Understanding pH management and plant nutrition
Part 2: Water quality

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Originally printed in 2003 in the Journal of the International Phalaenopsis Alliance, Vol. 13 (1).

Water quality is a key factor affecting pH and nutritional management in any container-grown crops, including orchids. One challenge is that the water quality in your operation can differ dramatically from that of your neighbor, and certainly from greenhouses in other locations both inside and outside the U.S. For example, the range of water qualities used by commercial greenhouses in the U.S. can be found in Table 1. For those of you using rain water or reverse osmosis purified water exclusively, the pH will range from 4.0 to 5.5 (if measured correctly), the alkalinity will be less than 10 ppm, and the concentration of other ions will be very low to nonexistent.

Understanding a few technical details about water quality will help you improve nutrient management appropriate for your own greenhouse. Always remember that the success or failure of any fertilizer will always depend on the water quality because it is the combination of the two that affect your plants. In Part 2 of this series, we will discuss how water quality affects pH and nutritional management of the substrate.

pH and Alkalinity are two different aspects of water quality

There is a great deal of confusion when it comes to understanding the definition of water pH and water alkalinity, and why they are important to the health of your plants.

The term pH is a direct measurement of the balance between acidic hydrogen ions (H^+) and basic hydroxide ions (OH^-), and can be measured with a pH meter. The pH of a solution can range between 0 (very acidic) and 14 (very basic). At a pH of 7.0, the concentrations of H^+ and OH^- are equal, and the solution is said to be neutral. When the pH is above 7.0, the concentration of OH^- is higher than H^+, and the solution is said to be basic or alkaline (not to be confused with alkalinity). When the solution is below 7.0, the concentration of H^+ is higher than OH^-, and the solution is said to be acidic.

Alkalinity is a measure of how much acid it takes to lower the pH below a certain level, also called acid-buffering capacity. Alkalinity is usually measured with a test kit where dilute acid is added until a color change occurs at a specific pH. Alkalinity is not a specific ion, but rather includes the concentration of several ions that affect acid-buffering capacity. Under most conditions, the ions that have the greatest effect on alkalinity are bicarbonates like calcium, magnesium, or sodium bicarbonate and, to a lesser extent, carbonates like calcium or sodium. Several other ions including hydroxides, phosphates, ammonium, silicates, sulfides, borates, and arsenate also can contribute to alkalinity, but their concentration is usually so low that they can be ignored.

In a water sample, the concentration of all of the ions that makes up the alkalinity term are combined

Table 1. Average and median values for irrigation water pH, EC, and nutrient concentration used by commercial greenhouses in the United States. Research by Bill Argo, John Biernbaum, and Darryl Warncke. (For more information, See HortTechnology 7(1):49-51).

	Units	Average	Median	Range
pH		7.0	7.1	2.7 to 11.3
EC	(mS/cm)	0.6	0.4	0.01 to 9.8
Alkalinity	(ppm)	160	130	0 to 1120
Calcium (Ca)	(ppm)	52	40	0 to 560
Magnesium (Mg)	(ppm)	19	11	0 to 190
Sulfur (S)	(ppm)	27	8	0 to 750
Sodium (Na)	(ppm)	33	13	0 to 2500
Chloride (Cl)	(ppm)	33	14	0 to 1480
Boron (B)	(ppm)	0.2	0.02	0 to 11.7
Floride (F)	(ppm)	0.1	<0.01	0 to 8.3
Ca:Mg Ratio		5.0	3.2	<0.1 to 150
SAR[1]		2.6	0.7	0 to 280

[1] Sodium-adsorption ratio is a formula that compares the concentration of sodium to the combined concentration of calcium and magnesium.

and reported as equivalents of calcium carbonate ($CaCO_3$, which is the main component of lime). Alkalinity can therefore be thought of as the "liming content" of the water. The units used to report alkalinity can be parts per million (ppm), mg/liter, or millequivalents (meq.).

Water alkalinity has a big effect on substrate-pH.

When it comes to managing the pH of a substrate, the alkalinity concentration has a much greater effect than does water pH. Alkalinity (calcium bicarbonate, magnesium bicarbonate, and sodium bicarbonate) and limestone (calcium and magnesium carbonate) react very similarly when added to a substrate. And just like too much limestone, the use of irrigation water containing high levels of alkalinity can cause the pH of the substrate to increase above acceptable levels for healthy plant growth.

