"Iron-Out": A nutritional program for geraniums and other crops prone to iron and manganese toxicity at low media-pH

Paul R. Fisher, University of New Hampshire and William R. Argo, Blackmore Co.
Technical information provided by Roger McGaughey, Kurt Weiss Greenhouses; John Biernbaum, Michigan State Univ.; Bill McElhannon, Micro Macro International; Shannen Ferry, The Scotts Co.; and Dan Jacques, Sun Gro Horticulture

"Iron-Out" is a nutrition management program designed to prevent iron and manganese toxicity in seed and zonal geraniums, marigolds, lisianthus, and any other container-grown crop that is efficient at taking up iron and manganese.

Iron/manganese toxicity is usually a result of a combination of factors. The first is low media-pH. As media-pH decreases, iron and manganese become more soluble resulting in higher concentrations in the soil solution.

Certain plant species are very efficient at taking up the soluble iron and manganese into the plant tissue. It is typically the combination of low media-pH and production of a sensitive species that results in iron/manganese toxicity.

Once plants show toxicity symptoms of necrotic spots and marginal burn, the affected leaves do not completely heal, and the only option is to produce healthy new growth that will cover the older foliage.

The best approach is therefore to prevent iron/ manganese toxicity (and low pH) from occurring. The Iron-Out program is based on pre-season preparation, regular monitoring, and rapid response to low media-pH or toxicity symptoms.

Table of Contents

Acknowledgements

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SECTION (A) TEN STEPS TO ELIMINATE IRON/MANGANESE TOXICITY

The Iron-Out program is based on ten steps you can take to “iron-out” low-pH problems:

A.1 Train a nutrition-scout in your business

This may be the grower or another staff member. Their responsibilities will be:

1. To read this Iron-Out report, and discuss the fertilizer program for the coming season with the main grower.
2. Maintain and calibrate pH and EC meters as needed to keep reliable measurements (see instructions for your meters).
3. Measure pH, EC, and alkalinity of irrigation water and fertilizer solution every week.
4. Measure pH and EC of fresh media out of the bag, and weekly tests of media from crops out in the greenhouse.
5. Inspect plant health, including nutritional problems, but also pest and disease problems in root and top growth every week.
6. Enter this information and observations into the tables and charts provided as soon as soil is tested.
7. Communicate these results to the grower (who makes soil fertility decisions) as soon as information is tabulated.
8. Ensure that any changes in fertility management have been put into action.

Be sure that the nutrition-scout reads the instructions on how to use the meters, and is confident enough in its use to question abnormal readings. For example, if the pH-meter measures a soil sample at pH 2.0, they should know to retest the sample and or check the meter. The nutrition scout should also know enough about nutrition and plant health to help identify problems.

A.2 Train your staff to recognize the symptoms of iron/manganese toxicity

Iron/manganese toxicity generally affects older leaves first, starting as chlorotic (yellow) spots scattered around the leaf and on the leaf margin (Figure1). These chlorotic spots turn necrotic (brown and dead), and an overall chlorosis and necrosis continues to develop. Plant growth rate and leaf expansion slows (Figure 2), even though root growth may appear healthy.

In marigolds (Fig. 1C), micronutrient toxicity usually appears as a bronzing, or as speckled necrotic spots which progress into an overall chlorosis and necrosis.

A.3 Understand the conditions (low pH and high fertilizer concentration with sensitive cultivars) that lead to toxicity problems

Iron and manganese toxicity is usually caused by a combination of factors. The first is low media-pH. The solubility of both iron and manganese will increase as the media pH decreases. Plant species differ greatly in their ability to take up and accumulate iron and manganese in their tissue. Some species including geraniums and marigolds are very efficient at taking up iron from the soil solution. With standard fertilization practices, a media pH of 6.0 appears to be the threshold where iron and manganese solubility can reach a level where toxicity can occur in plants that are efficient accumulators of these two nutrients.

The media pH can be below 6.0 for a number of reasons. There can be insufficient limestone added to the media at mixing to bring the media pH above 6.0. Both the irrigation water alkalinity and the ammonical nitrogen level in the fertilizer combine to influence the overall effect that the fertilizer solution has on media pH. Irrigation water with low alkalinity (either naturally or by over acidification) used with fertilizers that contain high levels of ammonical or urea nitrogen will produce an acidic reaction in the media and may cause the media pH to decrease over time. High soluble salt levels in the media can cause a suppression in the media pH and may be an indication that high levels of micronutrients are contained in the media. Finally, plant species such as geraniums will tend to drive the media pH down over time independent of the type of fertilizer solution applied.

Any combination of these factors can cause the media pH to be below 6.0. Once the media pH has dropped below 6.0, toxicity symptoms can occur in as little as 1 to 2 weeks.

Figure 3 clearly shows that the combination of high fertilizer concentration, high media EC, and low media-pH increases the likelihood of iron/manganese toxicity problems.

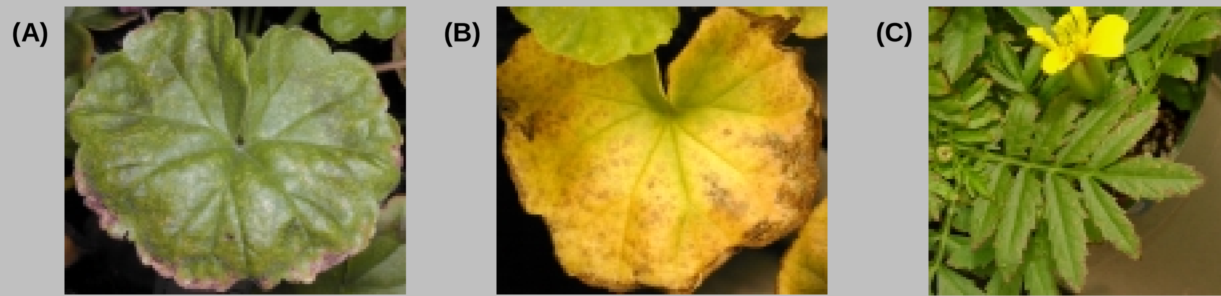


Figure 1. (A) and (B) Progression of iron/manganese toxicity in geranium foliage. (C) Iron/manganese toxicity in marigold.

