Managing the pH of container media.

UNIVERSITY of NEW HAMPSHIRE
COOPERATIVE EXTENSION

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pH determines micronutrient solubility in the root medium:
- low pH = very soluble
- high pH = less soluble

► **Plant takes up soluble nutrients through roots**

► **Nutrients transported into leaves and growing points:**
- Excess = toxicity
- Adequate = healthy
- Insufficient = deficiency

► **Toxicity or Deficiency results in stunted growth and poor plant appearance**

1. Why is pH important?

The most common nutritional problems occur in greenhouse crops when pH of the growing medium is outside the optimum range. Medium-pH is a measure of the acidity (low pH = acid) or basicity (high pH = basic, also called alkaline) of the growing medium. The pH of a growing medium is important because it affects a chain of events affecting plant health.

Plants only take up dissolved nutrients through their roots. Medium-pH drives the chemical reactions that determine whether nutrients are either available for root uptake (i.e. soluble) or unavailable for uptake (insoluble). Several nutrients are affected by medium-pH, but the most important are phosphorus and most micronutrients, especially iron, manganese, copper, zinc, and boron (which decrease in solubility at high pH), and molybdenum (which increases in solubility at high pH).

The optimum range for most crops growing in a soilless medium is 5.8 to 6.4, because in this range micronutrients are soluble enough to satisfy plant needs without becoming so soluble as to be toxic.

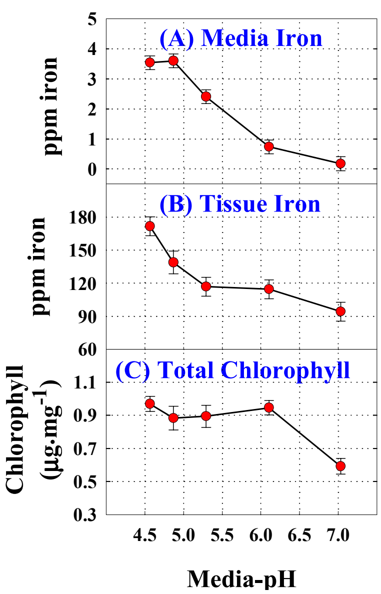

Figure 1. The effect of growing petunia at different medium-pH's on (A) Media iron content (from a saturated media extract using deionized water as the extractant), (B) Iron content in the tissue, and (C) leaf chlorophyll content. This figure shows that as pH increased there was a decrease in the available iron in the medium, and less uptake of iron into the leaves. At the highest pH, media iron levels were the lowest, tissue iron levels were the lowest, and the plants showed classic iron deficiency symptoms (chlorosis due to the lack of chlorophyll). Research by Brandon Smith and Paul Fisher, Univ. of New Hampshire, and William Argo, Blackmore Co.

2. Recognizing the problem

Iron is required by plants to produce chlorophyll (the pigment in leaves that give plants their green color. At high medium-pH, micronutrients (especially iron) become less soluble in the medium, resulting in lower uptake by the plant (Figure 1). Because micronutrients are not mobile within the plant, deficiencies induced by high pH tend to show chlorosis in the newest growth (yellowing caused by lack of chlorophyll), which is sometimes interveinal (leaf veins are green, but remaining tissue is yellow). As deficiency becomes more severe, plant lose vigor and the foliage becomes almost completely white with necrotic (dead) areas forming at the growing points.

At low medium-pH, iron and manganese are highly soluble in the medium. Excess micronutrients can accumulate in plant tissue, and cause chlorosis and necrosis (dead tissue) on leaf margins and as leaf spots. The damage tends to occur in older leaves because the longer a leaf grows on the plant, the more time it has to accumulate excess micronutrients.

3. Why do medium-pH problems arise?

Reasons that medium-pH can be too high or low include:

3A . Poor buffering of soilless media. In the last 20 years, the move away from use of soil in greenhouse container media has resulted in less buffering (chemical resistance to pH change). In peat and bark-based media, a change of up to 1 pH unit in a week can sometimes occur in commercial crops. Although use of soilless media has many benefits (uniformity, consistency, aeration, sterility) one downside is that pH is very likely to change over time even if the medium starts out at the optimum pH range at time of planting. Media pH can drift up or down depending on the balance of factors including water alkalinity, lime activity, acidification of the medium by plant roots, and use of an acid or basic reaction fertilizer. As a result, it is important not just to blame problems on the media, but rather to also understand how grower management can cause pH to change over time.

