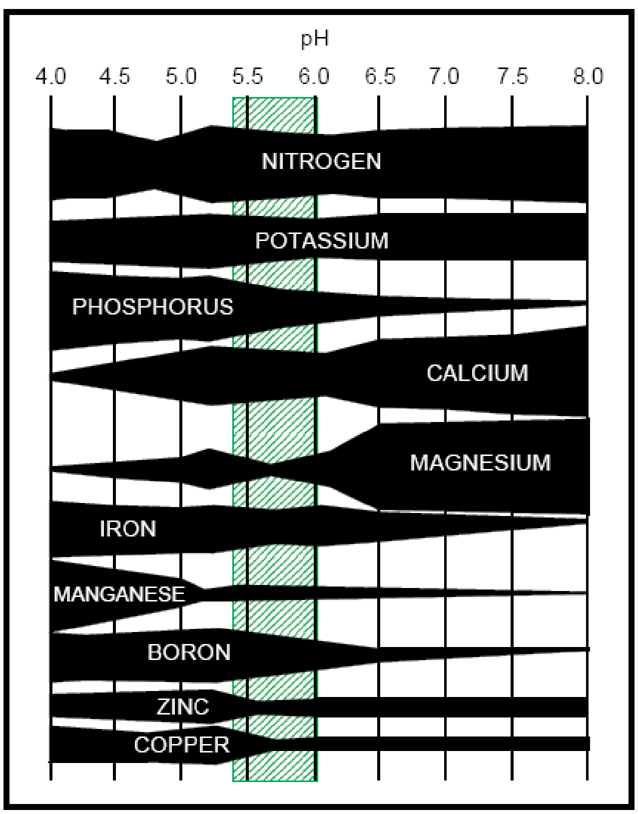
Cornell University
Cooperative Extension

Substrate pH: Getting it Right for Your Greenhouse Crops

Neil Mattson
Assistant professor and Floriculture Extension Specialist, Department of Horticulture
Cornell University, 134A Plant Sciences Bldg, Ithaca, NY 14853

pH affects the ability of nutrients to dissolve in water (solubility). The graph below shows nutrient solubility in container media as pH varies from 4 to 8. Solubility is important because roots can only take up nutrients that are dissolved in solution and cannot take up the solid form of the nutrient.



.

Source of figure:

Alkalinity control for irrigation water used in greenhouses by Douglas Bailey, North Carolina State University

http://www.ces.ncsu.edu/depts/hort/floriculture/plugs/alkalinity.pdf

Problems with Low pH

The micronutrients iron, manganese, zinc, and boron are highly soluble at low pH (pH 5.0-6.0). Therefore, at low pH these nutrients are available and readily taken up by roots. If pH is too low, typically below 5.0 for most plants, the nutrients become so soluble that they may be taken up at harmful or toxic concentrations. A classic symptom of this is iron toxicity which appears as leaf bronzing and chlorosis (yellowing) which appear first on lower leaves (Photograph 1). Certain plants that are especially efficient at taking up iron, such as seed and zonal geraniums and marigolds, can exhibit iron toxicity when pH is below 6.0.

Problems with High pH

At high media pH the low solubility of iron, manganese, zinc, and boron makes these nutrients less available to be taken up by roots and so deficiency symptoms can occur. Certain plants are less efficient at absorbing micronutrients (especially iron and manganese). These plants require a slightly lower pH to be able to absorb enough of these nutrients. A classic example of this is iron deficiency is petunia. Affected plants show yellowing between the veins on the upper leaves (Photograph 2). Often there is enough iron provided in the fertilizer/container media, but the pH is too high for roots to absorb it.

pH Guidelines

Based on the above problems, excessively high and excessively low pH should be avoided. For many plants a pH of 5.5-6.5 typically allows the various mineral nutrients to be absorbed at adequate levels; and not at levels too high that toxicity can result. As stated above, certain plants are more efficient at absorbing iron and other micronutrients. For this group, referred to as the "Iron-Efficient" or Geranium Group the optimal pH is slightly higher (6.0-6.6) so that iron toxicity does not occur. Conversely, Snapdragon, Caibrachoa, and Petunia are considered "Iron Inefficient" and so a lower pH is desired (5.4-6.2) so that enough iron can be absorbed.