Figure 2. Comparison of 'Ringo Scarlet' seed geraniums grown at media-pH 5.6 (left) and pH 4.1 (right) showing effect of micronutrient toxicity on plant size and health. Tissue from the plant on the right contained four times the level of iron and manganese compared with the plant on the left.

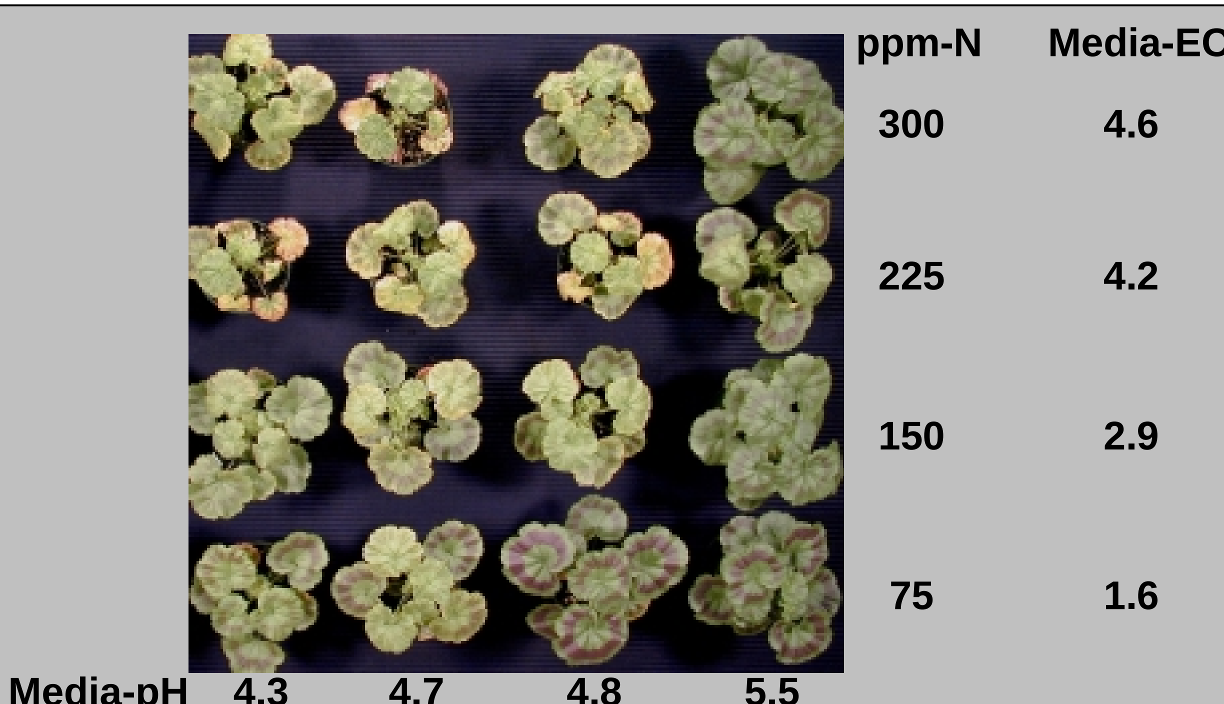


Figure 3. 'Ringo Scarlet' seed geraniums grown for three weeks at combinations of four media-pH's and four fertilizer concentrations. The chart shows the effect of low-pH and high fertilizer concentration on iron/manganese toxicity. EC is from a saturated medium extract.

Photographs by Brandon Smith, University of New Hampshire

Complete blended fertilizers contain both macronutrients (e.g. nitrogen, phosphorus and potassium) and micronutrients (e.g. iron and manganese). As the concentration of nitrogen (N) in the fertilizer solution increases, the concentration of all nutrients increases, including micronutrients like iron and manganese. For example, increasing the concentration of one brand of 20-10-20 from 100 ppm N to 200 ppm N will increase the concentration of iron from 0.5 ppm to 1.0 ppm in the applied solution.

"Peat-Lite" formulas also have higher micronutrient levels when compared with the older "General Purpose" formulas. However, the older "General Purpose" formulas also tend to be higher in ammonical and urea nitrogen (more acidic) then the newer "Peat-lite" formulas and may therefore result in a lower media-pH.

Geranium and marigold cultivars differ greatly in their susceptibility to iron and manganese toxicity. Examples of geranium cultivars where toxicity problems have been observed by soil testing laboratories include Aurora, Designer Grape, Floribunda, Melody Blue, Ringo Scarlet, and Sassy Dark Red. All of these cultivars can be successfully grown with the correct media-pH and overall nutrition, but extra care may be necessary to maintain the media pH above 6.0 and avoid iron/manganese toxicity. Other crops that are susceptible to problems caused by low media pH include marigolds, lisianthus, new guinea impatiens.

A.4 Purchase and regularly use an electroconductivity (EC) and pH meter

If you already have meters, check that they are working properly and that you have calibration fluid not more than one year old. It is best to store the unused portion of the calibration fluid in a refrigerator, but always allow it to warm up to room temperature before use. Calibrate the meters according to the manufacturer's instructions. Replace or fix meters that will not calibrate.