For example, 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 does not sound like much until you consider that after 10 irrigations you have effectively increased the limestone incorporation rate by 25%. Even if you are using a completely inert substrate, the liming effect that high alkalinity water has will cause your substrate pH to increase to unacceptable levels.

Units of measure for alkainity

The concentration of alkalinity (or any other plant nutrient) can be expressed a number of different ways.

1) Parts per million (ppm or mg/liter). The term ppm is a weight per weight ratio. One part per million is equivalent to 1 unit of something dissolved in a million units of something else. In the case of anything dissolved in water, 1 ppm is equal to 1 mg per 1,000,000 mg (or 1 Kg = 1 liter) of water. So, 1 ppm is equal to 1 mg/liter. A 1% solution (1 unit in 100 units) is equivalent to 10,000 ppm.
2) Milliequivalent (mEq./liter). The term mEq./liter is a chemistry term that is not only dependent on a materials concentration, but also on its molecular weight and charge. In the case of alkalinity, 50 ppm (or mg/liter) $CaCO_3$ equals 1 meq/liter $CaCO_3$. Sometimes the concentration of bicarbonates is also reported on a water test from a commercial laboratory. In most cases, bicarbonate makes up most of the alkalinity. The relationship is 61 ppm bicarbonate equals 1 meq alkalinity.
3) Grains per gallon (gpg): An outdated term for expressing concentration. 1 gpg = 17.1 ppm

To compare the effect of water pH or alkalinity on the ability to raise pH (or neutralize acid) in a medium, 50 ppm alkalinity (which is a low alkalinity) would be similar to having a water with pH 11 (i.e. an extremely high pH). A water with a pH of 8.0 would have the same effect on substrate pH as an alkalinity concentration of only 0.05 ppm (i.e., almost nothing).

Don't ignore water pH.

Water pH is still important for crop management. Even though it has little impact on the substrate, water-pH does affect the solubility of fertilizers, and the efficacy of insecticides and fungicides before you apply it to the crop. Generally, the higher the water pH, the lower the solubility of these materials.

Minimizing the effects of high alkalinity

The common problems associated with high alkalinity result from its tendency to increase substrate-pH. High substrate-pH can causes micronutrient deficiency in container grown crops because micronutrient solubility decrease as the substrate pH increases.

In commercial greenhouses, the most common method for minimizing the "liming effect" of high alkalinity is to add a strong mineral acid (usually sulfuric acid or phosphoric acid) directly to the irrigation water. As the pH of the water decreases, some of the alkalinity is neutralized. The ideal alkalinity concentration will depend on the type of fertilizer being used (to be covered in Part 3). All of the alkalinity has been neutralized when the pH of the water reaches 4.5. For more information on injecting strong mineral acids into irrigation water, you can download the "acid addition calculator" from Purdue University and North Carolina State University at www.ces.ncsu.edu/depts/hort/floriculture/software/alk.html.

For small greenhouse operations and hobbyists, strong mineral acids are very difficult and dangerous to use. Difficult because these acids are highly concentrated and therefore are difficult to add to a small volume of water, and dangerous because small greenhouses and hobbyists typically lack the specialize equipment needed to safely add acid to water. Some acids should never be considered, like anhydrous hydrochloric acid or anhydrous acetic acid because they not only are caustic, but are also fuming acids, which make them extremely dangerous to handle. Nitric acid is especially dangerous and should never be considered.

There are alternatives to adding mineral acids for alkalinity control. The first is using a weaker, organic acid, like citric acid. Citric acid is available in a pure granular form. A rate would be about 0.2 grams per gallon to remove 50 ppm alkalinity. Pre-mixed citric acid solutions (Seplex, GreenCare Fertilizer (815-936-0096)) are also available for alkalinity control. Other organic acids like vinegar and lemon juice will also work, but because the concentration of acid in these materials is variable, for example, the acetic acid content in vinegar can range from 4% to 8% by weight, that the results that you get will not be consistent.

Another option for alkalinity control is to use acidic fertilizers (to be covered in greater depth in Part 3). Fertilizers high in ammoniacal nitrogen produce an acidic reaction when added to the substrate, which can be used to neutralize the affect of water alkalinity. For example, 20-20-20 (69% NH_4-N) has enough acidity to be used with water containing around 200 ppm alkalinity water without further acidification.

There are several drawbacks to using fertilizer for alkalinity control. Fertilizers high in ammoniacal nitrogen may cause excessive growth and are not effective when the temperature of the substrate is less than 60^{o}F. In addition, you lose flexibility because you can only choose commercial fertilizers based on ammonium content. For example, high ammonium fertilizers available to you may lack calcium or other key nutrients.

