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Five Factors Controlling Substrate pH

Monitoring and controlling substrate pH will prevent the majority of nutritional problems encountered during crop production. Avoiding these problems will increase crop quality and your profits.

by Matt Taylor *and* Paul Nelson

Understanding pH and the five primary factors controlling pH — plant system, substrate, limestone properties, water alkalinity and fertilizer — are an integral part of developing a pH-management strategy for your operation. If you recall high school chemistry, you will remember that the definition of pH is the negative log of the hydrogen (H^+) ion concentration, and the range is 0 to 14.0. The negative component of the definition indicates that as the value of pH decreases, the concentration of H^+ (acidity) increases. Neutral pH is 7.0. Values below this number are acidic; values above this number are basic. The log component indicates that as the value of pH decreases by one unit, the concentration of H^+ increases exponentially by a factor of 10, rather than linearly (opposite).

In this article, we will describe each of the five major factors that control substrate pH.

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Iron deficiency in slipper flower is caused by high pH expressed as chlorosis of young growth.

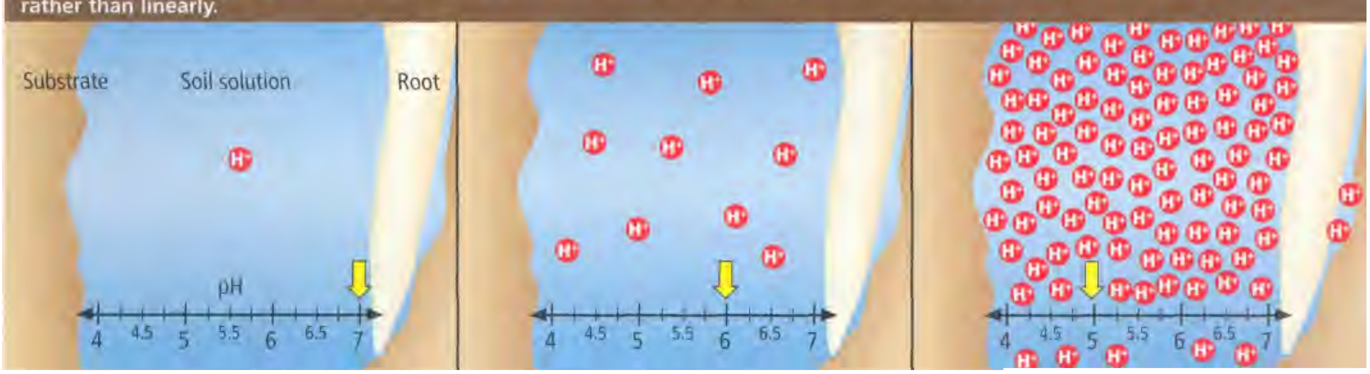
Plant system. Plants seldom exist alone. Microorganisms typically live on and around roots, benefiting from root sugars, organic acids and other compounds excreted from the roots. The plant roots and associated microorganisms are continually releasing carbon dioxide (CO_2) as a byproduct of respiration. CO_2 combines with water (H_2O) in the soil solution to form carbonic acid (Reaction 1: $CO_2 + H_2O$ — H_2CO_3 [carbonic acid]). Some of the H_2CO_3 disassociates to yield H+, which lowers the pH (Reaction 2: H_2CO_3 — H+ (acid) + HCO3 [bicarbonate]).

Because the plant system is continually acidifying the substrate, a compensating force must be present in our production system to maintain the substrate pH at the initial target level. This force can be a component of the root substrate, such as compost; limestone, which continually dissolves throughout crop production time; alkalinity in the irrigation water; or a basic (alkaline) fertilizer. The remaining four factors that impact substrate pH will be discussed in this order.

Substrate. The amount of limestone required when formulating a root substrate depends in great part on the components in the mix. Sphagnum peat moss and aged pine bark require large amounts of limestone, often ranging from 5 to 10 pounds per cubic yard of substrate, while coir coconut fiber can require only 0 to 5 pounds. The lime requirement has a lot to do with native pH, which is generally 3.0 to 4.0, 4.0 to 5.0 and 4.9 to 6.8 for peat moss, pine bark and coir, respectively.

Lime requirement is highly dependent on the buffer system of the substrate components. Peat, bark, compost, coir and calcined clay have negative charges along their surfaces that attract and hold positively charged ions, such as H^+, ammo-

When the value of pH decreases by one unit, the concentration of H^+ (hydrogen) increases exponentially (factor of 10), rather than linearly.