There are a number of good-quality meters available that have rapid 1- or 2-point calibration and replaceable sensors (so that you do not have to throw away the whole meter if the sensor fails). Some types of pH-sensors need to be stored wet or they will rapidly fail. Stay away from a meter that can not be calibrated because you never know when it will stop working properly.

One way to test the reliability of the meters is to prepare a media sample (using the 1:2, saturated media extract, or PourThru method *http://pourthruinfo.com*), and then test the same sample five times. If results vary by more than 0.2 pH units or 0.2 EC units (mS/cm or mmho/cm), that indicates a lack of precision in the meter.

Note that if you test in-house pH or EC and compare results against commercial laboratories, it is likely that results will differ. Differences between test results do not necessarily indicate an error in either measurement, but may be caused by different methods used to prepare samples. If you are confident in the way you are measuring pH and EC and in the meters that are used for the measurement, then trust your in-house tests.

A.5 Have water-quality tested regularly and use this information to select the fertilizer

Water should be tested in a commercial laboratory at least once a year (more frequently if the well is new, shallow, or if it has been an exceptionally wet or dry year). Be particularly attentive to alkalinity level because alkalinity, rather than water-pH, will have the greatest effect on media-pH over time.

Inexpensive alkalinity kits (around $1/test) are available for in-house testing from chemistry supply distributors. If testing alkalinity in-house, purchase an alkalinity test that works based on color-change in a solution, because these tests are more easily-read than test-strips.

After obtaining water quality results, use this information to decide whether to acidify your water, and also the type of fertilizer you will use.

Be cautious about using acidification with iron-accumulating crops such as geranium – it may well NOT be necessary. ONLY acidify the water if all the following are true:

1. IF high pH and lack of iron in plant tissue tends to be a problem in your greenhouse based on past years of growing geranium, marigolds, etc.
2. AND you can easily set up the appropriate injector system
3. AND you plan to test alkalinity each week through the season to ensure total alkalinity remains at 120 ppm
4. AND water alkalinity before acidification is above 120 ppm

ONLY if all these conditions are met, acidify water to 120 ppm total alkalinity. To calculate acid rates, use information from Greencare Inc. if using Seplex-L, or the guide from North Carolina State Univ. Cooperative Extension (Horticulture Information Leaflet #558, *http://floricultureinfo.com*) if using other acids.

Select the appropriate fertilizer using your experience and the table below as a guide. Many fertilizers can be used successfully for geraniums, and the fertilizers listed are examples only:

Alkalinity and fertilizer guidelines

Total alkalinity level (ppm)	Fertilizer reaction (calcium carbonate equivalency, lbs./ton)	% of total nitrogen in the Ammonium or Urea form	Example fertilizers
>150	"acidic"	40%	20-10-20
80-150	"neutral"	20-25%	17-5-17, or 20-10-20 alternated with 14-0-14, or 20-10-20 alternated with 15-0-15
<80	"basic"	10%	13-2-13

Be aware that the "acidity" or "basicity" of a fertilizer is a guide only, because your fertilizer is only one of several factors driving pH change in the media (the plant species, lime concentration and reactivity, and alkalinity, for example, all affect pH). Geraniums also tend to drop media-pH more than other species. Therefore, pH can still drop using a "basic" (i.e. nitrate-based) fertilizer. In our experience, changing to a nitrate fertilizer alone may not raise pH quickly enough in situations when pH is dropping in media.

A.6 Pre-test your media

Place your geranium-growing media into five pots. Irrigate to container capacity using either the fertilizer solution or clear irrigation water, depending on whether or not you plan to water-in plants with fertilizer. Cover loosely for a week to avoid evaporation, and place in the greenhouse.

Combine media from the bottom 2/3 of each container into one sample (the top 1/3 tends to accumulate salts), and test pH and EC in your own greenhouse. Also send in a sample to a commercial laboratory for a complete analysis.

Problem indicators from the pre-test that suggest increased chance of iron/manganese toxicity include:

(a) pH is below 6.0 using any soil test method

(b) EC (before planting) is above
- 1.2 (1:2 test),
- 2.5 (SME test), or
- 3.7 mS/cm (PourThru). For further information on Pourthru, see guidelines for geranium from North Carolina State Univ., Horticulture Information Leaftlet 590a, *http://pourthruinfo.com*).

NC State researchers note that PourThru results can be more variable than SME, depending on technique.
Macro Micro International also notes that EC ranges may be 1 unit higher than shown above for media that contain a high percentage of pine bark.

(c) Iron or manganese is above 3 ppm.

If pH is low, be sure to check media-pH one week after planting, and plan to apply flowable lime or potassium bicarbonate immediately if pH remains below 6.0 (see guidelines in Section B below).

If you consistently have problems with low media-pH out of the bag, discuss changing to the liming rates in your medium with your media-supplier or reformulate your recipe if mixing your own media.

If EC is high, beware of overfertilizing. Try to find out what is causing the high media EC. If it is made up of fertilizer salts (for example, nitrogen), then irrigate with clear water until EC drops to below the acceptable maximum levels in (b) above. If the high media EC is from unusable ions such as sodium, then leach heavily with clear water and reapply a complete fertilizer to reestablish adequate nutrition.

If iron is high, be especially vigilant that pH does not drop below 6.0 during production.

A.7 Stock up on pH-adjusting chemicals and basic fertilizers

Ensure that you have flowable lime and/or potassium bicarbonate in your fertilizer store-room before the season begins. The table below can be used as a guide to calculate how much lime is required should you need to correct a low-pH problem (see section (B) for more details).

Volume of potassium bicarbonate and flowable lime needed for different container sizes.