Media pH guidelines for some common greenhouse plants.*

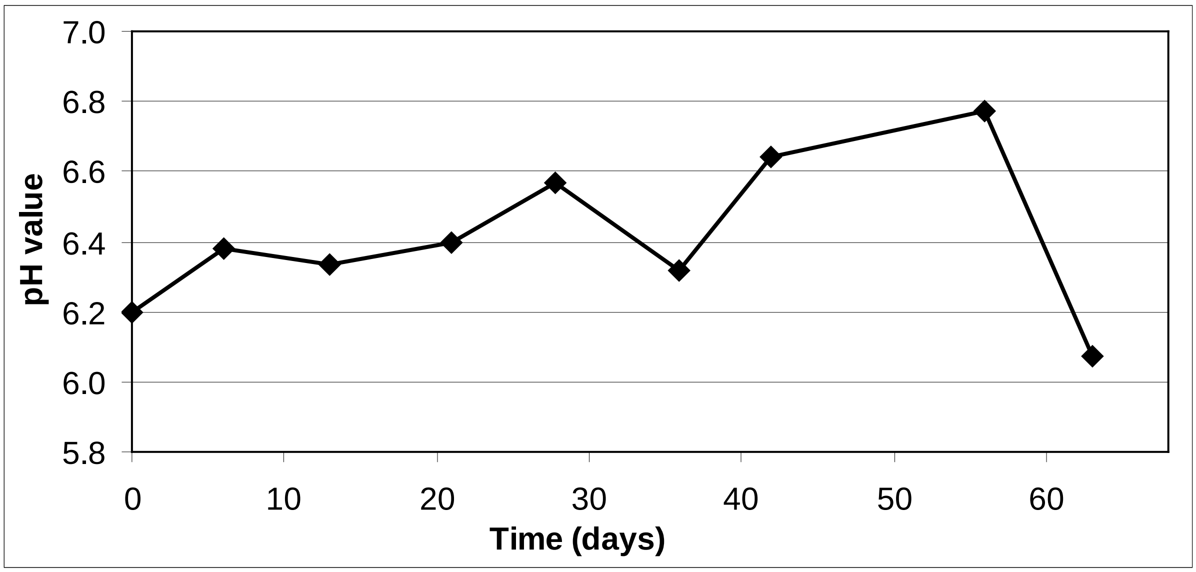
Iron Inefficient Plants pH 5.4 to 6.2	**General Group pH 5.8 to 6.4**	**Iron Efficient Plants pH 6.0 to 6.6**
bacopa	chrysanthemum	geranium (seed and zonal)
calibrachoa	geranium (ivy)	marigold
nemesia	impatiens	New Guinea impatiens
pansy	poinsettia	lisianthus
petunia		
snapdragon		
scaevola		

*Adapted from Managing pH for Container Media by Paul Fisher, Chapter 4 in Ball Redbook Crop Production, Volume 2, 17th Edition, Ball Publishing.

For more information on suggested pH ranges for specific greenhouse crops, see the publication: Monitoring and Managing pH and EC Using the Pour Thru Extraction Method. North Carolina State University. Online at: http://www.pourthruinfo.com/

Long-Term Monitoring Examples

Sampling container media for pH and EC is most effective when samples are taken periodically during crop production as opposed to measuring at only 1 time point. This allows you to look for trends. If pH or EC begin to creep outside of the preferred range, then action can be taken to bring these under control. For example:



Bedding plants were grown with a commercial fertilizer mix at 150 ppm N. The PourThru method was used to measure container media pH. The pH tended to increase over time during the first 28 days, so on day 28 an acidic fertilizer (21-7-7 acid special) was used for 7 days. pH began to creep up again, so on day 58, the acidic fertilizer was used again for another 7 days. (Data from Neil Mattson)

CORRECTING pH

Before we look at specific ways to lower or raise pH of the container medium, we will first look at some factors that affect pH.

The container medium that we use has an initial pH. Acidic media (pH less than 7) include: sphagnum peat, pine bark, coir, and many composts. Neutral media (pH around 7) include: perlite, sand, and polystyrene. Alkaline media (pH greater than 7) include: bark from hardwood trees, vermiculite, rockwool, and rice hulls. Many of our commercial container media mixes are comprised of a combination of peat, perlite/vermiculite, and some may contain bark or sand. These peat-based media are usually quite acidic initially so the manufacturers have added limestone to them to correct for pH. If you mix your own container media you can control the amount of limestone that you add to set your initial pH.