Micronutrient toxicity in geranium is the result of low pH.

nium (NH_4), potassium, calcium (Ca^{++}) magnesium (Mg) and sodium. The negative sites are always occupied by positive ions. The sketch of unlimed peat moss (below) shows the negative charges mainly balanced by acidic H^+ ions because the sphagnum moss that constitutes this peat grew in an acid bog where there was plenty of H^+, but few bases, such as Ca or NH_4^+

The coir fiber came from coconut trees that grew in nutrient-rich soil, which allowed them to pick up the basic ions along with a modest amount of acidic H^{++} ions (below). In a substrate system, positive ions are located in great quantity on the negative surfaces of components, such as the exchange sites, and in very small numbers in the soil solution. The number of ions that can reside in the soil solution is determined by the number on the exchange sites. A pH meter measures the concentration of H ions in the soil solution, not on the exchange sites.

To raise the pH of peat moss solution, it is necessary to reduce the number of H ions in the solution. This can only be done if many of the H ions on the exchange sites are replaced with nonacidic ions, such as Ca++ and Mg . This is accomplished with limestone. Limestone dissolves in the soil solution to yield Ca and carbonate ($CO_3^=$) ions. Ca ions move to the exchange sites where they knock off H+ ions. The H ions are attracted to the negative $CO_3^=$ ions. Each $CO_3^=$ ion reacts with two H ions to ultimately form CO_2 and H_20. In the end, fewer H ions on the exchange sites dictate fewer H ions in the soil solution, thus a higher pH. Components, such as coir, hardwood bark and compost, with fewer H ions on their exchange sites require less or no limestone to purge excess H ions.

Limestone properties. Limestone is calcium carbonate ($CaCO_3$) or a mixture of $CaCO_3$ and magnesium carbonate ($MgCO_3$). As seen on page 40, limestone dissolves in the soil solution to yield CO_3^- and Ca or Mg++ ions. The Ca++ or Mg++

Peat has negative charges along its surface that attract and hold positively charged ions. The negative charges are balanced by acidic H^+ (hydrogen) ions because this sphagnum peat moss grew in an acid bog where there was plenty of H^+, but few bases, such as Ca^{++} (calcium) or NH_4^+ (ammonium).

The coir fiber came from coconut trees that grew in nutrient-rich soil, which allowed them to pick up basic ions, such as NH_4^+ (ammonium), K^+ (potassium), Ca^{++} (calcium), Mg^{++} (magnesium) and Na^+ (sodium), along with a modest amount of acidic H^+ (hydrogen) ions.

Bronzing due to iron toxicity is shown in marigold at low pH.

ions displace H+ ions off the exchange sites out into the soil solution where they are neutralized by the CO_3^- ions.

Reactions involved in this neutralization are as follows:

- Reaction 1: H+ + CO_3^- — HCO, (first H+ neutralized)
- Reaction 2: H++ HCO3 – H_2CO_3 (second H+ neutralized)
- Reaction 3: H_2CO_3 H_20 + CO_2 (carbon dioxide)