	Volume applied/ container		Containers/ lb. of $KHCO_3$	Containers/ gallon of flowable lime
806 flat	2 qt	1.9 Liters	370	200
606 flat	2.3 qt	2.2 Liters	330	175
4-inch	4 oz	0.12 Liters	5970	3150
6-inch	7 oz	0.21 Liters	3410	1800

Regardless of your water quality, ensure that you have a “basic” fertilizer in stock (e.g. 13-2-13) that you can switch to immediately if media-pH drops.

A.8 Check the fertilizer concentration by testing the nutrient solution EC

The EC of the fertilizer solution (out of the hose, or in the subirrigation tank) equals the EC of the irrigation water plus the EC of the fertilizer.

Check that the EC reading of the fertilizer solution is at the level you expect for the given type and concentration of fertilizer.

The EC per 100 ppm of each individual fertilizer is different, and can be obtained from your supplier. Examples for 15-0-15 and 20-10-20 are shown in the table below. For example, 200 ppm of 15-0-15 will add an EC of 1.48 mS/cm to your fertigation solution. Note that units of mS/cm are the same as mmho/cm.

Use the examples below to check that you know how to calculate EC for your fertilizer solution.

Examples of Electroconductivity (EC) calculations for fertilizer solutions

Example 1: Calculate the EC of the fertilizer solution of 20-10-20 at 200 ppm (assuming the EC of clear irrigation water is 0.6 mS/cm)

Water EC	+	Fertilizer EC (@200 ppm N)	=	Solution EC
0.6 mS/cm	+	1.3 mS/cm (from the EC chart below)	=	1.9 mS/cm

Example 2: Calculate the fertilizer concentration when the nutrient solution of 20-10-20 has an EC of 1.9 mS/cm (assuming the EC of clear irrigation water is 0.6 mS/cm)

Solution EC	-	Water EC (0.6 mS/cm)	=	Fertilizer EC
1.9 mS/cm	-	0.6 mS/cm	=	1.3 mS/cm

An EC of 1.3 mS/cm corresponds to 200 ppm N (from the EC chart below).

Example EC Chart for commercial fertilizers (for complete charts, contact your fertilizer manufacturer).

	ppm N				
	50	**100**	**150**	**200**	**300**
15-0-15	0.37	0.74	1.11	1.48	2.22
20-10-20	0.33	0.65	0.98	1.30	1.95

Use your experience when deciding on fertilizer concentration. Suggested initial concentrations for beginning the crop are 100-150 ppm N if fertilizing with each irrigation. This concentration is likely to be too low if there is no nutrient charge in the medium at the start, or greater than 20% leaching occurs with each irrigation. Geraniums may require higher nutrient concentrations as growth rate increases during the middle of the crop, and less nutrients when plants are very small or near flowering.

If you do not fertilize with every watering, increase the concentration from your injector so that averaged across all irrigations you will provide the rates above.

Note that these are initial concentrations ONLY: During the crop, you may have to adjust the fertilizer concentration up or down based on media-EC and plant vigor. Depending on your media, climate and watering practices, these fertilizer concentrations may not be optimal if continued throughout the season.

A.9 Each week from planting onward, test pH and EC

Test both your media and fertilizer solution and inspect plant health (foliage and roots).

Enter information into the table and chart provided below. For the chart, add maximum and minimum lines for EC (similar to the lines already shown for pH), depending on your soil testing method. See EC guidelines in Section (C) below.

Interpret and act quickly on test results using the guidelines in Sections (B) and (C), and remember that "reading" the plant in terms of overall greenness of the foliage, growth rate, and chlorosis are key indicators of plant health that are as important as any laboratory test.

A.10 Take complete analyses of media and plant tissue

Take samples ten days after planting (and every 4 weeks afterwards for longer-term crops). Prepare soil samples by taking media from at least 1-inch below the soil surface (the top of the container tends to have a misleadingly high salt level), and combine small samples from 10 pots randomly scattered through the bench. Tissue samples should include fully expanded leaves (remove the very youngest and oldest leaves). It is best to wash leaves in distilled water and dry before sending, because dried fertilizer splashed onto the foliage will result in falsely-high nutrient analyses. Send soil and tissue samples to a commercial laboratory.

If any of the following results are found in a media pre-test, some action is needed:

a. Total iron or manganese concentration in media or tissue are above the laboratory's recommended levels (same management response is needed as for the low-pH guidelines in Section (B)).
b. Media-pH is below 6.0 (see the low-pH guidelines in Section (B)).
c. Media-EC is above recommended levels (see the EC guidelines in Section (C)).
d. There is an imbalance in other nutrients (consult your Laboratory, Cooperative Extension, or Fertilizer representative)

SECTION (B) GUIDELINES FOR INTERPRETING AND CORRECTING MEDIA-pH

B.1 Aim to keep pH in the range 6.0 to 6.6. Take these actions based on weekly pH-tests:

pH 6.7 or above:

Fertilize with an acidic fertilizer (30-50% of nitrogen in the ammonium form, e.g. 20-10-20) in order to reduce pH. Acidify water to below 120 ppm total alkalinity if this is practical for your operation. If plants appear chlorotic, or pH is not below 6.7 within two weeks, send tissue and soil samples to an analytical lab – iron deficiency may be a problem.

ALWAYS try to correct iron deficiency in iron-accumulating crops (geraniums, marigolds) by first manipulating pH with an ammonium-based fertilizer, rather than spraying iron chelate. Simply increasing fertilizer concentration may green up foliage, but check first that media-EC is not already high.

ONLY apply iron chelate (for a 20 ppm Fe spray, use 2 oz of a 13% FeEDTA/100 gals. as a foliar spray and repeat if necessary) if iron-deficiency symptoms (interveinal chlorosis with dark green veins in younger leaves) are evident and a tissue analysis confirms an iron deficiency.

