# Alkalinity Control For Irrigation Water Used in Greenhouses 



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High pH water and high alkalinity in water can be limiting factors in container production of greenhouse floriculture crops. An understanding of both is needed to accurately treat water with a high pH .

## Substrate Solution and Water pH Factors

$\mathbf{p H}$. A pH reading is a measurement of the hydrogen ion concentration of a solution (how acidic or basic a solution is), and readings range from 0 (most acidic) to 14 (most basic). Availability of micronutrients such as iron, manganese, zinc, copper, and boron and future plant growth can be reduced severely by high substrate and irrigation water pH (Figure 1). High pH water can cause salts to precipitate out of fertilizer stock tanks. High pH water can also reduce the efficacy of pesticides, such as Florel. Therefore, growers should test and know their irrigation water properties.

Although pH 7 is considered "neutral" (not acidic or alkaline), 7 is not the optimum pH for irrigation waters or substrate solutions for nutrient availability and growth in container production due to the substrate components typically used in greenhouse production.

The recommended range of irrigation water pH and substrate solution pH for greenhouse production depends on the crop being grown. The generally accepted pH range is 5.2 to 6.8 for irrigation water and 5.4 to 6.3 for the substrate solution. Acid treatment of your water to about pH 5.8 may be needed prior to use, if the pH and alkalinity are high and result in an out-of-range substrate solution pH (greater than the range given above) when used in on crops.

Alkalinity. Alkalinity is a measure of a water's capacity to neutralize acids. It is the concentration of soluble alkalis in a solution. Dissolved bicarbonates such as calcium bicarbonate $\left(\mathrm{Ca}\left(\mathrm{HCO}_{3}\right)_{2}\right)$, sodium bicarbonate $\left(\mathrm{NaHCO}_{3}\right)$, and magnesium bicarbonate $\mathrm{Mg}\left(\mathrm{HCO}_{3}\right)_{2}$ ); and carbonates such as calcium carbonate $\left(\mathrm{CaCO}_{3}\right)$ are the major chemicals contributing to alkalinity in irrigation water. Dissolved hydroxides are but a minor contributor in most cases. Ammonia, borates, organic bases, phosphates, and silicates can also be minor contributors to alkalinity.

Total carbonates. Since bicarbonates and carbonates are the major components of water alkalinity, most laboratories assume that Total Carbonates ( $\mathrm{TC}=$ carbonates + bicarbonates) equals alkalinity. In most cases, this is a
safe assumption. For most waters in the Southeast, bicarbonates account for more than $90 \%$ of all alkalinity present.

The term "alkalinity" should not be confused with the term "alkaline," which describes situations where pH levels exceed 7.0. Laboratory test results will express alkalinity as milligrams per liter (or parts per million) of calcium carbonate $\left(\mathrm{mg} / \mathrm{L}\right.$ or $\left.\mathrm{ppm} \mathrm{CaCO}_{3}\right)$ or as milliequivalents per liter of calcium carbonate (meq/ $\mathrm{LCaCO}_{3}$ ). You can convert between these two units using the following values: $1.0 \mathrm{meq} / \mathrm{L} \mathrm{CaCO}_{3}$ $=50.04 \mathrm{mg} / \mathrm{L} \mathrm{CaCO}_{3}$. The term "total carbonates" (TC) may also be used by some testing laboratories to refer to alkalinity


Figure 1. Influence of pH level on the availability of essential nutrients in a soilless substrate containing sphagnum peat moss, composted pine bark, vermiculite, and sand. The pH range recommended for most greenhouse crops is indicated by slashed lines.
of a solution. Some laboratories assume that all alkalinity is derived solely from bicarbonates $\left(\mathrm{HCO}_{3}^{-}\right)$and will report alkalinity as bicarbonates using $\mathrm{ppm}(\mathrm{mg} / \mathrm{L})$ or $\mathrm{meq} / \mathrm{L}$. To convert between these two units, use the following values: 1 $\mathrm{meq} / \mathrm{L} \mathrm{HCO}_{3}^{-}=61 \mathrm{mg} / \mathrm{L} \mathrm{HCO}_{3}^{-}$.