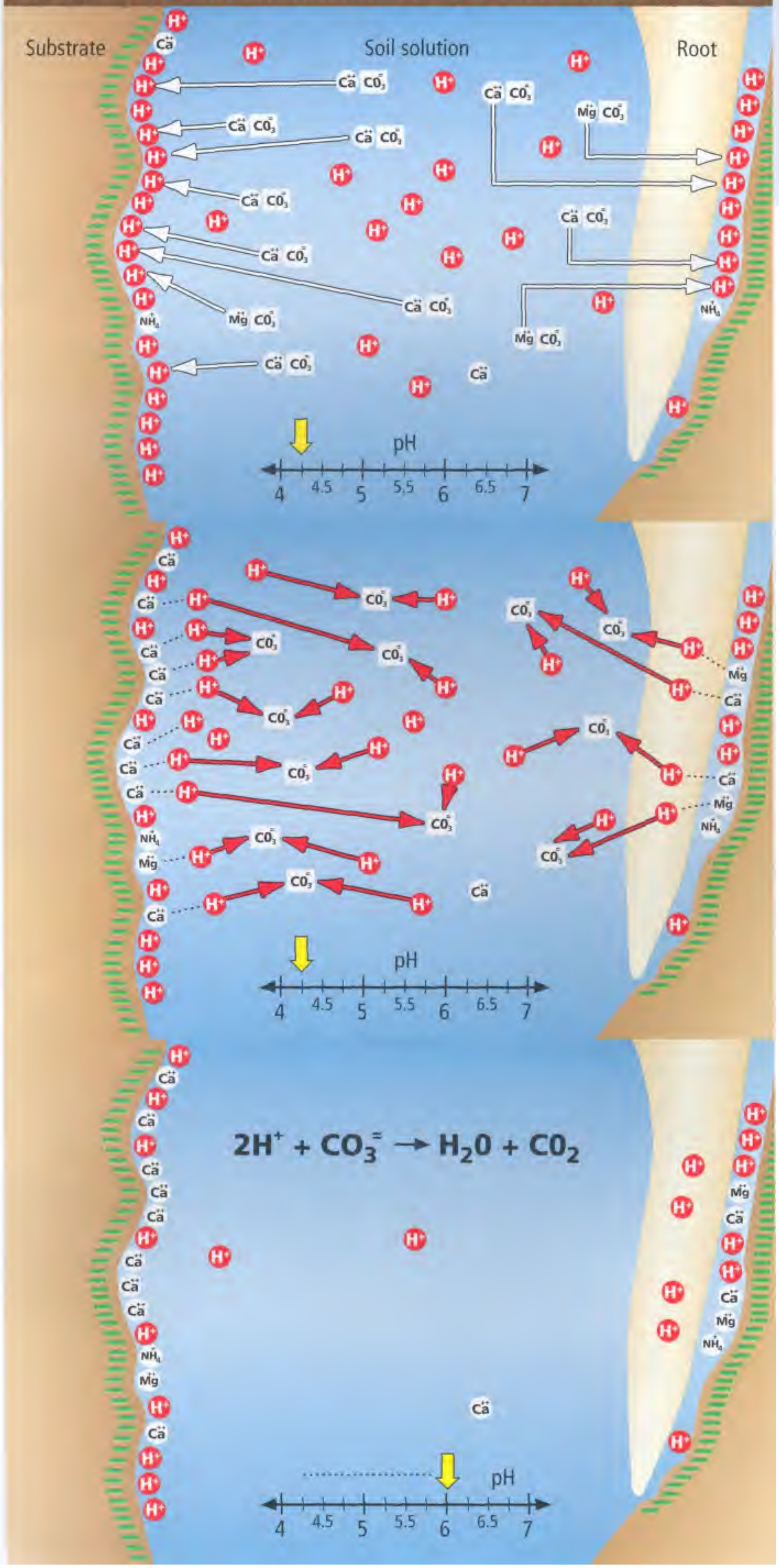
Not all of the agricultural limestone we use in root substrates dissolves during the few days after application. The limestone that does dissolve quickly is called immediate limestone, while the limestone that does not dissolve until later is residual limestone. It is desirable to have some immediate limestone to initially adjust the substrate to the target pH level and some residual limestone to counteract acidity continually produced by the plant system throughout its production cycle. Ideally, the residual limestone should dissolve during each week that the crop is growing, not just during the first three or four weeks after planting, or perhaps only during the eighth and later weeks.

Unfortunately, limestone labels do not tell us what portion is immediate and what portion is residual. If the label did indicate the proportions, it still would not indicate during what periods of time the residual fraction would dissolve. Because of this lack of information, a grower is obligated to continually monitor substrate pH and take corrective action as dictated.

A recent study by former North Carolina State University graduate student Janet Rippy and Paul Nelson has given additional insight into factors governing the residual nature of limestone. The major factors controlling the dissolution rate of limestone include:

- particle diameter — the greater the di-

Limestone dissolves in the soil solution to yield $CO_3^{=}$ (carbonate) and Ca^{++} (calcium) or Mg^{++} (magnesium) ions. The Ca^{++} or Mg^{++} ions displace H^+ (hydrogen) ions off the exchange sites out into the soil solution where they are neutralized by the $CO_3^{=}$ ions.



Acceptable range for alkalinity

Alkalinity range*	Container size
50 to 75 ppm	Plugs
80 to 120 ppm	Flats and small pots
100 to 140 ppm	4- to 5-inch pots
120 to 180 ppm	6-inch or larger pots

*ppm (parts per million) calcium carbonate equivalent
Conversions: ppm/50 = meq (1 milliequivalent) alkalinity; ppm/61 = meq bicarbonate

ameter, the lower the surface area per gram of limestone, thus the slower it dissolves;

- surface area — the more irregular the surface of the particles, the larger the surface area and the faster it dissolves;
- porosity — the presence of pores increases surface area and speed of dissolution; and

'proportion of Mg ++ to Ca ++ — the more Mg++, the slower it dissolves, and the harder the particle, the slower it dissolves.

