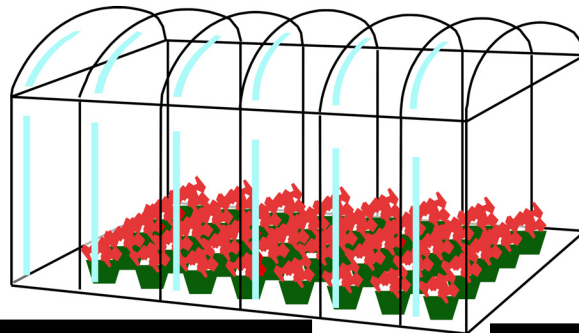




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Essential pH Management in Greenhouse Crops

Part I: pH and Plant Nutrition



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Essential pH Management in Greenhouse Crops

Part I. pH and Plant Nutrition

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How Does pH Affect Greenhouse Crops?

Plants need light, carbon dioxide, water and mineral nutrients in order to produce sugars (food) and grow. Water is supplied through the substrate, and it contains dissolved mineral elements. The mobility of these nutrients is determined by substrate pH (Fig. 3, page 4). Especially affected are those nutrients that plants require in small quantities, called micronutrients or trace elements. When the pH is too low, the micronutrients become more mobile and are absorbed in excess of what the plant needs, resulting in this potential for toxicities. When the pH is too high, the micronutrients are less mobile and the plant cannot absorb enough, which results in deficiencies, as illustrated in Figure 1. As evidenced by the chlorotic growing tip and young leaves, this plant is experiencing some sort of nutrient deficiency. This is typical symptomology of a pH-stressed plant.

Your goal as a greenhouse grower is to maintain a stable pH over the life of the crop. This is not an easy task since many factors can affect pH in the growing substrate. The pH can go up or down within several weeks of the crop cycle and if you wait for deficiency or toxicity symptoms to develop, you have already compromised the health of the crop and your profits.



Figure 1. Foliage discoloration such as chlorosis is a typical symptom of a nutrient deficiency caused by pH imbalance.

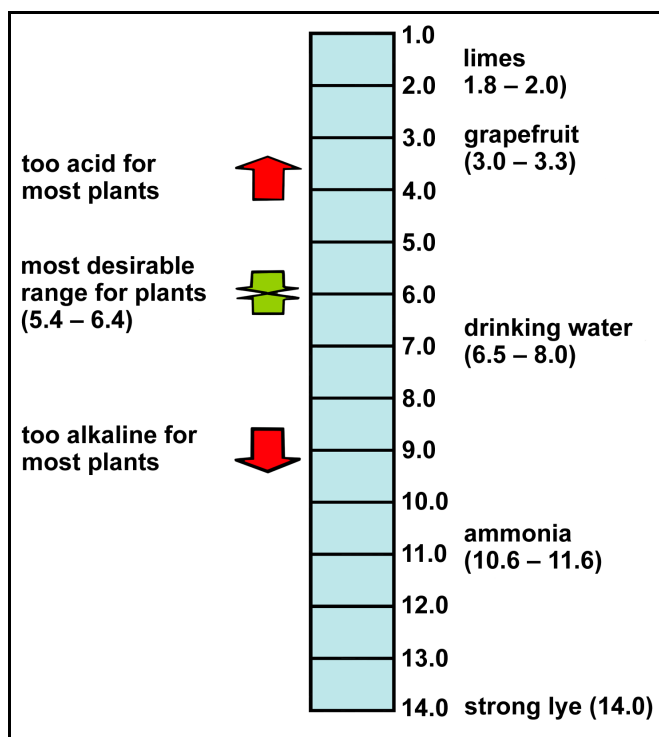


Figure 2. To give you an idea, lime juice has a pH of about 2.0, drinking water ranges from 6.5 to 8.0, and a strong lye solution reaches 14.0.

Knowing all factors involved is the first step to managing the substrate pH.

What Is pH?

A pH reading is a measurement of the acidity or basicity of a solution. The pH range is 0 (most acid) to 14 (most basic, Fig. 2). pH represents the number of hydrogen ions in solution. The scale used to measure pH is a logarithmic scale. Each increment of pH has 10 times more hydrogen ions than the previous increment. Therefore, a substrate with a pH of 5.0 has one hundred times more hydrogen ions than a substrate with a pH of 7.0. pH represents a balance between hydrogen and hydroxyl ions; the lower the pH, the higher the concentration of hydrogen ions relative to hydroxyl ions. Conversely, the higher the pH, the higher the concentration of hydroxyl ions relative to hydrogen ions (Fig. 3, p. 4).