Alkalinity is related to pH because alkalinity establishes the buffering capacity of a water. Alkalinity affects how much acid is required to change the pH . The following example may help explain the importance of alkalinity when trying to acidify water (Figure 2): Grower A has a water with a pH of 9.3 and an alkalinity of $71 \mathrm{mg} / \mathrm{L} \mathrm{CaCO}_{3}(\mathrm{TC}=1.42 \mathrm{meq} / \mathrm{L})$. Toreduce the pH of this water to 5.8 , it takes 15.8 fl oz . of $35 \%$ (w:w) sulfuric acid per 1,000 gallons of water. In contrast, Grower B has a water with a pH of 8.3 and an alkalinity of 310 $\mathrm{mg} / \mathrm{LCaCO}_{3}(\mathrm{TC}=6.20 \mathrm{meq} / \mathrm{L})$. To reduce this water to a pH of 5.8 , it takes 68.6 fl oz . of $35 \%$ sulfuric acid per 1,000 gallons of water. Despite the fact that Grower B's water is a full pH unit lower than Grower A's, it takes more than four times more acid to lower the pH to 5.8. Both alkalinity and pH are important to consider when adjusting the pH of a water.

Alkalinity can be a major problem in the Southeast, especially in the coastal plains. Levels of $2 \mathrm{meq} / \mathrm{L}$ and lower are safe for most crops. However, plug seedlings are more sensitive to alkalinity because the small volume of substrate provides little buffering against a rise in pH . Problems can occur in plug production if using water with more than 1.5 $\mathrm{meq} / \mathrm{L}$. If the alkalinity of your irrigation water is above 2.0 $\mathrm{meq} / \mathrm{L}$ (or above $1.5 \mathrm{meq} / \mathrm{L}$ for a plug producer), you should consider injecting an acid to neutralize the bicarbonates (alkalinity) present, thus preventing an undesirable rise of substrate pH over time.

## In-House Analysis of Water pH and Alkalinity

pH. Many relatively inexpensive ( $\$ 30$ to $\$ 250$ ) pH meters are available that are accurate enough for greenhouse use. When selecting a pH meter, look for an accuracy of $\pm 0.1$ pH unit and a range of 1 to 14 . You should also be able to calibrate the meter (meter should have some type of calibration adjustment such as a set screw). Make sure to order standard pH solutions (usually pH 4.0 and pH 7.0 ) in order to calibrate


Figure 2. Titrations of two different waters with sulfuric acid. Notice that although the beginning pH of Grower $A$ water is a full unit higher than Grower B water, it takes more than 4 times the acid to drop Grower B water to pH 5.8, due to the greater alkalinity in Grower B water.
your meter prior to use. Meters are available from many sources including the following: Cole-Parmer Instruments, 745 North Oak Park Ave., Chicago, IL 60648, (800)3234340; Extech Instruments Corp., 150 Bear Hill Road, Waltham, MA 02154 , (617) 890-7440; Myron L Co., 6231 C. Yarrow Drive, Carlsbad, CA 92009, (619) 438-2021.

Alkalinity. Alkalinity is measured by titrating a water sample with an acid (usually dilute sulfuric acid) to an endpoint pH of about 4.6 (varies from 5.1 to 4.5 depending on the indicator dye used and the initial alkalinity). A pH indicator dye (usually bromcresol green plus methyl red) is added to a known volume of water (indicated in the test kit instructions; usually 8 fl oz. ., and acid is added until the solution changes color. With the bromocresol green plus methyl red dye system, the color will change from green to pink.