We are currently working on this topic with hopes of bringing better control to the residual property of limestone.

Water alkalinity. Alkalinity in water is mainly HCO3 . One HCO3 ion added to the soil solution with irrigation water will neutralize one H+ ion. It is in reaction No. 2 (left) that limestone neutralizes H+. Thus, the addition of HCO_3 is equal to the addition of limestone. Water can range from having no HCO3 to levels that require continuous injection of acid into the irrigation water. Simple, do-it-yourself test kits for alkalinity can be purchased for approximately $60, bringing the price per test to approximately 50 cents. Although many water sources hold a constant alkalinity level throughout the year, there are cases where the level varies considerably. Generally, it rises during dry periods. This again illustrates the need for continual pH testing.

It is desirable to have some alkalinity in water to counteract plant acidity. The desirable level of alkalinity depends on the plant and container size, as seen in the table above. As little as 50 to 75 parts per million (ppm) of $CaCO_3$-equivalent alkalinity is recommended for plug crops, while 120 to 180 ppm of $CaCO_3$-equivalent alkalinity works well for crops in 6-inch pots, such as poinsettia.

When water alkalinity exceeds the recommended levels, one can use less limestone in the substrate and/or acidic fertilizers. If this fails to prevent substrate pH from rising to an adverse level, then acid should be injected into the irrigation water. Amounts of various mineral acids

Lowering water alkalinity

Amount of acid required to lower water alkalinity 50 ppm (parts per million; 1 milliequivalent) and nutrients supplied

Acid	Fluid ounces (fl oz) /1,000 gallons (gal)	Nutrients supplied with 1 fl oz/1,000 gal
Nitric acid (67 percent)	6.8	1.64 ppm NO_3-N
Phosphoric acid (75 percent)	8.3	6.60 ppm P_2O_5
Sulfuric acid (96 percent)	4.0	3.10 ppm SO_4-S
Sulfuric acid (35 percent)	11.0	1.14 ppm SO_4-S

Key: NO_3-N (nitrate-nitrogen), P_2O_5 (phosphorus pentoxide), SO_4-S (sulfate-sulfur)

used to lower the alkalinity level by 50 ppm (1 milliequivalent [meq]), as well as concentrations of nutrients contributed by these acids, are given in the table above.

An acid-injection calculator developed by North Carolina State University, Raleigh, and Purdue University, West Lafayette, IN, can work out acid amounts to achieve any desired endpoint pH or alkalinity level. The calculator can be accessed online at www.ces.ncsu.edu/depts/hort/floriculture/software/alk.html. In a fertilizer program, it is important to compensate for any essential nutrients supplied by the acid, such as nitrate (NO) or phosphate, to avoid excess application.

Fertilizer. Fertilizer can be used as a tool in your pH-management strategy. The fertilizer composition can cause substrate pH to decrease or increase, and the direction of the shift is controlled primarily by the form of nitrogen. Nitrogen is the most important pH-controlling ion because it is the only element required by plants that can be supplied as a cation (NH_4') or an anion (NO_3), and accounts for more than half of the nutrient ions taken up by the plant.

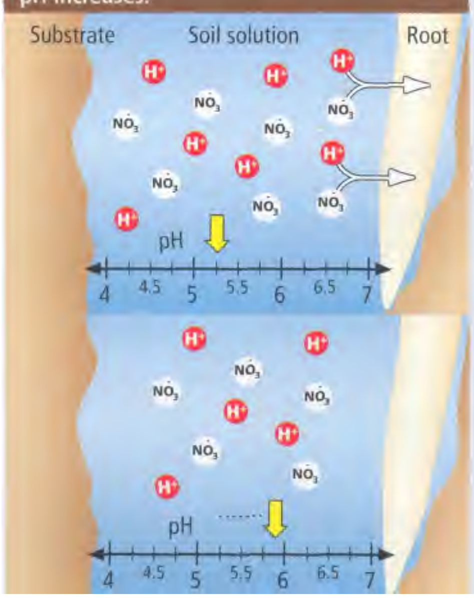
Fertilizers high in NH_4+ are acidic and cause substrate pH to decrease (page 44), and the opposite is true for fertilizers high in NO (below). When NH4' (or other cations) is taken up by the plant, a positive charge enters the root. The plant must remain electrochemically neutral, and thus, the roots secrete positively charged H+, which reduces the pH. When NO (or other anions) is absorbed, the roots balance the negative charge by absorbing H. As more NO is absorbed, more H+ is removed from the soil solution, and the substrate pH increases.