Each plant species has a preferred pH; in general, the optimal range for maximum growth is 5.4 to 6.8. Plants experience pH through the roots (Fig. 4, p. 4). The substrate is a mixture of water with dissolved nutrients, air and solid particles. Root hairs experi-

ence any changes that occur in this environment, such as variations in moisture, air, or concentrations of solutes in the substrate solution.

What Is CEC?

Cation Exchange Capacity (CEC) is a measure of the ability of substrate particles (such as peat, bark, and vermiculite) to adsorb and release cations (such as many plant nutrients). In any liquid, dissolved substances exist as charged particles, with a positive or a negative charge. Substrate components, such as peat moss, composted bark, and vermiculite have negatively charged surfaces and therefore attract cations, which are positively charged (Fig. 5, page 5). The larger the capacity to adsorb cations, the larger the CEC. Substrate components vary in their ability to attract and hold ions. Organic materials such as peat and well-composted bark are capable of adsorbing ions to a much larger degree compared to perlite or sand, which have almost zero CEC.

Substrate solutions often have the capacity to buffer pH (keep it from changing). This buffering capacity depends on the dissolved substances; some have large buffering capacity, other have very little. If a solution has low buffering capacity, when a chemical is added to it, the solution pH will change immediately in response to the pH of the added chemical. Therefore, it is desirable to maintain the pH within a limited range. For example, substrate with a large buffering capacity will resist pH changes when fertilizers and other chemical substances are added.

What Is Alkalinity?

Alkalinity is a total measure of the substances in water that have “acid-neutralizing” ability. You can

At high pH the micronutrients (Fe, Mn, B, Zn, Cu) become less available. At low pH, they become too available.

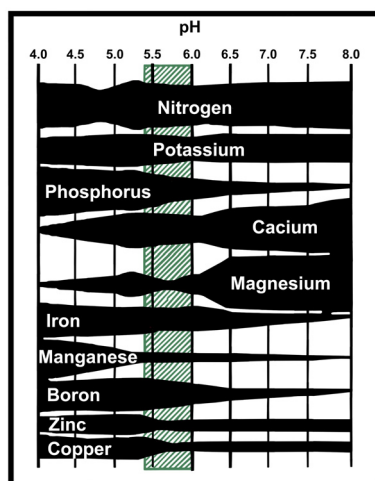


Figure 3. Nutrient availability as affected by substrate pH. Black areas indicate relative availability. Plants require micronutrients, also called trace elements — iron, manganese, boron, zinc and copper — in considerably smaller quantities compared to the macronutrients — nitrogen, phosphorus, potassium, calcium, magnesium. A pH range of 5.4 to 6.0 suits all nutrients. [Adapted from Bailey, 1996.]

think of alkalinity as the buffering capacity of water and such as how much lime is in the water. Alkalinity is attributed mostly to the amount of calcium and magnesium carbonates and bicarbonates, which are major components of limestone that is dissolved in that solution. Alkalinity should not be confused with pH. While this pH of a solution is the concentration of hydrogen ions in it and measures the strength of an acid or a base, the alkalinity reflects the power of the solution to react with acid and keep the solution pH from changing. The alkalinity, then, indicates how well a solution is buffered. While *alkalinity* sounds very much like *alkaline*, keep in mind that they are **not** the same thing; alkaline is a term applied to solutions with a pH higher than 7.0.

The alkalinity level has far-reaching implications because high alkalinity has a strong effect on the substrate pH. Of two water sources, one with a pH of 9.0 and alkalinity of 50, and the other with a pH of 7.0 and alkalinity of 300, the former will raise substrate pH very little, while the latter will cause a much higher raise in the substrate pH. *In general, water alkalinity is more important in determining effects on substrate pH than the actual pH of water.*

Because bicarbonates and carbonates are the major components of water alkalinity, most laboratories equate **Total Carbonates** [TC = carbonates (CO_3^{2-}) plus bicarbonates (HCO_3^-)] with alkalinity. Other laboratories assume that bicarbonates are the sole contributors to alkalinity.