3B. Limestone. Limestone is mixed into media to raise pH to around 6.0, because both peat and bark are acidic. Limestone sources differ in their composition, particle size, and hardness, which causes them to vary in how reactive they are (i.e. how many lb/cubic yard are required to raise pH at the start of the crop), and also in how long they continue to react during crop growth. If the incorrect type or quantity of lime is used during mixing of the medium, pH can either be out of range at the start of the crop, or drift over time. If mixing your own medium, (a) consult a fertilizer or media company to obtain a suitable type of lime, (b) run small batch tests to check how much lime is needed to bring pH up to the target level, and (c) if you change the source of lime, peat, bark, or vermiculite you will need to re-test your recipe. If you consistently run into problems with high or low medium-pH, and you have correctly matched the fertilizer type with water alkalinity, consider changing the lime type or rate.

3C. Wide range in crops. Species differ in their nutritional needs, and can be separated into three nutritional groups based on their efficiency at taking up micronutrients.

- **Petunia group:** Also known as iron-inefficient species, prone to iron deficiency at high pH, especially combined with low fertilizer concentration or high media pH. Examples include bacopa, calibrachoa, diascia, nemesia, pansy, petunia, snapdragon, vinca. Grow at a lower pH range of 5.4-6.2 to increase solubility of micronutrients. This group is often misdiagnosed as a "high feed" or "high iron" group. They do not necessarily require higher rates of fertilizer or iron, but are especially sensitive to high pH and the need for adequate iron.
- **General group:** (e.g. chrysanthemum, impatiens, ivy geranium, poinsettia). Grow at a moderate pH range of 5.8-6.4.
- **Geranium group**: (iron-efficient, prone to iron/ manganese toxicity at low pH, especially when combined with high fertilizer concentration). e.g. marigold, seed and zonal geranium, New Guinea impatiens, lisianthus. Grow at a higher pH range, 6.0-6.6 to limit the solubility of micronutrients.

3D. Fertilizer type. You cannot measure the acid or basic reaction of a water-soluble fertilizer by measuring the pH of the stock tank or the solution coming out of the end of the hose. Rather, it is the tendency of a water-soluble fertilizer to change medium-pH over time. Information on any bag of fertilizer will include the acid or basic reaction of a water-soluble fertilizer is written on the bag as an acidic or basic "calcium carbonate equivalency" (CCE), which is a relative measure of the tendency of the fertilizer to raise or lower medium-pH (Table 1).

Table 1. Calcium carbonate equivalency (CCE), and the percent of acidic nitrogen = (ammoniacal + urea nitrogen)/total nitrogen, contained in several commercially available water-soluble fertilizer.

Formula	CCE	% Acidic Nitrogen
21-7-7	1520 acidic	100%
20-20-20	680 acidic	70%
20-10-20	429 acidic	40%
17-5-17-3 Ca-1 Mg	0 acidic	25%
13-2-13-6 Ca-3 Mg	330 basic	5%

[1]% acidic nitrogen is calculated as the sum of ammoniacal and urea nitrogen divided by the total nitrogen contained in the formula
[2]Units for CCE are pounds acidity or basicity per ton of fertilizer.

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

More importantly, the label tells the type and percentage of the different forms of nitrogen (ammonium, nitrate, or urea), as well as the percentage of the other nutrients contained in the fertilizer. In general, ammoniacal and urea nitrogen are acidic, and tend to drive the media pH down, whereas nitrate nitrogen is basic and tends to drive the media pH up.

Several factors are important when using fertilizers to raise or lower medium-pH:

- Nitrate only increases medium-pH when the fertilizer is taken up by plant roots. Therefore, if plants are small, or are stressed and not growing, nitrate has little influence on medium-pH.
- Ammonium can cause the medium-pH to go down even if the plant is small or is not growing, because soil bacteria acidify the medium through a process termed nitrification.
- Ammonium is less effective at lowering medium-pH in cool, saturated soil because nitrification is inhibited. In addition, ammonium toxicity in plants can occur in cool, wet conditions because plants are more likely to take up excess ammonium.
- Sometimes ammonium will not drop medium-pH at all, because other factors (especially high lime or water alkalinity) can have a stronger effect on pH than the fertilizer.

3E. Irrigation water alkalinity. Irrigation water pH affects chemical solubility of solutions, but has little effect on medium-pH. Instead, medium-pH is affected by water alkalinity, which is a measure of the basic ions, mainly bicarbonates and carbonates, dissolved in the water. Alkalinity can be thought of as the "liming content" of the water, and irrigating with a high alkalinity water (above 150 ppm $CaCO_3$ of alkalinity) can cause medium-pH to increase over time.