Effect of Water Alkalinity

Most of our water sources naturally contain some impurities in the form of dissolved alkalis: $Ca(HCO_3)_2$, $NaHCO_3$, $Mg(HCO_3)2$, $CaCO_3$. These dissolved alkalis tend to raise the pH of the container medium over time. The more often a container is water and the more dissolved alkalis it contains the more the pH will increase over time. Alkalinity is reported in terms of ppm $CaCO_3$ (or meq, in which case: 50 ppm = 1 meq

$CaCO_3$). For greenhouse water sources, the alkalinity typically varies from 50 to 500 ppm. A moderate alkalinity (80-120 ppm) is considered optimal as it adds to the buffering capacity of the container medium. If the alkalinity is too low (typically less than 100-120 ppm) then pH fluctuations can occur very quickly. If alkalinity is too high, it can cause container medium pH to rise out of the optimal range.

It is recommended that growers test their water alkalinity once or twice a year. Testing can be done by a qualified nutrient diagnostic laboratory; or home kits are available which will give you the approximate range. If your alkalinity is greater than about 100 ppm you can expect that pH of the container medium will tend to increase over time unless preventative measures are taken such as injecting acid to neutralize the alkalinity or using a more acidic fertilizer. Once you know your water's alkalinity an Extension Educator or a representative from the diagnostic lab can help you design a fertilizer program or acid injection program to control for pH drift.

Why does pH not equal alkalinity?

To put it simply pH measures the amount of hydrogen ions dissolved in water; while alkalinity measures the amount of dissolved alkalis (carbonates/bicarbonates of calcium, magnesium, or sodium) in the water. Therefore by definition, pH measures one thing, while alkalinity measures another. However, there is some connection between pH and alkalinity because the alkalis in water can react with the hydrogen ions to bring about a rise in pH. The chemical formula for this is: $H^+ + HCO_3^- \rightarrow H_2O + CO_2$ (i.e. the hydrogen ions combine with carbonates to form water and carbon dioxide which is bubbled away). Because of this reaction water with high alkalinity typically has a high pH (7 or above), but water with high pH doesn't always have high alkalinity.

Another reason that alkalinity and not pH is more important for your water source is that the pH in a water sample can rise the longer it is shake around with open air. When a water sample is shake around (or air is bubbled in) some of the oxygen will dissolve in the water which will create some new hydroxyl (OH^-) ions which will raise the pH. Conversely if you bubble carbon dioxide into water (from a soda fountain or by blowing into it with a straw) some CO_2 will dissolve in water and some carbonic acid (H_2CO_3) will form. The carbonic acid will decrease the water pH. While this changes pH it has little effect on alkalinity. In the long run, it is your water's alkalinity that has the most effect on substrate pH changes. The alkalinity in your water can be thought of as liquid limestone, the more you water a pot with alkaline water the more liquid limestone you are adding to that pot and the more you will cause pH to increase.

Injecting Acid

Using a fertilizer injector to add acid to your water directly reduces the alkalinity. A hydrogen ion from the acid will combine with a bicarbonate molecule (from the alkali) to form carbon dioxide and water. (For the chemists: $H^+ + HCO_3^- \rightarrow CO_2 + H_2O$). Different types of acids can be used, including: sulfuric, phosphoric, nitric, and citric. Typically, a grower will add enough acid to reduce the pH of the water to 5.8. The amount of acid that you need to add depends on your water's alkalinity level. An excellent article with more detailed information is available online at:
http://www.ces.ncsu.edu/depts/hort/floriculture/plugs/alkalinity.pdf

Selecting a Fertilizer to Correct pH

Plants have the ability to take up several forms of nitrogen (ammonium, nitrate, and urea). Ammonium and urea are acidic forms of nitrogen, meaning they tend to decrease the pH of container medium. Nitrate is a basic form on nitrogen, meaning that it tends to increase the pH of the container medium. Most commercial fertilizer mixes contain a combination of all three forms of nitrogen. The fertilizer label will provide the percentage of each type and will tell you if the net effect is to increase pH or decrease pH; this is reported as the fertilizer's potential acidity or basicity. The table on the following page lists the potential acidity or basicity of several commercial fertilizers.

High pH can be corrected by switching to a more acidic fertilizer. One example is 21-5-20 fertilizer which has a potential acidity of about 400. In other words, application of one ton of 21-5-20 causes acidification which would require 400 lbs of calcium carbonate limestone to counteract. Similarly, 15-0-15 has 420 lbs of potential basicity and can be used to increase low pH. For crops that are known to have issues with pH decline, using a nitrate based fertilizer such as 15-5-15 may aid in slowing or halting pH decline over time. The greater the potential acidity or basicity the more pH change occurs.

The following table lists approximate guidelines for selecting a water soluble fertilizer. Remember to Consult your extension educator or fertilizer supply representative to select the appropriate fertilizer based on your water supply, container medium and specific crops.