Another option for alkalinity control is to change water sources. There are a number of sources, such as rain water or reverse osmosis purified water, that contain little if any alkalinity. Drawbacks to using alternative water sources include cost and storage problems. Changing water sources will also change the composition of the fertilizer solution applied to the crop.

Low alkalinity Effects

Not everybody in the world has irrigation water with high alkalinity. In the United States alone, there are a large number of growers in states like AL, AR, CA, CO, GA, HI, NC, NJ, NY, VA, and New England states that have alkalinity levels below 40 ppm without any acidification. Even in areas were high alkalinity is considered the norm, some growers have switched to low alkalinity sources such as reverse osmosis purified water or rain water.

The primary problem associated with low alkalinity water is a tendency for substrate-pH to drop over time, which can cause micronutrient toxicity problems. Usually, low pH problems are a result of fertilizer selection. Fertilizers high in ammoniacal nitrogen are acidic, and without any alkalinity in the water to balance the reaction (resist lowering of pH), acidic fertilizers will tend to drive the substrate-pH down over time.

What about Hardness?

Hardness is a measure of a water's ability to form scale in pipes, produce suds from soap, or to leave spots on leaves. Like alkalinity, the units used to report hardness are calcium carbonate equivalents ($CaCO_3$). However, while alkalinity is a measure of all chemical bases in the water (bicarbonates and carbonates), hardness is really a measure of the combined concentration of calcium and magnesium in the water because it is insoluble salts of ions, like calcium carbonate, that form scale. Another difference is that while alkalinity is an important measure in pH and nutritional management, hardness is not, because its combined concentration tells you little about a waters ability to supply nutrients to a plant.

A water softener is typically used to remove hardness. What is occurring with hardness removal is that the calcium and magnesium ions are being replaced with an ion that doesn't cause scale, like sodium or potassium. However, with hardness removal, the carbonates and bicarbonates still remain in the water but they have been changed from calcium and magnesium bicarbonate to sodium or potassium bicarbonate. Thus, hardness removal has no effect on pH management. In comparison, with alkalinity control, an acid is used to neutralize the carbonates or bicarbonates, which will affect pH management, but the calcium and magnesium concentration remains unchanged.

What else is important in my water?

Electrical conductivity (EC, also know as conductivity or soluble salts) is a term used to measure the total concentration of salts in the water. The higher the EC, the more salts that are dissolved in the water. With irrigation water, EC is used to determine the potential risk for salt buildup when water is applied to a substrate. With fertilizer solutions, EC can be directly correlated with the concentration of individual nutrients (typically nitrogen) from a variety of fertilizer salts, or with the total concentration of nutrients supplied by a water-soluble fertilizer.

Electrical conductivity or EC units have changed over the years. Twenty years ago, the units for measuring EC were millimhos (mmhos) or micromhos (μmhos). Currently, the units used to measure EC are millisiemens/cm (mS/cm), microsiemens/cm (μS/cm), or decisiemens/m (dS/m). The conversion for all these units are 1000 μmhos = 1000 μS/cm=1 mmhos = 1 mS/cm = 1 dS/m.

A term closely related to EC is total dissolved solids or TDS. A TDS meter measures the EC and then converts the measurement into ppm by multiply by a constant, usually 1 mS/cm = 1000 ppm salts. The problem with TDS measurement is that the constant is based on one salt (potassium chloride) and therefore TDS measurements do a poor job estimating the actual concentration of fertilizer salts under most situations. It is important to remember that TDS measurements are used to determine the acceptability of drinking water, not fertilizer solutions. For these reasons, commercial greenhouses use EC measurements almost exclusively for fertility management

Another important consideration is the concentration of individual plant nutrients. In general, irrigation water is not a significant source of the primary macronutrients nitrogen (N), phosphorus (P), or potassium (K), which are the numbers that you see on a bag or bottle of fertilizer. However, irrigation water can contain high levels of the nutrients calcium (Ca), magnesium (Mg), and sulfur (S). And just like alkalinity, the concentration of nutrients contained in the irrigation water can vary dramatically between different locations (Table 1).

Since irrigation water can be an important source of calcium, magnesium, or sulfur, water can contribute a significant amount of the total concentration of these nutrients being applied to a crop. In other words, the water-soluble fertilizer that you apply (like 30-10-10) is not the only nutrient source. However, if you are using a very pure water source, like RO or rain water, the only source of these nutrients may be the fertilizer.