Alkalinity may be expressed as parts per million (ppm), milligrams per liter (mg/L), or milliequivalents per liter (meq/L) of equivalent calcium bicarbonate or carbonate alone. Various sources prefer to use one or other of these units, and unless you are familiar with the conversion factors, it could be rather confusing. The following is the conversion from one unit of measurement into another:

$$50 \text{ ppm CaCO}_3 = 50 \text{ mg/L CaCO}_3 = 1 \text{ meq/L CaCO}_3 = 61 \text{ ppm HCO}_3^- = 61 \text{ mg/L HCO}_3^- = 1 \text{ meq/L HCO}_3^-$$

In the aquifer, water comes in contact with the rocks and dissolves some of the component minerals. The longer the duration of contact, the more min-

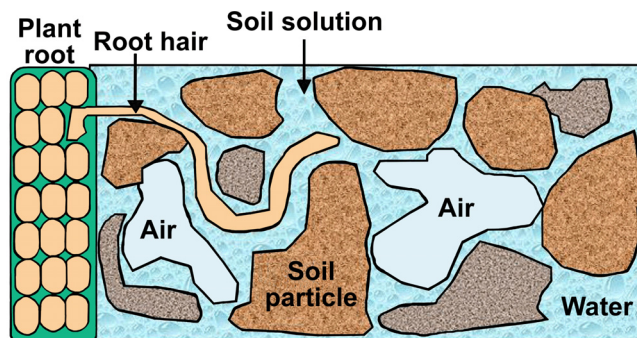


Figure 4. Plant roots are exposed to the substrate solution. The root hairs, extensions of the root epidermal cells, are the interface between the plant and the substrate solution. Roots are very sensitive to pH. The acidity or basicity of the substrate solution determines how well the roots can take up nutrients and how well the plant can grow.

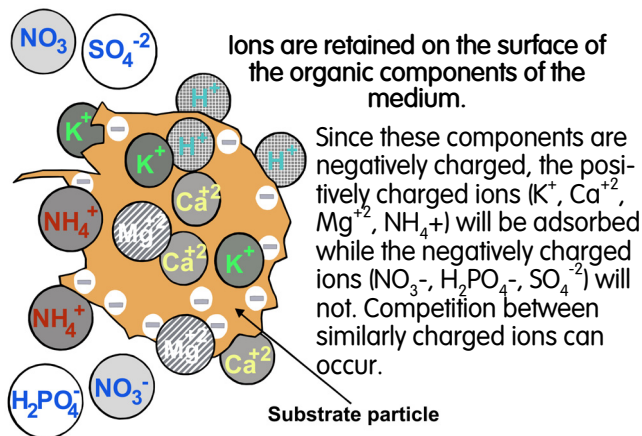
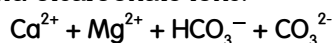
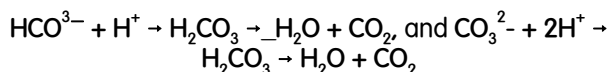


Figure 5. Chemical elements such as hydrogen, ammonium, calcium, potassium, sodium and magnesium are all positively charged ions, known as *cations*. The negatively charged ions (called *anions*) are hydroxyl, nitrates, carbonates, sulfates and phosphates. At low pH, the concentration of hydrogen ions is high. These positively charged ions can replace some of the positively charged micronutrients that are absorbed on the substrate. These micronutrients will then go into the substrate solution where they are readily available for plant uptake. Thus, as pH decreases, micronutrients may become available in excessive amounts and become toxic.

erals are dissolved (this is why after prolonged periods of drought the alkalinity of a well may rise and the opposite may occur during rainy periods). When the calcium and magnesium carbonates and the calcium and magnesium bicarbonates are dissolved, they dissociate into calcium (Ca), magnesium (Mg), carbonate, and bicarbonate ions:



The substrate pH rises because the carbonate and bicarbonate ions react with the substrate acidity (H^+) to form carbonic acid, which in turn converts to water and carbon dioxide.



In these reactions, the acidity (H^+) and carbonates and bicarbonates are consumed. The loss of hydrogen ions in the substrate results in a higher pH level. This is the mechanism through which alkalinity in the water increases substrate pH.