Most water sources acceptable for greenhouse use will have alkalinity in the range of 0 to $8 \mathrm{meq} / \mathrm{L}$ ( 0 to 400 ppm alkalinity expressed as $\mathrm{CaCO}_{3}$ ). When looking for a test kit, this is the range that is needed. The level of accuracy does vary from kit to kit; $\pm 0.4 \mathrm{meq} / \mathrm{L}$ ( 20 ppm alkalinity expressed as $\mathrm{CaCO}_{3}$ ) is accurate enough for most situations, but more precise kits are available. We have used Hach alkalinity kits \#24443-01 (about \$30 for 100 tests) and \#20637-00 (about $\$ 155$ for 100 tests, but includes versatile digital titrator) and are satisfied by both (Hach Company, P.O. Box 389 Loveland, Co 80539; phone (800) 227-4224). Although the second model is more expensive, it does have twice the accuracy ( $\pm$ $0.2 \mathrm{meq} / \mathrm{L}$ ) and also comes with a digital titrator that can be used to measure other solution parameters (using different titrants and indicators) such as water hardness, chlorine, iron, nitrite, and sulfite concentrations.

## Acidification Procedures to Neutralize Alkalinity

Acidification reduces the amount of bicarbonates (and carbonates) in water. Injecting acid into irrigation water neutralizes alkalinity resulting in the formation of carbon dioxide and water:
$\mathbf{H}^{+}($from acid $)+\mathbf{H C O}_{3}^{-}$(in the water) $\rightarrow \mathbf{C O}_{2} \uparrow+\mathbf{H}_{2} \mathbf{O}$
Sulfuric $\left(\mathrm{H}_{2} \mathrm{SO}_{4}\right)$, phosphoric $\left(\mathrm{H}_{3} \mathrm{PO}_{4}\right)$, nitric $\left(\mathrm{H}_{2} \mathrm{NO}_{3}\right)$, or citric $\left(\mathrm{H}_{3} \mathrm{C}_{6} \mathrm{H}_{5} \mathrm{O}_{7}\right)$ acid are commonly injected into irrigation water to neutralize water alkalinity (Table 1). When deciding on which acid is best for your situation, evaluate (1) the safety and ease of use for the acid; (2) the relative cost of the acid; (3) the plant nutrient being injected by the acid (how much $\mathrm{N}, \mathrm{P}$, or S will be injected into your irrigation water); and 4 the availability of the acid.

Safety. Citric acid, $75 \%$ phosphoric acid and the 35\% sulfuric acid are relatively safe to work with as compared to the $67 \%$ nitric acid (Table 1). Nitric acid is much more caustic and can cause serious injury to exposed tissue, especially eyes. Nitric acid can also fume during handling. Take care to avoid contact and do not breath fumes.

Avoid skin and eye exposure when handling any acid. Acid-resistant eye wear, gloves, and apron should be worn. Acids are corrosive and can damage clothing that is not immediately rinsed.

When mixing acid stock solutions, always add acid to a larger volume of water to create the stock. Never add water to concentrated acid.

Cost. In general, sulfuric and nitric are less expensive than phosphoric and citric (Table 1). Citric acid is somewhat cost prohibitive for uses other than neutralization of water used in pesticide sprays and in fertilizer stock solutions. Note the prices used in these calculations. Acid prices do vary with supplier and quantity. Youmay need to recalculate acidification costs using your acid costs.

Nutrients from acids. With the exception of citric acid, the acids used for water acidification also supply a plant nutrient in conjunction with supplying $\mathrm{H}^{+}$. The nutrient supplied can be beneficial to plant growth (if not supplied in excess), but it can also react with fertilizer salts in concentrated stock solutions or with pesticides if mixed into spray solutions.