Table 2. Approximate guidelines to matching the ammoniacal nitrogen levels in the water-soluble fertilizer with water alkalinity in order to achieve a stable medium-pH over time.

Alkalinity Concentration (in ppm $CaCO_3$)	CCE (in lbs./ton)	% Acidic Nitrogen	Examples
250 – 300	>500 acidic	>50%	20-20-20 21-7-7
150 – 250	200 acidic – 450 acidic	40%	20-10-20 21-5-20
60 – 150	150 acidic – 150 basicc	20% - 30%	17-5-17 20-0-20
30 – 60	> 200 basic	<10%	13-2-13 14-0-14

[1]% acidic nitrogen is calculated as the sum of ammoniacal and urea nitrogen divided by the total nitrogen contained in the formula

Souce: Paul Fisher and William Argo, Managing the pH of container media: http://extension.unh.edu/agric/AGGHFL/pHarticl.pdf

Potential Acidity/Basicity

Table 1. Some commercially available fertilizers, their percentage of total nitrogen as nitrate or ammonium plus urea, and potential acidity or basicity [a].

Fertilizer	% Nitrate (NO_3)	% (NH_4 [b])	Potential acidity [c] or basicity [d]
Ammonium sulfate	0	100	2200 a
Urea	0	100	1680 a
21-7-7 acid	0	100	1539 a
21-7-7 acid	0	100	1518 a
Diammonium phosphate	0	100	1400 a
Ammonium nitrate	51	49	1220 a
Monoammonium phosphate	0	100	1120 a
18-9-18	47.7	53.3	708 a
20-20-20	27.5	72.5	532 a
21-5-20	62.3	37.7	407 a
20-10-20	59.5	40.5	404 a
20-10-20	60	40	401 a
21-5-20	60	40	390 a
17-5-17	70.6	29.4	106 a
20-0-20	54	46	0
15-0-20	76.7	23.3	38 b
15-5-15	80	20	69 b
15-5-15	78.7	21.3	131 b
15-0-14	82.7	17.3	165 b
15-0-15	86.7	13.3	221 b
15-0-15	80.8	18.8	319 b
Calcium nitrate	100	0	400 b
Potassium nitrate	100	0	520 b
Sodium nitrate	100	0	580 b

[a] Table adapted and revised from Paul Nelson: Greenhouse Operation and Management. p. 315. 6th ed. Prentice Hall. New Jersey.

[b] The percentage of total N in the ammonium plus urea forms; remaining N is nitrate

[c] Potential acidity is defined as the pounds of calcium carbonate limestone required to neutralize the acidity of 1 ton of fertilizer

[d] Potential basicity: applying 1 ton of this fertilizer has the pH neutralizing effect of this many pounds of calcium carbonate limestone

Ways to Lower pH

As we have seen, there are several tools we have available to adjust container medium pH. The specific the method you choose will depend on whether or not you need a quick fix or a gradual method to control pH over time.

Quick methods to lower pH

- Apply a one-time phosphoric acid drench (3.5 ounces of 75-85% phosphoric acid in 100 gallons of water) or
- Apply a one-time sulfuric acid drench (1.8 ounces of 90-95% sulfuric acid in 100 gallons of water) or
- as a last resort, apply an iron sulfate ($FeSO_4 \cdot 7H_2O$) drench (3 lbs per 100 gallons of water). Be sure to mist off the foliage immediately after application or foliage burning can occur.

Gradual methods to lower pH

- Switch to a fertilizer that has a greater potential acidity (consider long-term fertilizer changes if pH is a continual problem).
- Continual acid injection to decrease water alkalinity to 120 ppm (or to bring the water source pH down to 5.8

When using ammonium/urea to decrease pH watch out for ammonium toxicity. That is, under cool wet conditions (typical in winter and early spring), plants can absorb too much ammonium which cause the symptoms of upward or downward curing of lower leaves (depending on plant species); and yellowing between the veins of older leaves which can progress to cell death. To avoid ammonium toxicity it is recommended that growers use a fertilizer with 40% or less ammonium/urea nitrogen when growing conditions are cool and wet.