Factors that Affect Substrate pH

Substrate Components

Organic. Peat moss has different characteristics depending upon how finely it is shredded and from where it was harvested. Peat imparts a very strong pH effect, being very acidic; pH ranges from 3.0 to 4.0. It has been a routine practice in greenhouse production to add crushed limestone to compensate for the acidity of peat. Because the quality of peat varies depending on the source, the amount of lime must be tailored to that particular source.

Growers who mix their own substrate should have a thorough knowledge of the peat and/or bark that they are using. Both peat and bark eventually break down, and their ability to impart acidic pH can decrease over time.

Bark, similar to peat moss, also can be very acidic, with pH values ranging between 4.4 and 4.7. Lime is added to adjust for the acidity. One of the greatest challenges substrate mix manufacturers have to over-come is finding the right size particle of lime to accommodate the long production life of the mix. Stock plants may be in the same container for two years or longer.

Inorganic. Perlite is crushed aluminum-silica volcanic rock, which has been heated rapidly to very high temperatures, during which process it expands to a lightweight, chemically inert, and sterile material. Perlite has no nutrients, and with a pH of 7 to 7.5 (neutral) it does not contribute to the substrate pH. Perlite also has no CEC.

Vermiculite is a clay mineral. It has been treated at high temperatures and, similar to perlite, is lightweight, chemically inert, and sterile. Unlike perlite, it has a large CEC, but like perlite, its pH is 7-7.5. Both perlite and vermiculite increase substrate porosity.

Substrate Amendments

Limestone is the primary means of adjusting media pH before planting. Lime sources vary, but the potential basicity for most limestone sources is known. Three factors contribute to how quickly limestone affects initial substrate pH and how long the effect lasts:

Type of limestone — calcitic limestone ($CaCO_3$) is more reactive than dolomitic limestone [$CaMg(CO_3)_2$].

Particle size — small particles with large surface areas release the base-forming ions rapidly. If such lime is used, the pH will rapidly rise high and then drop precipitously over a few weeks of production as the lime is exhausted. If particle size is large, the pH may drop initially, then continue downward for weeks until the larger particles begin to break down — at which point the pH can rise quickly. Substrate companies must mix different sized lime particles so that there is the right mix of small, medium and large particles to cover the pH effect of the media components for the life of the crop.

Hardness — agricultural lime is a soft crystal; it breaks down faster than construction-type lime, which has a hard crystal and breaks down much slower. Neither too small nor too large lime particles are desirable to use in greenhouse substrates.

Fertility Sources

The type of fertilizer you are using can significantly affect substrate pH over time. Each fertilizer has been carefully formulated, and its ability to cause an acidic or basic effect is known and documented in the fertilizer analysis.

In simple terms, “Potential Acidity” or “Potential Basicity” as listed on the fertilizer package refers to the effect that this fertilizer product has on substrate pH (Fig. 6). The higher the number for “Potential Acidity,” the more acidity the fertilizer provides and the more acidity there is to react with lime or alkaline water. “Potential Basicity” works the same way. The higher the number, the greater the potential to provide basic ions (OH⁻) and raise pH. We say “potential” because like substrates, it also depends upon what water you are using, what substrate type you are adding the fertilizer to, and which amendments are present that can influence pH.

Some fertilizers, in particular containing urea phosphate (e.g., 15-5-15 Cal-Mag), may be very acid (pH of about 3.0, when used with water with low alkalinity). Such fertilizers will reduce substrate pH, irrespective of their potential acidity/basicity. The potential basicity listed on the label of 15-5-15 Cal-Mag, for example, is 150 lbs/ton, but it will actually reduce pH, if used with water with low alkalinity (for which it is recommended). Thus, the effects of this fertilizer are the opposite of what would be expected from its potential basicity.

Ionic balance. Ions carry electrical charges and because of that physiological reactions are sensitive to changes in the concentration of ions within living cells. Therefore, the plant cells maintain ionic balance; for each ion that is absorbed, another opposite charged ion, must leave the plant (Fig. 7, page 7). Because ions with a single charge are absorbed much faster compared to double-charged ions, the single-charged ions have a greater effect on pH.

Nitrate vs. Ammonium. Although the balance of all nutrients in a fertilizer determines its pH, it is often said that it is the nitrogen form alone controls pH. This is true most of the time, because nitrogen is

the only nutrient that can be supplied as either a negative ion (nitrate), or positive ion (ammonium) (Fig. 8, page 7).