Every bag of fertilizer has a potential acidity or basicity rating, which refers to the equivalent pounds of agricultural limestone needed to neutralize the acidity or equal the basicity of 1 ton of that particular fertilizer. A good example would be the acidic fertilizer 20-10-20, which has a potential acidity of 429. This means it would take approximately 429 pounds of agricultural lime to neutralize the pH effect of 1 ton of this fertilizer. If this was a basicity rating, 1 ton of fertilizer would have a similar effect on pH as 429 pounds of agricultural lime.

The table on the opposite page shows a list of commonly used acidic and basic fertilizers, and their potential acidity or basicity ratings. When using fertilizers for pH adjustment, you can expect the pH to shift 0.2 to 0.6 pH units within three to five days. The magnitude of the shift depends on the acidity or basicity rating of the fertilizer and the size and growth rate of the plant because the change in pH is dependent on nutrient uptake by the roots.

pH correction. Moderate corrections of high and low substrate pH can be handled by switching to acidic or alkaline fertilizers. When water alkalinity causes substrate pH to increase more than what can be corrected by using alkaline fertilizer, one should inject acid into the irrigation water, as previously discussed. Larger deviations in pH may require substrate drenches. Drenches for raising pH include flowable limestone and potassium bicarbonate. For lowering pH, they include iron or aluminum sulfate and mineral acids. Drenches are last resorts. Large pH shifts

Fertilizers high in NO_3^- (nitrate) cause substrate pH to increase. When NO_3^- is absorbed, the roots balance the negative charge by absorbing H^+ (hydrogen). As more NO_3^- is absorbed, more H^+ is removed from the soil solution, and the substrate pH increases.



Low substrate pH corrections

Why is pH low?

- Low residual limestone
- Low water alkalinity
- Fertilizer too acidic for situation

Note: Because plants naturally lower substrate pH, an alkaline force is needed.

Small corrections

- Switch to alkaline fertilizers
- Generally shift pH 0.2 to 0.6 pH units in three to five days

Note: Because pH correction is a function of plant-nutrient uptake, the size and growth rate of the plant govern the rate of correction.

Large corrections

- Flowable limestone
  - 1 to 2 quarts per 100 gallons
  - The resulting suspension requires continuous stirring during application
  - Can clog water emitters
- Potassium bicarbonate
  - 2 pounds per 100 gallons (993 parts per million potassium [K])
  - Leach next day with a fertilizer containing calcium (Ca) and magnesium (Mg), such as 13-2-13-6 Ca - 3 Mg, to leach excess K and re-establish the K-to-Ca-to-Mg balance

Note: Immediately rinse plants after application to remove residues and prevent burn. Allow three days of reaction time, then recheck pH.

Acidity and basicity ratings

The following are some acidic and basic fertilizers, and their potential acidity or basicity ratings (the ratings are in pounds per ton)

Acidic fertilizers	Potential acidity
21-7-7	1,520
25-10-10	1,040
9-45-15	940
24-9-9-1 Mg - 2 S	822
20-20-20	680
20-10-20	429
12-5-20	389
15-15-15	260
20-0-20	0
34-0-0 (ammonium nitrate)	1,200
12-62-0 (monoammonium phosphate)	1,160
46-0-0 (urea)	1,400

Basic fertilizers	Potential basicity
16-4-12	73
15-5-15-5 Ca - 1 Mg	141
14-4-14-5 Ca - 2 Mg	200
13-2-13-6 Ca - 3 Mg	380
14-0-14-6 Ca - 3 Mg	410
15-0-15-11 Ca	420
15.5-0-0 (calcium nitrate)	400
11-0-0 (magnesium nitrate)	460
13-0-46 (potassium nitrate)	510

Key: Mg (magnesium), S (sulfur), Ca (calcium)

often come about from failure to continually monitor substrate pH or from an unexpected change in water alkalinity.