Ways to Raise pH

Quick methods to raise pH:

- Apply a flowable lime or potassium bicarbonate drench. A nice set of instructions available online at: http://extension.unh.edu/agric/AGGHFL/pHarticl.pdf

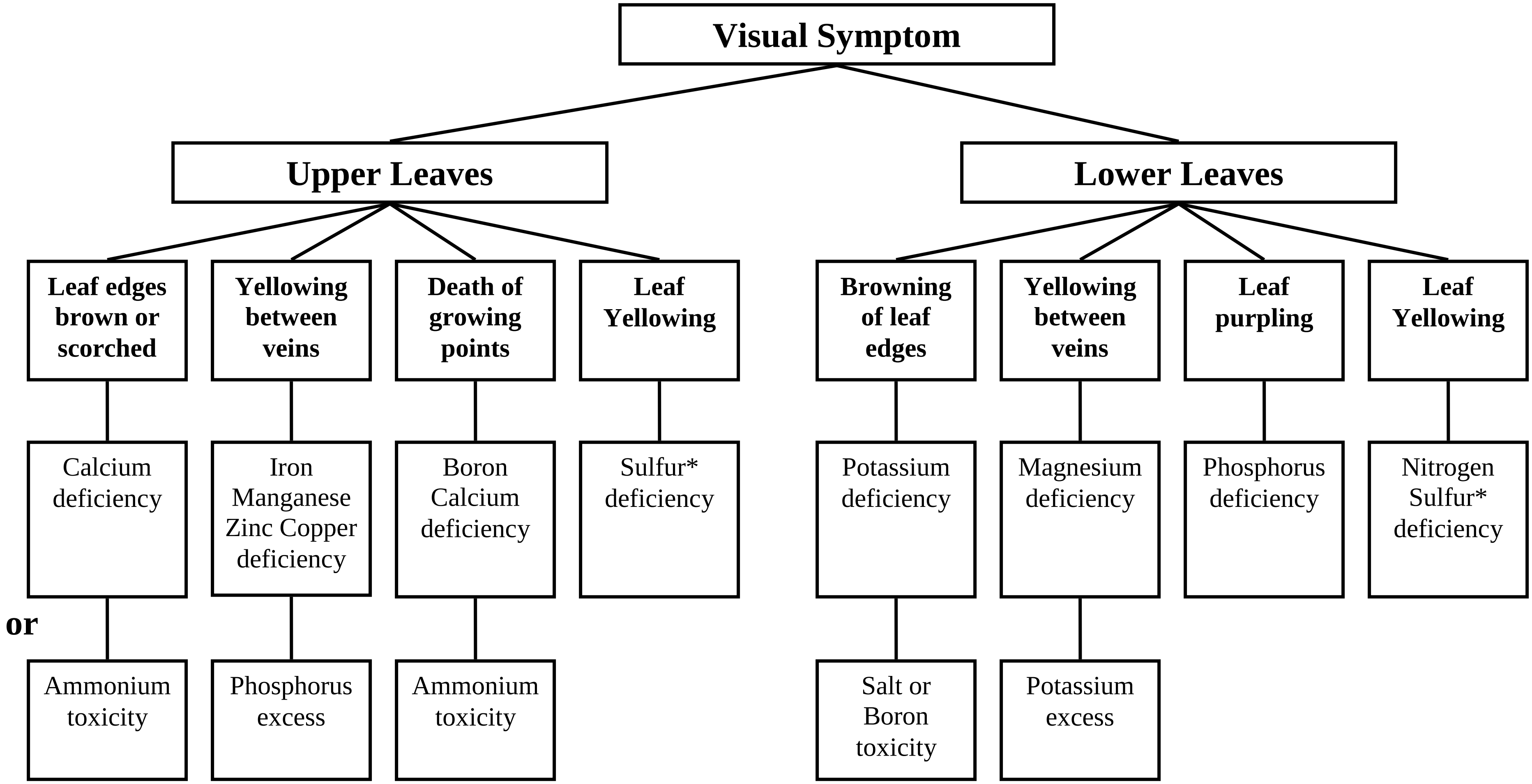
Gradual methods to raise pH:

- Stop acidifying water if acid is being injected
- Alternate to a nitrate based fertlizer

Photograph 1. This marigold displays symptoms of Iron Toxicity: which includes leaf bronzing and yellowing of leaf edges that occurs first on the lower leaves.

Photograph 2. Petunias and snapdragons are less efficient at absorbing iron, and will often display iron deficiency symptoms before other plants. Symptoms are yellowing between the veins on upper leaves.

KEY TO VISUAL DIAGNOSIS OF NUTRIENT DISORDERS



* Sulfur deficiency usually appears as yellowing of both upper and lower leaves

Key adapted from: Diagnosing nutrient disorders in fruit and vegetable crops. Peter Bierman and Carl Rosen, University of Minnesota. Available online: http://www.extension.umn.edu/distribution/horticulture/M1190.html

Note: This diagnostic key is based on the most common symptoms. Plants vary in how they express nutrient disorders. Analysis of tissue or container media samples by a qualified laboratory is required to confirm the symptoms.