A third form of nitrogen, urea, has no electrical charge. Nitrate being negatively charged, is easily leached from the substrate.

Every time a nitrate ion moves in the interior of the root cells, a hydroxyl ion is exported to the outside, contributing to the basicity of the substrate solution. It is then that the substrate pH is increased by the hydroxyl ion. If, for whatever reason, the plant is not absorbing the nitrate, the pH of the substrate solution does not change. Plants can absorb significant amounts of nitrate without any adverse reaction by storing it in their cell vacuoles along with other ions.

Ammonium, being positively charged, is adsorbed by substrate particles and is not easily leached. It is absorbed in root cells exchange of a hydrogen ion by the plant, thus adding an acidic component to the substrate. In addition, ammonium is converted to nitrate in the substrate by the action of substrate nitrifying microorganisms. In the process, a hydrogen ion is released to the medium, which reduces pH. Urea also undergoes bacterial nitrification, releasing hydrogen ions in the process.

Thus, a high nitrate fertilizer imparts basic pH only after being absorbed by the plant, while a high ammonium fertilizer imparts acidic pH even without absorption. Roots take up ammonium in limited quantities because it is toxic. Storage capacity is limited and, if too much ammonium is absorbed, toxicity can occur. Note that nitrifying bacteria work best at warm temperatures. This is why recommendations emphasize that fertilizer should contain low ammonium if applied in cool weather.

GENERAL PURPOSE 20-10-20	
(For Continuous Liquid Feed Programs)	
Guaranteed Analysis	F1143
Total nitrogen (N)	20%
7.77% ammoniacal nitrogen	
12.23% nitrate nitrogen	
Available phosphate (P ₂ O ₅)	10%
Soluble potash (K ₂ O)	20%
Magnesium (Mg) (Total)	0.05%
0.05% Water Soluble Magnesium (Mg)	
Boron (B)	0.0068%
Copper (Cu)	0.0036%
0.0036% Chelated Copper (Cu)	
Iron (Fe)	0.05%
0.05% Chelated Iron (Fe)	
Manganese (Mn)	0.025%
0.025% Chelated Manganese (Mn)	
Molybdenum (Mo)	0.0009%
Zinc (Zn)	0.0025%
0.0025% Chelated Zinc (Zn)	
Derived from: ammonium nitrate, potassium phosphate, potassium nitrate, magnesium sulfate, boric acid, copper sulfate, iron EDTA, manganese sulfate, ammonium molybdate, and zinc sulfate.	
<u>Potential acidity: 487 lbs. calcium carbonate equivalent per ton.</u>	

15-5-15 CAL-MAG	
(For Continuous Liquid Feed Programs)	
Guaranteed Analysis	F1143
Total nitrogen (N)	15%
1.20% ammoniacal nitrogen	
11.75% nitrate nitrogen	
2.05% urea nitrogen	
Available phosphate (P ₂ O ₅)	5%
Soluble potash (K ₂ O)	15%
Calcium (Ca)	5%
Magnesium (Mg)	2%
2.0% water soluble magnesium (Mg)	
Boron (B)	0.015%
Copper (Cu)	0.007%
0.007% water soluble copper (Cu)	
Iron (Fe)	0.075%
0.075% chelated iron (Fe)	
Manganese (Mn)	0.037%
0.037% water soluble manganese (Mn)	
Molybdenum (Mo)	0.007%
Zinc (Zn)	0.040%
0.40% water soluble zinc (Zn)	
Derived from: ammonium nitrate, calcium nitrate, potassium nitrate, urea phosphate, magnesium nitrate, boric acid, copper sulfate, iron EDTA, manganese sulfate, ammonium molybdate, and zinc sulfate.	
<u>Potential basicity: 140 lbs. calcium carbonate equivalent per ton.</u>	

Figure 6. Labels for two popular fertilizers: 20-10-20 and 15-5-15. Notice the numbers for “Potential acidity” and “Potential basicity” underlined in red.