Growers who acidify their water should adjust their fertilization program for the nutrient supplied by the acid used (Table 1). For example, if using phosphoric acid, make sure to reduce your phosphorus feed accordingly to account for the $P$ supplied from the acid. When attempting to acidify waters very high in alkalinity, phosphoric acid may not be feasible. For example, if your water supply contains $6.0 \mathrm{meq} / \mathrm{L}$ of alkalinity and you used phosphoric acid to neutralize the alkalinity, over $126 \mathrm{ppmP}\left(280 \mathrm{ppmP}_{2} \mathrm{O}_{5}\right)$ are supplied ateach irrigation, an extremely high level of phosphorus. A maximum of $55 \mathrm{ppm} \mathrm{P}\left(125 \mathrm{ppm} \mathrm{P}_{2} \mathrm{O}_{5}\right)$ is recommended. Use another acid if more than this amount of P is being injected from phosphoric acid. If using nitric acid, account for the additional N supplied from the acid. Using $67 \%$ nitric acid to acidify water containing $6.0 \mathrm{meq} / \mathrm{L}$ of alkalinity would supply 67 ppm N at each irrigation, a significant quantity of nitrogen. Sulfuric acid treatment for 6.0 meq of alkalinity would supply 75 ppm S, more than sufficient sulfur for plant production (20 to 30 ppm S is suggested for most floriculture crops).

Acid recommendations. Citric acid is ideal as an acidifier for nutrient stock solutions and pesticide solutions, as it is much less likely to react with fertilizer salts or pesticides than the other three acids. Use citric acid for acidifying water used to make concentrated fertilizer stocks and pesticide solutions. However, the cost of citric acid makes it less desirable as an acidifier for large volumes of water used for irrigation and fertilization.

For acidification of irrigation water, we recommend sulfuric acid over nitric acid due to it's relative safety. Sulfuric is recommended over phosphoric acid for very alkaline water due to the higher cost of phosphoric acid and the possibility of over application of P . The sulfuric acid recommended is a battery electrolyte product named Qual ${ }^{\oplus}$ and can be purchased from most auto supply stores for about $\$ 10$ per 5 gallons.

Table 1. Acids commonly used to acidify irrigation water and their properties.

| Acid | Formulation and density (d) or formula weight (FW) | Amount of acid to add for each meq/L of alkalinity to result in a water pH of approximately $5.8^{*}$ | Concentration of nutrient provided by one fl oz . of acid per 1000 gallons water** | Cost per meq/L per 1000 gal*** | Relative safety**** |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Citric acid (2-Hydroxy-1,2,3propanetricarboxylic acid)$\mathrm{H}_{3} \mathrm{C}_{6} \mathrm{H}_{5} \mathrm{O}_{7}$ | $\begin{aligned} & 99.5 \%(\mathrm{w}: \mathrm{w}) \\ & \text { granular } \\ & \text { FW = } 192.1 \end{aligned}$ | $9.1 \mathrm{oz} / 1000$ gals | none | \$0.59 | can cause minor skin and eye irritation |
|  | 50\% (w:w) <br> liquid $\mathrm{d}=1.21$ | 14.5 fl. oz/1000 gals | none | \$0.96 | can cause minor skin and eye irritation |
| Nitric acid $\mathrm{H}_{2} \mathrm{NO}_{3}$ | 67\% (w:w) <br> liquid $\mathrm{d}=1.42$ | $6.6 \mathrm{fl} \mathrm{oz} / 1000$ gals | 1.64 ppm N | \$0.26 | use extreme caution; very caustic and dangerous; avoid contact with fumes as well as acid |
| Phosphoric acid $\mathrm{H}_{3} \mathrm{PO}_{4}$ | $75 \% \text { (w:w) }$ <br> liquid $\mathrm{d}=1.58$ | $8.1 \mathrm{fl} \mathrm{oz} / 1000$ gals | 2.88 ppm P | \$0.44 | slightly caustic; can cause skin and eye irritation as well as damage clothing |
| Sulfuric acid $\mathrm{H}_{2} \mathrm{SO}_{4}$ | 35\% (w:w) <br> liquid $\mathrm{d}=1.26$ | $11.0 \mathrm{fl} \mathrm{oz} / 1000$ gals | 1.14 ppm S | \$0.16 | slightly caustic; can cause skin and eye irritation as well as damage clothing |