Chlorotic tissue is not always caused by iron deficiency. Several other nutritional deficiencies will also appear as chlorosis in the new growth. The only way to know for sure what is causing the problem is to use tissue analysis.

pH 6.0 to 6.6:

Optimum range and no change is required. Note that geraniums occasionally show iron deficiency in this pH range, and you should make decisions based on plant health – if plants appear chlorotic see notes under (a) above for tissue analysis and also check EC.

IF pH has dropped by 0.5 points or more in the last week (i.e. since the previous test) AND pH is

6.2 or below, then change to a basic fertilizer regardless of alkalinity and consider reducing acidification of irrigation water.

pH below 6.0:

If acidifying water, reduce or stop acidification. Apply flowable lime or potassium bicarbonate immediately (see tips for applications below) and check media-pH again after 3 days. Reapply flowable lime or potassium bicarbonate if pH remains below 6.0 after 3 days. Change to a basic fertilizer (e.g. 13-2-13) at 150 ppm N or a lower fertilizer rate, regardless of alkalinity.

B.2 Research on raising media-pH

Industry sources usually recommend a switch to a nitrate-based fertilizer (e.g. 13-2-13) in order to correct low media-pH. This approach, combined with stopping acidification of the irrigation water, helps to avoid a further drop in media-pH.

As a rapid corrective action, however, when pH is already low and crops face iron/manganese toxicity, it is also necessary to either apply flowable lime or potassium bicarbonate.

Research at the University of New Hampshire (UNH) combined with commercial experience has extensively evaluated flowable lime (Limestone-F™) and potassium bicarbonate ($KHCO_3$) for quickly raising media-pH on bedding plant crops after planting. Both flowable lime and potassium bicarbonate are highly effective, and each have benefits for certain situations.

Increasing concentration of the basic chemical increases the effect on media-pH (Figure 4). The flowable lime ("Flow Lime" in Fig. 4) and potassium bicarbonate ("pot bicarb" in Fig. 4) were the only chemicals tested that consistently raised media-pH by up to 1 point at recommended rates of 4 qt./100 gal. flowable lime or 2 lb./100 gal. potassium bicarbonate.

The reason that only 2 lb./100 gal is recommended for potassium bicarbonate is that phytotoxicity to roots or foliage can occur at higher concentrations, particularly if the solution is not immediately rinsed off foliage. No phytotoxicity has been observed with flowable lime, but this material leaves more white residue as concentration increases, and at above 4 qt./100 gal. it is also hard to keep in a well-mixed solution.

We have found a similar pH-response from a single 2X application rate or two applications of a 1X rate one week apart for these two chemicals. Therefore, two applications of 2 qt./100 gal. of flowable lime has a similar effect to a single drench with 4 qt./100 gal.

We also evaluated potassium hydroxide ("pot hydroxide" in Fig. 4), which should only be used as a repeat application under close guidance by a fertilizer consultant. Potassium hydroxide is highly caustic to people and plants, and care must be taken in handling this material.

A supernatant of calcium hydroxide, the "hydrated lime" treatment in Figure 4, is sometimes recommended for correcting low media-pH. We do not recommend this approach because UNH and other researchers have reported that pH-effects of the hydrated lime solution are inconsistent between trials.

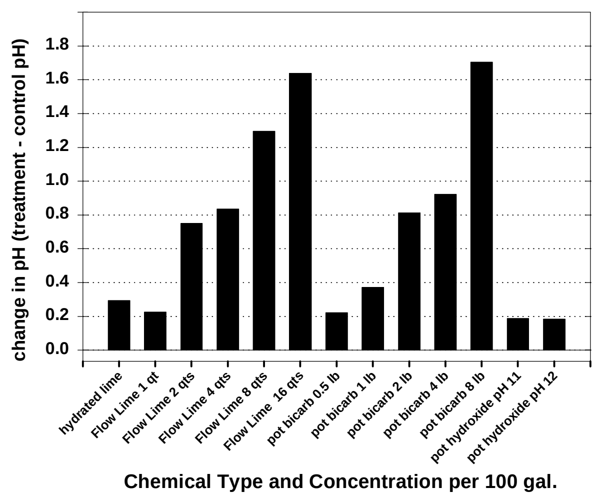


Figure 4. Effect of chemical type and concentration on increasing media-pH.

Both potassium hydroxide and flowable lime have a rapid effect on media-pH. Figure 5 shows the increase in media-pH over time following a single application of flowable lime or potassium bicarbonate to a peat/perlite medium. Potassium bicarbonate raised media-pH by 1.5 units within 24 hours. Most of the effect of flowable lime occurred within one day, but the full effect was not achieved until a week later. We have repeatedly found that flowable lime tends to maintain a stable high pH for longer than potassium bicarbonate.

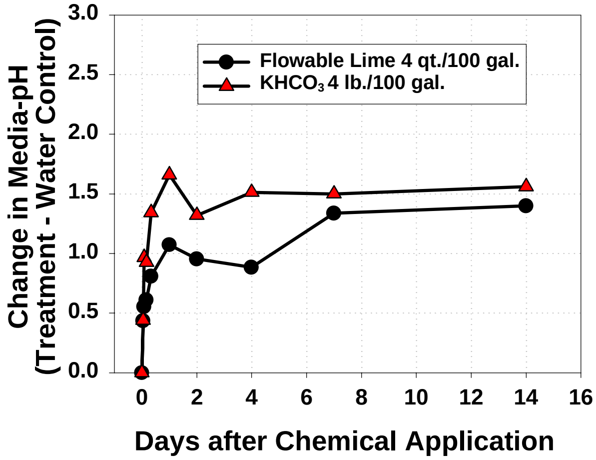


Figure 5. Effect of flowable lime and potassium bicarbonate on media-pH over time.