Balance of positive-to-negative charged ions taken up

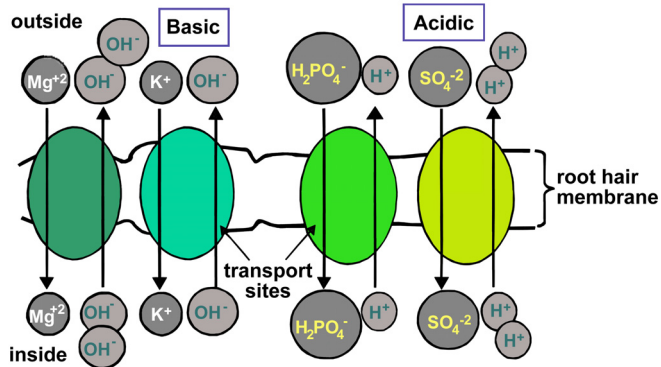


Figure 7. How plants maintain ionic balance. Transport sites embedded in the root cell membrane move positively or negatively charged ions. For example, each time a potassium ion moves in the interior of the root cells, a hydroxyl ion is exported to the outside, contributing to the basicity of the substrate solution. Conversely, each time a phosphate ion is absorbed, a hydrogen ion is expelled to the outside, contributing to the acidity of the substrate solution. Magnesium or calcium, having two positive charges, is exchanged for two hydroxyl charges. Similarly, sulfate, having two negative charges, is exchanged for two hydrogen ions.

An example of a basic nitrate fertilizer is calcium nitrate, $[\text{Ca}(\text{NO}_3)_2]$. Because it contains one double charged calcium ion (Ca^{+2}) that is slowly taken up and two single charged ions (NO_3^-) that are absorbed rapidly, calcium nitrate imparts basic reaction to the substrate. More negatively charged ions are taken up in a given period of time, causing a pH rise. The pH change caused can be slow, but when calcium nitrate is applied for more than a five- or six-week period, the pH can drift significantly toward higher pH.

Ammonium nitrate (NH_4NO_3) is an interesting example of a fertilizer with a strongly acidic reaction in the substrate. From its formula it contains equal amounts of ammonium and nitrate ions; we would expect a neutral effect. But ammonium ions are taken up much faster than nitrate, causing a significant acidic pH to build in the substrate. This is because of the different rate of uptake of single-charge ions. This happens with double-charged ions as well.

Urea fertilizer is first converted to ammonium then to nitrate, and in the process hydrogen ions are released, thus acidifying the substrate pH. Urea conversion to ammonium is very slow, therefore, initially, it is not considered to affect pH significantly, but over time it does lower medium pH.

Water Source

Knowing the characteristics of your water source is an absolute necessity in container plant production. Complex interactions among water, substrate and fertilizer determine the availability of various nutrients essential for normal plant growth. Water quality can vary significantly depending on factors such as geographic location, season of the year and water source. For example, rainwater and most surface

Nitrate vs. Ammonium

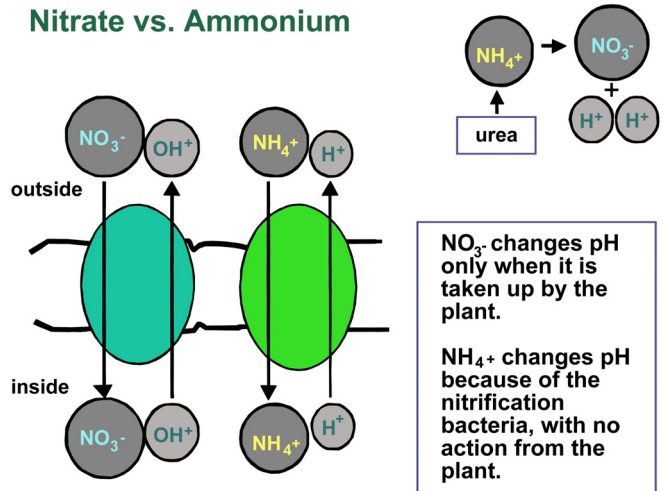


Figure 8. Nitrate and ammonium ions change substrate pH through different modes of action.

water supplies are pure because they contain relatively few minerals. In contrast, deep aquifers in coastal southeastern areas can contain high levels of minerals.

During dry seasons wells tend to have a higher mineral concentration compared to rainy seasons. Various mineral elements are always present in water, whether in almost undetectable or excessive amounts. Both situations can create problems for the greenhouse grower, and this is why prior knowledge of water quality before crops are grown, is crucial. Often signs of a particular problem that have developed in the plants could point to a likely culprit. For example whitish or reddish brown deposits on foliage after overhead irrigation are a sign of poor water quality. In the first case, white deposits are usually associated with water high in calcium and/or magnesium carbonates, and in the second, brown spots indicate excessive iron in the water. When designing the nutrition program, consider the presence or absence, and the relative quantities of various chemical elements in your water source. When you water your plants often, and by volume, you add more water to the crop than any other greenhouse input. The rule is that the higher the level of dissolved ions and salts in your water, the more potent the water will be at affecting your substrate solution pH.