Commercial laboratories or on-site test kits can report alkalinity in a number of different ways including ppm or mg/liter calcium carbonate ($CaCO_3$), milliequivalents (meq.) of $CaCO_3$ alkalinity, and ppm or mg/liter bicarbonate. To convert between units, 50 ppm $CaCO_3$ alkalinity = 1 meq. $CaCO_3$ alkalinity = 61 ppm or mg/liter bicarbonate.

Options for alkalinity management are:

- Alkalinity can be reduced by injecting acid into the irrigation water. The easiest way to calculate the amount of acid needed is to use acid addition calculator from Purdue University and North Carolina State University which can be downloaded from the internet at the web site www.ces.ncsu.edu/depts/hort/floriculture/software/alk.html.
- It may be feasible to change or blend water sources. Rain water collected in cisterns or ponds and water purified using reverse-osmosis contain little if any alkalinity.
- Matching the appropriate fertilizer type to balance alkalinity is the most important decision growers can make to maintain a stable pH (Table 2). A low-alkalinity water should be balanced with a basic (low ammonium) fertilizer. A high-alkalinity water can be balanced with an acidic (high ammoniacal nitrogen) fertilizer, although this is not a good approach in cool, dark weather because of the risk that plants may accumulate toxic levels of ammonium.

4. Regular testing

Basing fertilizer decisions on regular tests (every 1-2 weeks) of medium-pH, medium-EC, and the EC of the fertilizer solution solves 90% of nutritional problems by alerting growers to problem trends before plants are stressed. A soil test of pH is also an easy way to confirm a suspected medium-pH problem. Monitoring other factors (e.g. root diseases, greenhouse temperatures, pest problems, high or low medium-EC) help rule out these problems, because many factors other than medium-pH can cause problems in the crop.

To interpret results from a test of medium-pH:

- **Low pH problem:** Medium-pH is below 6.0 for a seed or zonal geranium crop, marigolds, lisianthus, or New Guinea impatiens (these are crops that tend to accumulate excess iron and manganese at low pH), or below 5.4 for most other species.
- **High pH problem:** Medium-pH is above 6.3 for a petunia, calibrachoa, diascia, nemesia, pansy, petunia, snapdragon, or vinca crop (and other species that tend to be inefficient at taking up iron at high pH), or above 6.6 for most other species.

Correcting pH Problems – Use Caution!

The following recommendations for raising or lowering medium-pH are intended for crops already under severe stress. Prevention of pH problems is better than relying on a cure, and these actions are intended for crops that would be unsaleable without some type of intervention. It is important to remember that there is some risk associated with the handling or application of any chemical in the greenhouse or nursery. It is up to you to balance the risk of applying caustic chemicals to yourself or to the crop against the potential for damage caused by high or low medium-pH. The proper handling, mixing, and storage of chemicals are the responsibility of the individual grower. When applying any chemical to a plant, the authors advise a test application on a small number of plants to check for phytotoxicity before applying to the entire crop. When plants are already stressed, it may not be possible to correct problems and produce a marketable crop, even after taking these or any other recommended actions.

5. Correcting low medium-pH

When pH falls below the optimum range, the first steps are to (a) stop acidifying water if acid is being injected, and (b) shift to a nitrate-based fertilizer (e.g. 13-2-13 or 15-5-15). Further action is needed if pH has not risen within a week and plants are becoming stressed, especially for a species in the Geranium group when pH is below 6.0, or other crops below pH 5.4.

Consider soil drenches with either flowable lime or potassium bicarbonate. Both materials are incompatible with all types of water-soluble fertilizer and other chemicals, and need to be applied by themselves as a soil drench. Other options (hydrated lime or potassium hydroxide) have specialist uses but are less reliable and predictable as a corrective liming material.

Several factors affect the choice between flowable lime versus potassium bicarbonate. Flowable lime has the more predictable and stable effect on medium-pH, without increasing medium-EC. Potassium bicarbonate is more soluble and should be used on flood floors or when applied through low-volume drippers. Both liming materials are fast-acting and show most of their effect on medium-pH within one day. Following a drench, you can reapply after five days if pH is not up to the optimum range.

To minimize phytotoxicity from flowable lime or potassium bicarbonate, apply in cool weather so the material does not dry quickly on foliage; avoid splashing of foliage during application; immediately rinse foliage with a fine spray; and apply with generous leaching to maximize the effect at low concentration.