EC can increase somewhat following an application of potassium bicarbonate (Figure 6). In addition, potassium bicarbonate at 2 lb./100 gal. provides 933 ppm potassium. For this reason, if applying potassium bicarbonate we recommend leaching the media heavily with a basic fertilizer solution that contains calcium and magnesium (e.g. 13-2-13 or 14-0-14) one day after application in order to remove the high levels of potassium and to restore the nutrient balance.

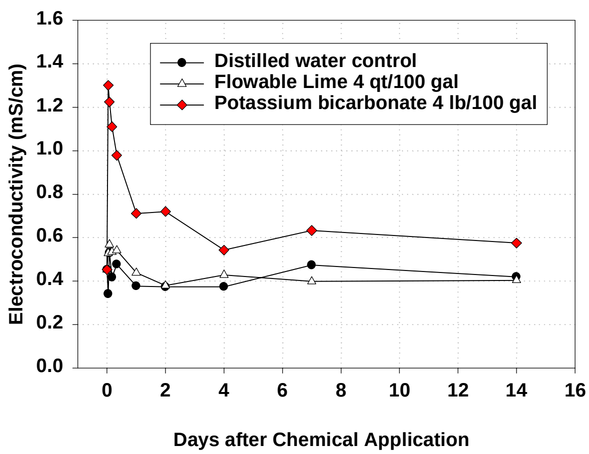


Figure 6. Effect of flowable lime and potassium bicarbonate on media-EC over time.

Application volume is important – chemicals should be applied with generous leaching to have the maximum effect. The horizontal axis in Figure 7 shows the number of quarts of base applied to a flat of 36 x 606 bedding plants. The vertical axis shows how much the media-pH changed as a result of the application. Only 2 qt. were required to saturate the media at the time of application, so volumes above 2 qt. resulted in leaching.

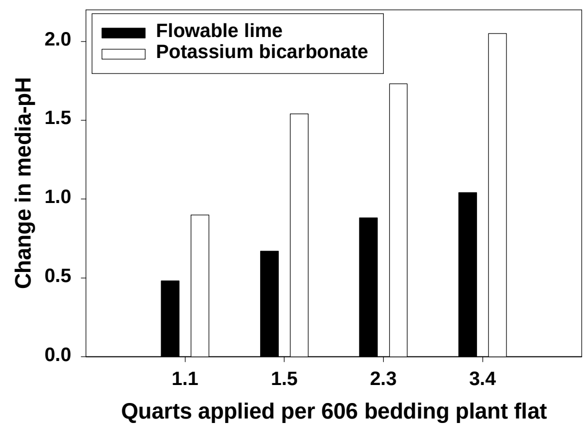


Figure 7. Effect of application volume on the pH-response from flowable lime and potassium bicarbonate. (1 quart = 0.95 liters)

The medium tested in Figures 4 to 7 was a 70% peat/30% perlite medium, with hydrated lime as the lime source. Response to basic chemicals will vary depending on media-type (Figure 8). In the experiment shown in Figure 8, basic chemicals were applied to six commercial media and the UNH peat/perlite research medium at 90 mL (3 fl.oz.) per 171 mL container.

The six commercial media differed in their response to the chemicals, but tended to be more buffered to pH change than the peat/perlite research medium. pH response to flowable lime tended to be less variable than the response of media to potassium bicarbonate.

Both flowable lime and potassium bicarbonate are inexpensive (see following tables) compared with the cost of crop losses caused by iron/manganese toxicity. Flowable lime (2000 prices) costs around $11.30/gal, and potassium bicarbonate costs $1.60/lb.

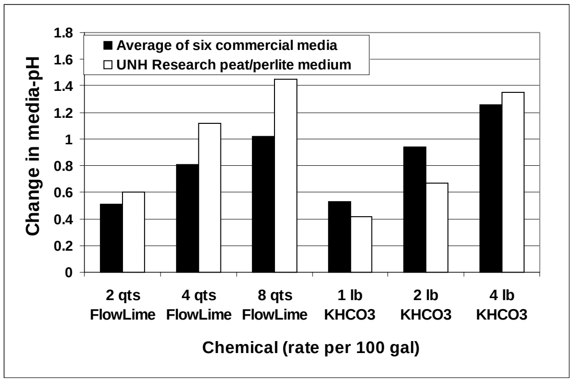


Figure 8. Comparison between commercial and research media in their pH-response to applications of flowable lime and potassium bicarbonate.

Cost of flowable lime applications

	Volume applied/ container		Containers/ gallon of lime	$/ Container
806 flat	2 qt	1.9 Liters	200	$0.057
606 flat	2.3 qt	2.2 Liters	175	$0.065
4-inch	4 oz	0.12 Liters	3150	$0.004
6-inch	7 oz	0.21 Liters	1800	$0.006

Cost of potassium bicarbonate applications

	Volume applied/ container		Containers/ lb. of $KHCO_3$	$/ Container
806 flat	2 qt	1.9 Liters	370	$0.016
606 flat	2.3 qt	2.2 Liters	330	$0.018
4-inch	4 oz	0.12 Liters	5970	$0.001
6-inch	7 oz	0.21 Liters	3410	$0.002

B.3 Choosing between flowable lime and potassium bicarbonate

The main criterion for choosing between potassium bicarbonate and flowable lime is availability and ease of application. Potassium bicarbonate is available from fertilizer or industrial chemical suppliers can be applied to flood floors, through low-volume drippers, and into hard-to-reach corners. In other situations, use flowable lime, which is available through most greenhouse/nursery suppliers. Flowable lime is also a better choice if your media already has a high EC, because potassium bicarbonate will increase salt level.

