

Leaching

Leaching is the application of water or fertilizer solution beyond what can be held by the substrate. Applying extra water is recommended to thoroughly wet the substrate, and to remove excess salts from the substrate. The leaching fraction is the volume of water that drains from the substrate relative to the volume of water applied. For example, if you apply 15 fluid ounces (0.44 liters) of water, and 3 fluid ounces (0.08 liters) comes out of the bottom of the pot then 3 divided by 15, then times 100 equals a 20% leaching fraction. In other words, 20% of the water applied to the plant came out of the bottom of the pot.

It is generally taught that you should have between a 10% and 20% leaching fraction with every watering. However, research has shown that leaching is not necessary for long periods of time if you have a good water source (RO or rain water is ideal) and the fertilizer you use does not contain any harmful salts like sodium or chloride. There are reasons to leach pots, usually because the fertilizer concentration that is applied to the crop is too high for the growth rate, or the water quality is poor, and unused salts (like calcium, magnesium, or sodium) build up in the substrate. In general, whether or not you leach should be based on soil test information showing salt levels actually building up in the substrate, rather than because somebody tells you too.

Leaching rates also affect the optimal fertilizer concentration for your crop. Research has shown that the same nutrient levels could be maintained in a peat-based substrate if a solution containing 400 ppm nitrogen were applied with 50% leaching or a solution containing 100 ppm nitrogen were applied with 0% leaching. This research also showed that applying a solution containing 400 ppm nitrogen with 0% leaching rapidly lead to salts building up in the substrate to unacceptable levels, while applying a solution containing 100 ppm nitrogen with 50% leaching lead to nutrient deficiencies because there wasn't enough of the fertilizer remaining in the pot because of the excess leaching.

Applying fertilizer to a substrate

When you apply fertilizer to a substrate, which is more important, the concentration of the fertilizer solution, or the volume that you apply? In fact, both are important because as a plant grows, it adds mass, and a portion of this mass is made up of fertilizer nutrients. It has been shown in a number of experiments that it is the amount of fertilizer applied to a crop that affects crop quality, not simply the fertilizer concentration.

To calculate the amount of fertilizer applied, you need to know both the fertilizer concentration and the volume applied. For example, applying 1 liter (about 1 quart) of a fertilizer solution containing 100 ppm (100 mg nitrogen/liter) will supply 100 mg of nitrogen. If only 0.5 liters (about 1 pint) were applied of the same fertilizer solution, then only 50 mg of nitrogen would be applied.

This can be especially important when you are only applying fertilizer on a weekly basis. If the amount of fertilizer solution being absorbed into the substrate decreases for any reason (decreased water-holding capacity), they you could end up starving your plants.

How do commercial growers manage pH and nutrient levels

Commercial growers have learned that a single fertilizer concentration may or may not work depending on a number of factors including leaching, growth rates, light levels, irrigation frequency, etc. Instead, many growers will manage the pH or nutrient level within the substrate itself. This requires that the grower tests the pH, electrical conductivity, and perhaps even the specific nutrient levels contained in the substrate on a regular basis (see Sidebar).

These measured values can be used to make adjustments to the fertilizer solution. For example, if the substrate pH is too high, then a grower might switch to a fertilizer containing more ammoniacal nitrogen, or they may lower the alkalinity of the water. If the EC of the substrate is too high, the grower may increase the leaching rate, or decrease the concentration of fertilizer applied to the crop. The point is that by measuring the pH and EC of the substrate, they can make sure that a particular fertilizer solution is doing what they think it is doing, and make changes if things are going wrong, usually long before there are noticeable problems with the plant.

Even though there is not a lot of specific knowledge about acceptable ranges for substrate pH and EC with orchids, it is probable that they are similar to almost all other crops and so will grow best in a substrate pH around 6.0. Because they appear to be somewhat salt sensitive, they will also grow best with a substrate EC slightly lower than the optimal level recommended for most crops. If testing with a pour-thru method, then the desired substrate EC would be between 1 and 2 mS/cm.

Monitoring Media pH and Nutrient Levels

For successful pH and nutritional management of container grown crops, the goal is to keep the pH and nutritional levels within an acceptable range and to spot problem trends early on. This is a far better strategy than blindly applying fertilizer and hoping everything is OK, or having to take dramatic steps to rescue stressed plants.

Using reliable meters, you can measure pH (which affects the availability of nutrients) and electrical conductivity or EC (the overall concentration of fertilizer salts) in substrates. Other advantages or in-house testing are that the tests are inexpensive and the results to be obtained quickly, typically in less than 1or 2 hours. How often do you test? Typically commercial growers will test substrate pH and EC every 2 to 3 weeks. That does not mean they test every pot or every crop every two or three weeks. Instead, they may do some random sampling to make sure everything is pH and EC are within acceptable levels, or they may test a few know problem crops and then assume that if their pH and EC are within acceptable levels, then other, less sensitive crops are not having problems.

There are a number of different testing methods commonly used for measuring the pH and EC in container substrates.