*Add this amount for each meq/L of alkalinity present. For example, if your water report indicates an alkanity of 3 meq/L and you choose to use sulfuric acid, you would add 33 fl oz . of $35 \%$ sulfuric acid per 1000 gallons of water ( $11 \mathrm{fl} \mathrm{oz} / \mathrm{meq} / \mathrm{L} \times 3 \mathrm{meq} / \mathrm{L}$ $=33 \mathrm{fl} \mathrm{oz}$ ). Calculations based on the following dissociation values: $2.07 \mathrm{meq} \mathrm{H}^{+}$per $3 \mathrm{meq} \mathrm{H}_{3} \mathrm{C}_{6} \mathrm{H}_{5} \mathrm{O}_{7}, 1 \mathrm{meq}^{+} \mathrm{H}^{+}$per 1 meq $\mathrm{H}_{2} \mathrm{NO}_{3}, 1.02 \mathrm{meq} \mathrm{H}^{+}$per $3 \mathrm{meq} \mathrm{H}_{3} \mathrm{PO}_{4}$, and $1 \mathrm{meq} \mathrm{H}^{+}$per $1 \mathrm{meq} \mathrm{H}_{2} \mathrm{SO}_{4}$.
**In the above example, the acid would supply 38 ppm S at each irrigation ( $33 \mathrm{fl} \mathrm{oz} \times 1.14 \mathrm{ppm} \mathrm{S} / \mathrm{fl} \mathrm{oz} .=33 \mathrm{ppm} \mathrm{S}$ ).
***Acid cost to neutralize $1 \mathrm{meq} / \mathrm{L}$ alkalinity per 1000 gallons of water. Based on the following costs: $\$ 1.04 / \mathrm{lb}$ of $99.5 \%$ citric acid; $\$ 8.45 / \mathrm{gal}$ of $50 \%$ citric acid; $\$ 5.00 / \mathrm{gal}$ of $67 \%$ nitric acid; $\$ 7.00 / \mathrm{gal}$ of $75 \%$ phosphoric acid; $\$ 1.90 / \mathrm{gal}$ of $35 \%$ sulfuric acid.
****Use caution with ALL acids. Wear eye protection, acid-resistant gloves, and an acid-resistant apron when handling any acid.

To accurately predict the amount of acid required to acidify to a given pH , both the pH and alkalinity of the irrigation water must be known. Table 1 outlines starting amounts of acid to inject to drop the pH to approximately 5.8. However this table is only taking alkalinity into account (and does not account for the starting pH of a water sample), and fine tuning of the amount of acid added will be necessary. When acidifying water, an end point of 5.8 is adequate to control substrate solution pH rise due to alkalinity in the irrigation water.

Cooperative research NC State University and Purdue University floriculturists led to the development of an Excel ${ }^{\oplus}$ spreadsheet that allows users to input their water pH and alkalinity then select sulfuric, phosphoric, or nitric acid to use as an acidifying agent to reach a target pH or alkalinity. The spreadsheet modules calculate the nutrient additions from the acid injection and will report your acidification costs, if you input the price per gallon for the acid you wish to use.

You can acquire a copy of this spreadsheet to aid in your water acidification needs via the world wide web at http:// www2.ncsu.edu/floriculture/ or by contacting the author by email (doug_bailey @ ncsu.edu) or FAX (919-515-7747).

Acid injection equipment. The injector used to add the acid into your water should be approved for acid injection by the manufacturer. Consult the manufacturer to select an injector for acid injection.

Do not mix acid stock solutions with fertilizer stock solutions, as fertilizer salts could precipitate out of solution with certain acid / fertilizer combinations. Use separate injectors for each solution.

Acidic water will corrode galvanized piping and fittings over time. Be sure to check the integrity of greenhouse plumbing periodically.

## Suggested Readings

Bailey, D.A., T. Bilderback, and D. Bir. 1996. Water considerations for container production of plants. NC State University Hort. Info. Lflt. \#557. (available at http:/ /www2.ncsu.edu/floriculture/)
Farnham, D.S., R.F. Hasek, and J.L. Paul. 1985. Water quality: its effects on ornamental plants. University of California Cooperative Extension Leaflet \#2995.
Reed, D.M. (ed.). 1996. Water, media, and nutrition for greenhouse crops. Ball Publishing, Batavia, Ill.