B.4 Tips for applying flowable lime and potassium bicarbonate

- Do not apply to completely dry soil – media should rewet and absorb the chemical solution easily.
- Apply a generous volume (sufficient for at least 30% leaching. This equals approx. 2 qt./806 flat, 2.3 qt./606 flat, 4 fl.oz./4-inch-diameter pot, and 7 fl.oz./6-inch pot.
- Apply in the cool part of the day so that lime does not dry quickly on foliage and can be easily washed off.
- Immediately rinse foliage before chemical dries using clear water in a back-pack sprayer or a breaker with fine spray, to eliminate residue.

Flowable lime

- If applying through an injector, dilute solution in stock tank to at least one-half strength. We recommend using a simple, cheap proportioner (e.g. Hozon) that is easy to clean. Other proportioners should be used at a low dilution rate, but be aware that immediate cleaning is essential and the lime particles can damage rubber seals.
- To get a 4 qt./100 gal. solution,
  - If using a 1:15 proportioner, such as a Hozon, mix the stock solution using 15 parts flowable lime to 85 parts water.
  - If using a 1:50 proportioner, mix the stock solution using1 part flowable lime to 1 part water.
- Halve the strengths above for 2 qt./100gal.
- Rinse equipment immediately after application.
- Keep stock tank agitated (one person stirring continuously or place circulating pump into the stock tank). If using a circulating pump, check that the model does not have seals that will be in contact with the abrasive solution.
- Apply directly to soil with a hose and breaker rather than through dripper lines.

Potassium bicarbonate

- Apply at 2 lb./100 gal.
- Can be delivered through drip-emitters or on flood floors.
- One day after application, apply a basic fertilizer (e.g. 13-2-13) with moderate to high leaching to wash out salts and to reestablish nutrient balance.

SECTION (C) GUIDELINES FOR INTERPRETING EC RESULTS

- Do not overfertilize – keep media-EC in the moderate range. It is possible to grow an excellent crop with EC's below the recommended rates below, if a low level of fertilizer is applied regularly. High media-EC, however, is more likely to result in salt damage and toxicity problems.

- It is essential to visually inspect plants, and do not over-react based on EC results if the plants appear healthy and vigorous.

- Geraniums may need more fertilizer during the middle part of the crop compared with the establishment and flowering phases of production. A high EC is especially problematic during the early establishment stage (salt burn to tender roots) and late flowering stage (overfertilization for finished plants).

- Suggested ranges for geranium:
  - 1:2 test = 0.4 to 1.2;
  - saturated media extract = 1.0 to 2.5
  - PourThru = 2.2 to 3.3, but with a target EC approximately 1 mS/cm lower during the first and last two weeks of the crop (based on geranium recommendation from North Carolina State Univ. Horticulture Information Leaflet 590A, *http://pourthruinfo.com*).
  - Note that different units are sometimes shown on EC meters, and 1 mS/cm = 1 mmho/cm = 1 dS/m = 1000 µS/cm.

- Before making any changes in fertilizer strength, be sure to check the injector is calibrated correctly (see section A.8 above).
- If media-EC is low, then check plant health. If growth is chlorotic or stunted and EC is low, then increase fertilizer concentration (for example by 50 ppm).
- If EC is high, then reduce fertilizer concentration (for example by 50 ppm), or irrigate with clear water until EC returns to the accepted range.
- High media EC can sometimes be caused by specific ions not used by the plant (i.e. sodium) or not needed by the plant at such high levels (i.e. potassium after the application of potassium bicarbonate). In these cases, apply a basic fertilizer (e.g. 13-2-13) with moderate to high leaching to wash out salts and to reestablish nutrient balance.
- High media-EC can sometimes be caused by an error in sampling - Remember that soil taken from the top 1/3 of the container is likely to have a higher EC than the rest of the root zone. Be sure that you only sample from the bottom 2/3 of the pot in order to test the correct EC.
- Even if EC is within the recommended range, the advantage of weekly soil tests is that you can be aware of trends of rising or falling EC over time that may lead to future problems.

For more information, contact Paul Fisher, Dept. of Plant Biology, University of New Hampshire, Durham, NH 03824, USA. Paul.Fisher@unh.edu
Tel. (603) 862 4525, Fax (603) 862 4757

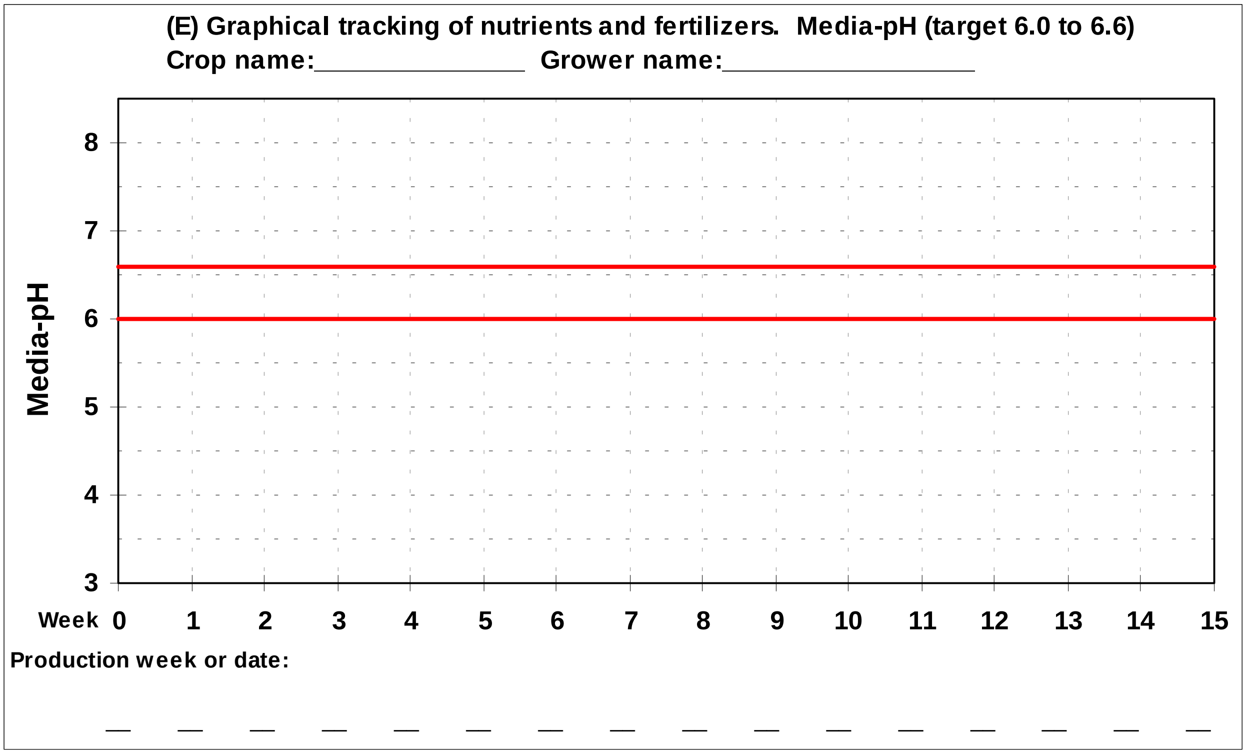
As of Jan 1, 2008 contact:
Brian A. Krug
University of New Hampshire
Cooperative Extension
Durham, NH 03824, USA
Brian.krug@unh.edu
Tel. (603) 862-0155
Fax. (603) 862-2717