1:2 method	**Saturated media extract method.** For additional information on the saturated media extract method, see Michigan State University extension bulletin E-1736 "Greenhouse growth media: Testing and nutrition guidelines" by D. Warncke and D. Krauskopf.	**Pour-thru method** For more information on the Pour-thru method, see the web site www.pourthruinfo.com.	**Squeeze Method.**
Step 1. Collect a small amount of substrate from the bottom 2/3rd of the pot. For very small plants, like those being grown in plug trays or bedding flats, use the whole cell as a sample. Take samples from 5 to 10 or more plants distributed in the group of plants to be sampled. When a sufficient amount of substrate is collected, thoroughly mix the sample to ensure uniformity. ***Step 2***. Measure out a known volume of substrate in a beaker or cup [usually 2-4 oz. (50 to 100 ml)]. The beaker should be firmly filled with the substrate so that it is slightly more compressed than when it was in the pot. Place 2 equal volume of distilled water into cup. Allow the solution to equilibrate (30-60 minutes) before measuring pH and EC. ***Step 3.*** Measure pH and EC directly in the slurry.	***Step 1***. Collect a small amount of substrate from the bottom 2/3rd of the pot. For very small plants, like those being grown in plug trays or bedding flats, use the whole cell as a sample. Take samples from 5 to 10 or more plants distributed in the group of plants to be sampled. When a sufficient amount of substrate is collected, thoroughly mix the sample to ensure uniformity. ***Step 2***. About 4 to 8 oz (150 to 300 ml) of fresh substrate is placed in a cup. Distilled water is slowly added while the sample is constantly stirred with a spatula or knife until it has reached a consistent moisture level. This is determined to be when the sample behaves like a paste, the surface glistens with water, but there is no free water on the surface of the sample. The solution is allowed to equilibrate for 60 minutes ***Step 3.*** Measure pH directly in the slurry. ***Step 4.*** Extract the solution from the media by squeezing slurry through paper towel or a coffee filter. Measure EC in extracted solution.	***Step 1.*** Irrigate the crop one hour before testing, making sure the substrate is thoroughly wet. Allow the pots to drain for 30-60 minutes. ***Step 2.*** Once drainage has stopped, place the pot to be sampled into a plastic saucer and pour onto the surface enough distilled water to get about 2 oz. (50 ml) to come out of the bottom of the pot. ***Step 3.*** Measure pH and EC directly in the leachate	***Step 1.*** Irrigate the crop one hour before testing, making sure the substrate is thoroughly wet. Allow the pots to drain for 30-60 minutes. ***Step 2.*** Collect a small amount of substrate from the bottom 2/3rd of the pot. For very small plants, like those being grown in plug trays or bedding flats, use the whole cell as a sample. Take samples from 5 to 10 or more plants distributed in the group of plants to be sampled. When a sufficient amount of substrate is collected, thoroughly mix the sample to ensure uniformity. ***Step 3.*** Squeeze the solution from the media. For a cleaner sample, media can be squeezed through a paper towel or coffee filter. The volume of solution needed will depend on the type of pH or EC meter used for testing. ***Step 4.*** Measure the pH and EC in the extracted solution

In general, there is no one "best" method for measuring substrate-pH or EC in the greenhouse. However, with orchids, especially with specimen plants, the pour-thru method may work best because it will not damage roots. Other reasons for deciding on which method to use in your greenhouse include any experience that you have with a particular method as well as how much help and advice you can get from other people that are close by such as other growers, extension agents, universities, or soil testing laboratories.

Whichever soil testing method you choose, consistency is the key to making that method work. Consistency starts with having a single, trained person taking the test. Other tips include:

1) Choose one soil testing method and stick with it. Different methods can give different results.
2) When removing substrate from the pot, take the sample from the bottom 2/3rd of the pot. The bottom 2/3rd is typically were the roots are in the pot and sampling in this way avoids fertilizer salts that can accumulate at the substrate surface with all irrigation methods (not just subirrigation).
3) Try to take media samples roughly the same time before or after an irrigation. This is especially important with the squeeze method.
4) Choose a reliable pH and EC meter and calibrate it regularly. Calibrating solution has an expiration day and should be discarded when that date is reached.

Table 1. Interpretation of media pH levels for container grown crops. Values are the same for all testing methods. Adapted from: W. Argo and P. Fisher. 2002. Understanding pH management of container grown crops, Meister Publishing, Willoughby, OH.

	Acceptable range	**Examples**
Iron-inefficient or "Petunia" Group	5.4 to 6.2	Azalea, bacopa, Calibrachoa, dianthus, nemesia, pansy, petunia, rhododendron, snapdragons, verbena, vinca, and any other crop that is prone to micronutrient deficiency (particularly iron) when grown at high media pH.
General Group	5.8 to 6.4	Chrysanthemum, impatiens, ivy geranium, osteospermum, poinsettia, and any other crop that is not generally affected by either micronutrient deficiencies or toxicities.
Iron-efficient or "geranium" group	6.0 to 6.6	Lisianthus, marigolds, New Guinea impatiens, seed geraniums, zonal geraniums, and any other crop that is prone to micronutrient toxicity (particularly iron and manganese) when grown at low media pH

Table 2. Interpretation of media electroconductivity (EC) or soluble salt levels. For salt sensitive crops, like orchids, the low fertility level range would be a good starting point. Values are reported in mS/cm.

	2:1 method	**Saturated media extract method**	**Pour-thru method**	**Squeeze method**
No fertility	0 – 0.25	0 to 0.75	0 to 1.0	0 to 1.0
Low fertility	0.30 to 0.75	1.0 to 2.0	1.0 to 2.5	1.0 to 2.5
Acceptable range	0.30 to 1.50	1.0 to 3.5	1.0 to 6.0	1.0 to 5.0
High fertility	0.75 to 1.50	2.5 to 3.5	4.0 to 6.0	2.5 to 5.0
Potential root damage	>2.50	> 5.0	> 8.0	> 8.0

The units of measure for EC can be mMho/cm, dS/m, mS/cm, µM/cm, or mMho x 10^{-5}/cm. The relationship is 1 mMho/cm=1 dS/m=1 mS/cm=1000 µS/cm=100 mMho x 10^{-5}/cm.

Special Note: It is important to remember that EC is a measure of the total salt concentration in the extracted solution. It does not give an indication of the concentration of any of the plant nutrients. The only way to determine exactly what ions make up the EC is to use a more extensive commercial laboratory analysis.