Tips for applying flowable lime:

- Apply at 4 qts./100 gallons (10 mL/Liter = 1:100).
- An injector can be used to dilute the solution, but the lime particles can be very abrasive. Immediately clean equipment after application.
- Do not apply through drippers or on flood floors because it will clog equipment and leave residue.

Tips for applying potassium bicarbonate:

- Apply at 2 lbs./100 gals (2.4 grams/Liter).
- Can be delivered through emitters or on flood floors.
- One day after application, apply a basic fertilizer (e.g. 13-2-13) with moderate leaching to wash out salts and to reestablish nutrient balance.
- It is likely that repeat applications may be needed.

6. Correcting high medium-pH.

Several steps can be necessary when medium-pH is too high:

6A. Use a high-ammonium fertilizer combined with low alkalinity. Check with your fertilizer manufacturer to select a high-ammonium (very acidic) fertilizer (e.g. 9-45-15 or 21-7-7). The effect on medium-pH can sometimes be slow (> 1-2 weeks) especially in cool wet conditions, or with small plants growing in large containers. Repeated applications of ammonium in cool, dark conditions may also cause toxic levels of ammonium to accumulate in leaf tissue.

If you have the necessary equipment, and alkalinity is >80 ppm, acidify water to drop the irrigation water-pH to around pH 4.5 (which gives near-zero alkalinity). Continue until medium-pH is in the target range. For the appropriate acid rate for your water source, see www.ces.ncsu.edu/depts/hort/floriculture/software/alk.html.

As a guideline for the commonly-used 35% sulfuric acid ("battery acid") or other acid forms, use the following table as a guideline to drop the pH of irrigation water to 4.5 with different starting alkalinities:

Table 3. Approximate amount of acid (in fluid ounces per 100 gallons) required to neutralize alkalinity in the irrigation water, and bring pH of irrigation water down to approx. 4.5. Make sure to check the pH of the solution coming out of the hose. Be extremely careful about using irrigation water with a pH below 4.5 because of phytotoxicity on plants. If alkalinity is already below 50 ppm, acidification is unnecessary when using highly acidic fertilizers to correct high medium-pH.

	Sulfuric		Nitric		Phosphoric		Seplex Organic acid
Alk.	35%	93%	61%	67%	75%	85%	
50	1.4	0.4	0.9	0.8	1.0	0.9	1.0
100	2.8	0.7	1.9	1.7	2.1	1.7	2.0
200	5.6	1.4	3.8	3.4	4.2	3.4	4.0
300	8.4	2.1	5.7	5.1	6.2	5.1	6.0
400	11.2	2.8	7.5	6.8	8.3	6.8	8.0

Table 4 Commercially-available forms of iron

Form	% iron	Other names
Iron sulfate	20.5% Fe	Ferrous sulfate
Iron EDTA	13% Fe	Sequestrene Fe Dissolzine EFe13
Iron DTPA	10-11% Fe	Sequestrene 330 Sprint 330 Dissolzine DFe11
Iron EDDHA	6% Fe	Sequestrene 138 Sprint 138 Dissolzine QFe6

6B. Correct micronutrient deficiencies. Masking the symptoms of high pH with micronutrient applications can be very effective for keeping plants alive and healthy when grown under high medium-pH conditions. However, unless your customers continue the iron sprays or drenches, or transplant the plants soon after receiving them, quality will suffer. Always use a tissue analysis to test which nutrient is deficient. Although iron deficiency is most common, if a different nutrient (e.g. manganese) is limiting then application of iron may worsen the problem because of antagonistic effects.

Iron comes in different forms that vary in solubility at high pH. Best to worst in terms of effectiveness as a drench at high pH are: Iron-EDDHA > Iron-DTPA > Iron-EDTA > Iron sulfate (See Table 4).

The recommended application rate for an iron drench is 5 oz/100 gal of either Iron-EDDHA (provides 22.5 ppm iron), or Iron-DTPA (37.5 ppm iron). Apply solutions with generous leaching, followed immediately by washing of foliage to avoid leaf spotting. All options are low cost, at less than 0.1 cents per 4-inch-diameter pot. Iron-DTPA can be purchased from greenhouse and nursery suppliers. Ask for Iron-EDDHA from a fertilizer representative.

Foliar sprays can also be somewhat effective, especially if iron chlorosis is mild, but phytotoxicity is likely. Apply foliar sprays to a test group and wait 3 days to check for damage before applying to the entire crop. Suggested iron sprays are Iron-EDTA (60 ppm iron, equals 6.1 oz/100 gal) or Iron-DTPA at 60 ppm iron (8 oz/100 gal). Repeat applications are likely to be needed every 5 days because the iron is not transported to new leaves, and the plant can grow out of a foliar spray.