Waste ions

Some ions contained in irrigation water are either not needed by the plant, or the plant requirement is so low that only small amounts are required. Examples of waste ions are sodium (Na) or chloride (Cl). Generally their presence in irrigation water at high concentrations increases the risk of salt build up in the substrate. Even calcium, magnesium, or sulfur can be considered a waste ion if their concentration is too high or it is difficult to balance their concentration in the nutrient solution with water-soluble fertilizer.

With most ions (including Na, Cl, Ca, Mg, or S), excessive concentrations can be removed with reverse osmosis purification. High salt concentrations can also be managed by leaching at a heavier rate than the commonly recommended 20% to remove any excess salt build up. However, if you do use higher leaching rates, then you may also have to increase the fertilizer concentration because leaching washes out all salts from the container including essential plant nutrients.

Boron (B) is a special example of a waste ion. Even though it is an essential plant nutrient, the presence of boron in irrigation water at high concentrations can cause significant challenges. Unfortunately, the difference between deficient, adequate, and toxic levels of boron are very small. In general, it is recommended that the maximum concentration of boron in water used for plants be no more than 1.0 ppm.

Unlike most other waste ions, boron can not be effectively removed with reverse osmosis purification. Instead, the only option for managing excessive boron levels is to maintain a substrate pH above 6.0 and use calcium-based fertilizer. The idea is that the high pH and calcium will caused excess boron to precipitate out of the soil solution, making it unavailable to the plant. Another option for controlling high boron in the water is to change water sources.

High concentrations of iron (Fe) in the irrigation don't usually effect plant nutrition or pH management. However, iron can cause staining problems on plant leaves and other surfaces, and the presence of iron in the water can lead to the presence of iron-bacteria growing in the pipes, which can clog mist nozzles, or anything else with small openings. Water treatments that oxidize the water, such as treatments with ozone or potassium permanganate, can effectively remove iron from the water.

Fluoride (F) and chlorine (Cl_2) are commonly added to municipal water at concentrations up to 4 ppm and can cause problems growing crops. Generally, high levels (above 1 ppm) of fluoride and chlorine can cause damage to the foliage (especially at the tip) and the flowers. These materials are easily removed from the water source by using an activated charcoal filter.

Water testing is only a starting point

Obtaining a water test is an important first step in determining if your fertility program will work, or if you need to reevaluate. Most water sources (with the exception of rain water) are susceptible to change. In commercial greenhouses, it is recommended to do a water analysis at least once a year, either to make sure that the water source is not changing, or if it is changing, to make adjustments in the nutrition program.

Equally important is understanding how your fertilizer affects pH and nutrition by itself, and through its interaction with your water. Next issue: fertilizer.

Where to get a water test?

Obtaining a water test is an important first step in determining if your fertility program will work, or if you need to reevaluate. The type of testing should be to determine if the water is acceptable for plants, i.e. for greenhouses and nurseries, not suitability for drinking water (there is a difference). The test should include, water pH, EC, and the concentration (in ppm or mEq/liter) of alkalinity (and or bicarbonates), nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, zinc, copper, boron, sodium, chloride, and fluoride.

There are number of testing laboratories in the U.S. that work closely with commercial greenhouse and nurseries, and so are familiar with many of the issue discussed in this article. A number of these laboratories also have international ties. They are:

Name	Location	Web site or E-mail	Phone Number
A & L Southern Laboratory	Pompano Beach, FL	Lgriff6250@aol.com	954-972-3255
J.R. Peters Laboratory	Allentown, PA	www.jrpeterslab.com	800-743-4769
Micro-Macro International	Athens, GA	www.mmilabs.com	706-548-4557
Quality Analytical Laboratories	Panama City, FL	www.qal.us	850-872-9535
Soil and Plant Laboratories, Inc.	Orange, CA	www.soilandplantlaboratory.com	714-282-8777

The cost of a water test will range from $25 to over $100 per sample. Remember that UPS and FedEx will ship anywhere in the US, so it pays to shop around

Many state universities still operate testing laboratories, so you can also have your water tested through the state extension service. Fees vary from state to state, and the time required to get the test back is usually longer than with commercial laboratories.

Drinking water companies will also perform water testing, but they are testing for the suitability for drinking, and whether or not you need some type of water treatment. If you want to grow plants, you need better, and more precise testing than is supplied by these companies.