All drenches are potentially phytotoxic to the crop. Whenever any drench is applied, the foliage that has been contacted should be rinsed off immediately with clear water (water that does not have a dye from fertilizer). Even with this precaution, flowers — and to a lesser degree foliage — may burn. Growers should test drenches on a small number of plants. Where injury cannot be avoided, a grower must decide whether the benefit is justified, then apply the treatment early enough to allow for new flowers to develop before market. A good example is the burn that occurs on pansy flowers from an iron sulfate drench.

Drenches are applied to thoroughly saturate the substrate with a 15 percent to 20 percent leach. Most drench chemicals are water-soluble; however, flowable limestone is not. It is important to have one person stirring the flowable limestone concentrate or suspension so it does not settle before entering the fertilizer injector or being pumped to the crop. Some growers mix the flowable limestone in a pesticide sprayer that has an agitator, then pump the solution through the spray

High substrate pH corrections

Why is pH high?

- Water alkalinity too high
- Too much residual limestone
- Fertilizer too basic for situation

Small corrections

- Switch to acidic fertilizers
- Generally shift pH 0.2 to 0.6 pH units in three to five days

Notes: The size and growth rate of the plant govern the rate of correction. Acidic fertilizers are high in ammonium, and the probability of ammonium toxicity increases with declining pH. Thus, do not lower pH below the recommended level for a crop.

Moderate corrections (due to water alkalinity)

- Inject acid into the irrigation water

Large corrections

- Iron or aluminum sulfate drench

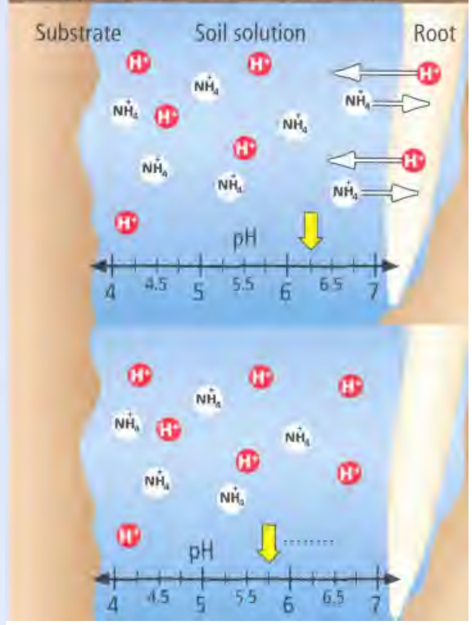
Iron form recommended*

- 1 to 3 pounds per 100 gallons
- Wash foliage immediately after application
- Never use the ferrous sulfate $FeSO_4$ form on iron-efficient plants, such as geranium and marigold
- Recheck pH two to three days after application

* Use the $FeSO_4$ form, not the ferric sulfate ($Fe_2(SO_4)_3$) form of iron sulfate. It should be bluish powder; if yellow, it has converted to ineffective ferric sulfate.

- Mineral acid drenches
  - Not the same as acid injection into irrigation water for alkalinity correction
  - A one-time shot to the substrate to correct pH
  - Use same acids used for acid injection
  - Rate: Add sufficient acid to drench solution to reach a pH of 1.5 to 2.0
  - Rinse foliage immediately after application because solutions are very phytotoxic
  - Recheck pH two to three days after application

Fertilizers high in NH_4^+ (ammonium) are acidic and cause substrate pH to decrease. When NH_4^+ is taken up by the plant, a positive charge enters the root. The plant must remain electrochemically neutral, and thus, the roots secrete positively charged H^+ (hydrogen), which reduces the pH.



Distorted growth from boron deficiency in pansy is caused by high pH.

hose, which is fitted with a water breaker rather than a nozzle. Three days after drench application, the substrate pH should be checked to see if a repeat application is required.

The plant/soil system is dynamic, and pH is always changing due to the type of substrate used, rate of plant growth, species of plant, limestone properties, water alkalinity shifts, fertilizer selections and environmental conditions. By constantly monitoring the system, you have the ability to make small corrections when needed. This will prevent large pH adjustments, reduce crop losses and increase profits. A toolbox for a quality pH-management strategy should include acidic fertilizers (21-7-7 and 20-10-20), basic fertilizers (15-5-15 and 13-2-13), an acid drench (ferrous sulfate) and an alkaline drench (flowable lime).

Be careful: Some of the chemicals for adjusting and controlling water and substrate pH can be injurious to personnel, as well as phytotoxic to some plants. It is the responsibility of the grower to test these procedures on a small group of plants to avoid injury to the entire crop and to determine safe handling procedures.

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