Tips for maximum effectiveness of foliar sprays:

- Include an organosilicone surfactant (e.g. Capsil™ at 13 oz/100 gal).
- Apply in early morning on cool, cloudy days for gradual drying of leaves in order to increase uptake and reduce spotting.
- Spray both sides of leaves because penetration may be better on the underside of leaves where the cuticle is thinner.

6C. Consider iron sulfate drenches in extreme cases. Iron sulfate drenches can reduce medium-pH but **phytotoxicity is very likely**. Iron sulfate provides iron (which is usually deficient in plants at high pH) in addition to causing a temporary drop in medium-pH. This material also increases EC (1.2 dS/m at 2 lb/100 gal) and adds high levels of iron (2 lb/100 gal provides 500 ppm iron) which may cause problems if pH falls below 6.0. Iron sulfate should **NEVER** be used with iron-efficient species (Geranium group) or long-term crops. The maximum recommended rate is 2 lb./100 gal because although higher rates may reduce medium pH even faster, but there is also a much greater risk of phytotoxicity.

Tips to applying iron sulfate:

- Store dark and dry. Iron sulfate oxidizes over time, and has a 6-12 month shelf life. Mix in water with a pH below 7.0 and only use if the final solution is not cloudy.
- Can stain plastic subirrigation benches or cement floors.
- Leach heavily with a complete fertilizer after one week to try to remove excess iron and restore nutrient balance.

6D. Other options. Sulfuric acid can be injected into irrigation water to reduce the drench solution pH to 1.5 to 2.0 in order to lower medium pH. The advantage over iron sulfate is that it does not add micronutrients. However, sulfuric acid is highly caustic to people and plants and therefore these high rates of acid are not commonly recommended. Aluminum sulfate should only ever be used to lower medium-pH for hydrangeas, because otherwise it is will cause nutrient imbalances. Flowable or elemental sulfur is sometimes used to lower pH in the nursery trade, but tends to cause a gradual reduction in medium-pH over time that is difficult to control (because microbial action is needed for the sulfur to be effective).

Prevention Is Better Than A Cure

As a final note, remember that medium-pH problems should never cause crop losses if you

1) Set up a sensible nutrient management program that is suited to your crop types and water source,
2) Establish a regular monitoring regime, and
3) Develop strategies that will keep pH and EC on track before you need extreme "rescue" measures.

Additional Readings

Understanding pH management of container grown crops.
By: William R. Argo and Paul R. Fisher, (Due out in August 2002)
Available through: Meister Publishing, (440) 942-2000, www.Meisternet.com

Greenhouse Grower Series on Understanding pH management.
By: William R. Argo and Paul R. Fisher
Available through: Greenhouse Grower magazine, (440) 942-2000

1) Introduction, November 2000 (vol. 13), pgs.42-52
2) Root-media and Lime, December 2000 (vol. 14), pgs. 24-30.
3) Irrigation water, January 2001 (vol. 1), pgs. 72-82.
4) Water-soluble fertilizer, February 2001 (vol. 2), pgs. 62-72.
5) Fertilizer choices, March 2001 (vol. 3), pgs. 58-66.
6) Rapidly increasing pH, April 2001 (vol. 4), pgs. 50-56.
7) Management of geraniums and marigolds, May 2001 (vol. 5), pgs. 44-54
8) Avoiding micronutrient deficiencies at high pH, July 2001 (vol. 8), pgs. 32-54
9) Using ammonium fertilizer and low alkalinity to lower pH, September 2001 (vol. 10), pgs 116-126.
10) Using acidic chemicals to lower pH, November 2001 (vol. 13), pgs. 54-62.
11) Drenching and foliar spraying iron, January 2002 (vol. 1), pgs. 50-60
12) Soil testing and nutrient monitoring, February 2002 (vol. 2), pgs. 58-68.
13) How two greenhouse operations approach plant nutrition, April 2002 (vol. 4), 48-56.

"Iron-out" A nutritional program for geraniums and other crops prone to iron and manganese toxicity at low media-pH
By: Paul R. Fisher and William R. Argo
Available through: Floriculture Industry Research and Scholarship Trust [Formerly Bedding Plants Foundation, Inc (BPFI) and Ohio Floriculture Foundation (OFF)]. (517) 333-4617
Also available online at: www.firstinfloriculture.org/2001-1_IronOut.pdf