While pure water may have very low or high pH, because there is little material in the water to interact with the substrate, it is not going to change the substrate pH. On the other hand, if you have hard water, rich in calcium salts and other minerals, the pH of your water will be very potent (Fig. 9, page 8).

Symptoms of pH Imbalances

How do growers recognize visual symptoms of pH imbalances in greenhouse crops? Figures 10-12 (pages 9 and 10) are good examples of pH-related nutrient deficiencies and toxicities.

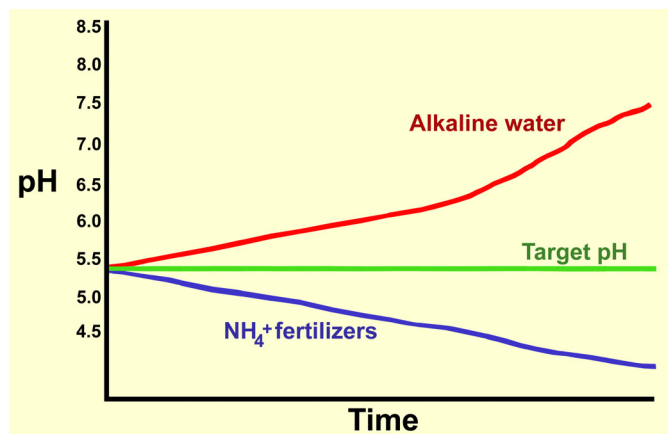


Figure 9. The combination of alkalinity in the irrigation water and the reaction of the water-soluble fertilizer affects media pH. The balance between ammonical nitrogen in the fertilizer and water alkalinity has the greatest effect on media pH over time.

Table 1. Approximate guidelines to matching fertilizers with Water Alkalinity (adapted from Argo and Fischer, 2002).

Alkalinity (ppm CaCO ₃)	Pot. Acidity (lbs/ton)	Examples	% Nitrate
30-60	>159 pot. basicity	13-12-13 14-0-14	>85%
60-120	150 basic – 150 acidity	20-0-20 17-5-17	70-80%
120-200	150-500 pot. acidity	20-10-20 21-5-20	60%
200-300	>500 pot. acidity	20-20-20 25-10-10	<50%

Testing Substrate pH

There are several techniques to use. Growers can send samples to a commercial testing facility for analysis or you can do an in-house testing using the PourThrough method developed by researchers from North Carolina State University (www.pourthruinfo.com). The PourThrough method is an easy, non-destructive and effective technique for assessing pH and electrical conductivity (EC) of the growing substrate. Growers can track actual pH values on a weekly basis and devise management plans long before a problem develops. In order to use this method you need to invest in a reliable testing instrument (Fig. 13, page 10).

Commercial laboratories use different methods to obtain pH and EC information, such as Saturated Media Extract (SME), 1:2, or 1:5 extraction methods. If sending substrate media to outside services for analysis, you need to refer to the following table to correctly interpret your EC results.

You also need to develop a schedule for testing the substrate pH of your crops and record the readings on charts for each crop. Results can be inter-

preted using recommended pH and EC ranges (for more information on crop pH ranges, pH and EC charts go to <http://floricultureinfo.com>).

Table 2. Different extraction methods for substrates and interpretive ranges for electrical conductivity values. [Adapted from NCSU, <http://floricultureinfo.com>].

1:2	SME	PourThru	Indication
0 to 0.3	0 to 0.8	0 to 1.0	Very Low
0.3 to 0.8	0.8 to 2.0	1.0 to 2.6	Low
0.8 to 1.3	2.0 to 3.5	2.6 to 4.6	Normal
1.3 to 2.3	3.5 to 5.0	4.6 to 6.5	High
1.8 to 2.3	5.0 to 6.0	6.6 to 7.8	Very High
> 2.3	> 6.0	> 7.8	Extreme

Summary

The essential factors that play a role in determining your substrate pH are water alkalinity, substrate components, fertilizer type, and species grown. Your goal as a greenhouse grower is to maintain a stable pH over the life of the crop. Knowing all factors involved is the first step in managing the substrate pH. It is the combination of the alkalinity in the irrigation water and the reaction of the water-soluble fertilizer that affects media pH. pH affects nutrient mobility; to prevent pH imbalances, you need to institute a pH-testing program to assess substrate pH on a regular basis. A thorough testing of all preplant production inputs, including water source, fertilizer, and greenhouse substrate, is recommended.