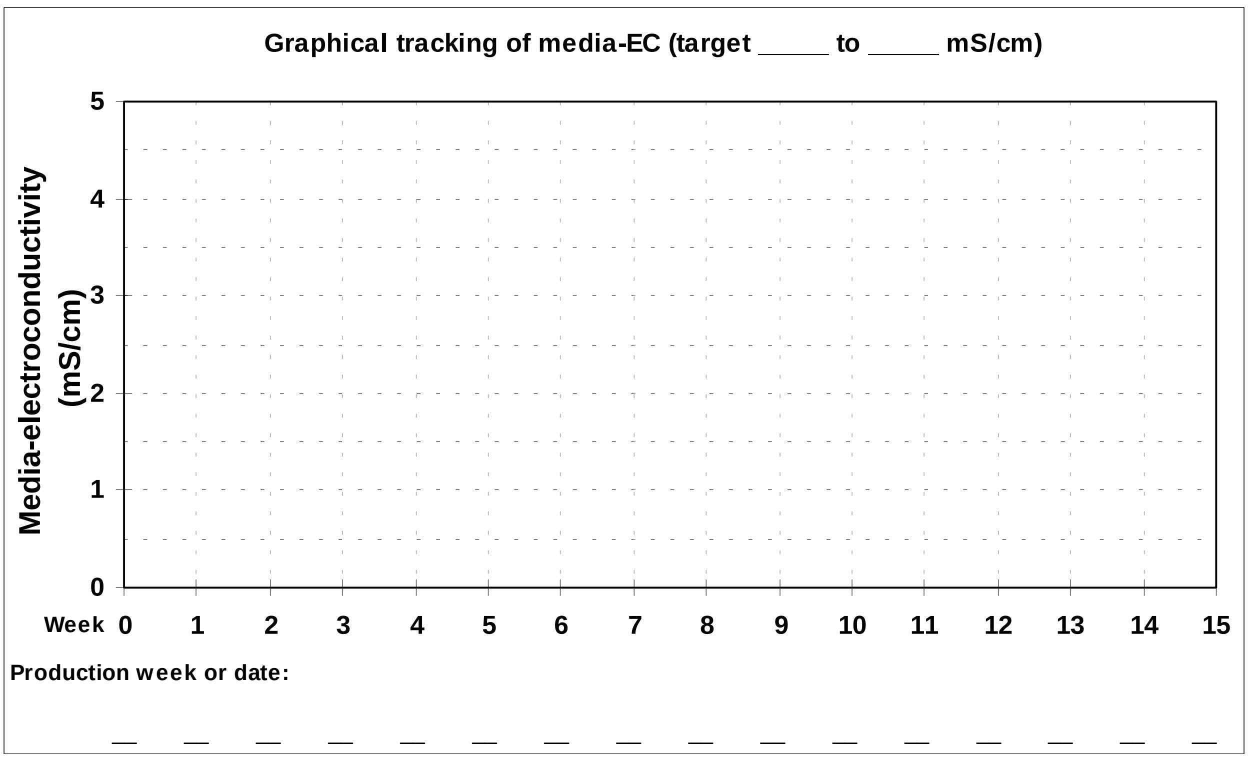
SECTION (D) RECORD TABLE FOR IRON-OUT PROGRAM

Crop Name:______________________________ Grower Name:_________________________________

Production Week/ date	media-pH	media-EC (mS/cm)	fertigation-pH	Measured fertigation-EC (mS/cm)	Clear-water alkalinity (ppm)	Other observations on plant health	Changes in fertility management, notes

SECTION (E) CHART FOR GRAPHICALLY TRACKING NUTRIENT LEVELS





Enter target lines for EC into the bottom chart. Suggested guidelines for geranium are

- 0.4 to 1.2 mS/cm for 1:2 soil test
- 1.2 to 2.5 mS/cm for saturated media extract (SME)
- 2.2 to 3.3 for PourThru (based on North Carolina State University Horticulture Information Leaflet #590a). NCSU recommends a lower EC range during the establishment (1.3 to 2.0 mS/cm) and flowering (1.1 to 2.1 mS/cm) stages.