Part 2 of the series will address pH management and the steps to take to correct low or high pH.

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Figure 10. pH too high — plants showing typical symptoms of iron deficiency. Top, l-r: petunia, pentas, calibrachoa. Bottom, l-r: scaevola, bougainvillea.

Notice the progressive chlorosis (yellowing of young foliage). A grower may incorrectly diagnose these as generally low nutrition and apply additional fertilizer. Although a “toning up” may result after the treatment (probably by the iron in the fertilizer), soluble salt level may become too high, causing salt stress and root damage. A more appropriate course would be to test the substrate pH and EC; if EC is normal but pH is too high, lower the pH to make the micro-nutrients more available.

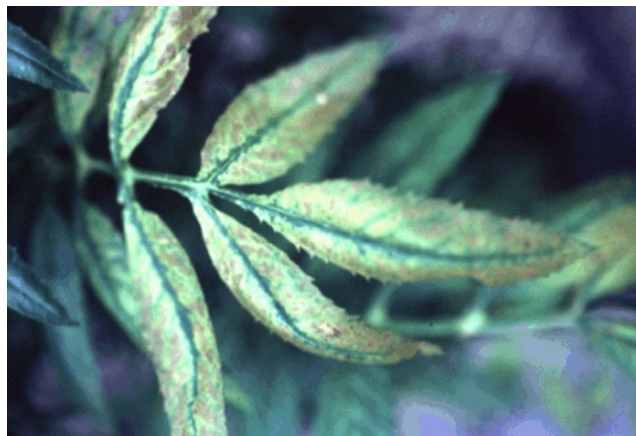
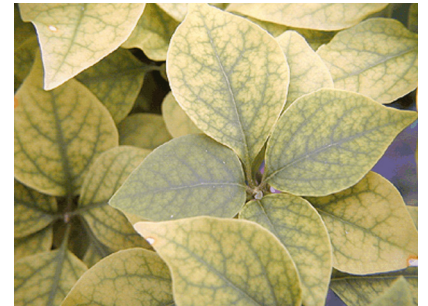
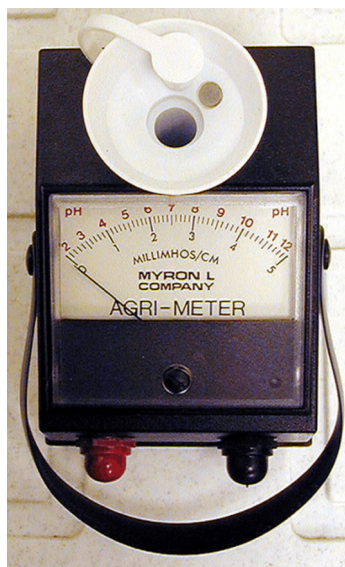


Figure 11. pH too low — plants showing typical symptoms of iron/manganese toxicity. In geranium (l) the older foliage is affected first, starting as chlorotic spots scattered around the leaf and on the leaf margin, later turning necrotic (brown and dead). Entire leaves turn yellow and necrotic in advanced toxicity. [Photo courtesy of Brian Whipker, North Carolina State University.] In marigold (r), micronutrient toxicity appears as bronzing or necrotic speckles that progress into an overall chlorosis and necrosis.



Figure 12. High medium pH is not the only cause of chlorosis on developing leaves. This ivy geranium was grown at high (>75 degrees F) day and night temperatures and high light but with normal pH and EC levels. Other reasons for chlorosis can be genetic variation in the leaf pigment.

Figure 13. Many models of pH meters are available; make sure you select one that is accurate within 0.2 and has resolutions of 0.1 pH units; range of pH 2 to 12; and 2-point calibration, i.e., using a pH 4 and 7 buffer solution. Less expensive models are not as accurate and also need frequent replacement. We recommend that you invest in a good quality meter. Purchase calibration solutions of pH 4 and 7 and replace them once the expiration date has passed.



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