Department of Horticultural Science

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ALKALINITY CONTROL FOR IRRIGATION WATER USED IN NURSERIES AND GREENHOUSES

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

Substrate Solution and Water pH Factors

pH. 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 the properties of their irrigation water.

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. This is due to the substrate components typically used in nursery and greenhouse production.

The recommended range of irrigation water pH and substrate solution pH for production depends on the crop being grown. In general, pH should range from 5.2 to 6.8 for irrigation water and 5.4 to 6.3 for substrate solution. If the pH and alkalinity are high, your water may need acid treatment prior to use 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 ($Ca(HCO_3)_2$), sodium bicarbonate ($NaHCO_3$), and magnesium bicarbonate $Mg(HCO_3)_2$); and carbonates such as calcium carbonate ($CaCO_3$) are the major contributors to alkalinity in irrigation water. Dissolved hydroxides are 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 (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 (mg/L or ppm $CaCO_3$) or as milliequivalents per liter of calcium carbonate (meq/L $CaCO_3$). You can convert between these two units using the following values: 1.0 meq/L $CaCO_3$ = 50.04 mg/L $CaCO_3$. The term "total carbonates" (TC) may also be used by some testing laboratories to refer to alkalinity of a solution. Some laboratories assume that all alkalinity is derived solely from bicarbonates (HCO_3^-) and will report alkalinity as bicarbonates using ppm (mg/L) or meq/L. To convert between these two units, use the following values: 1 meq/L HCO_3^- = 61 mg/L HCO_3^-.

Alkalinity establishes the buffering capacity of water and 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 water with a pH of 9.3 and

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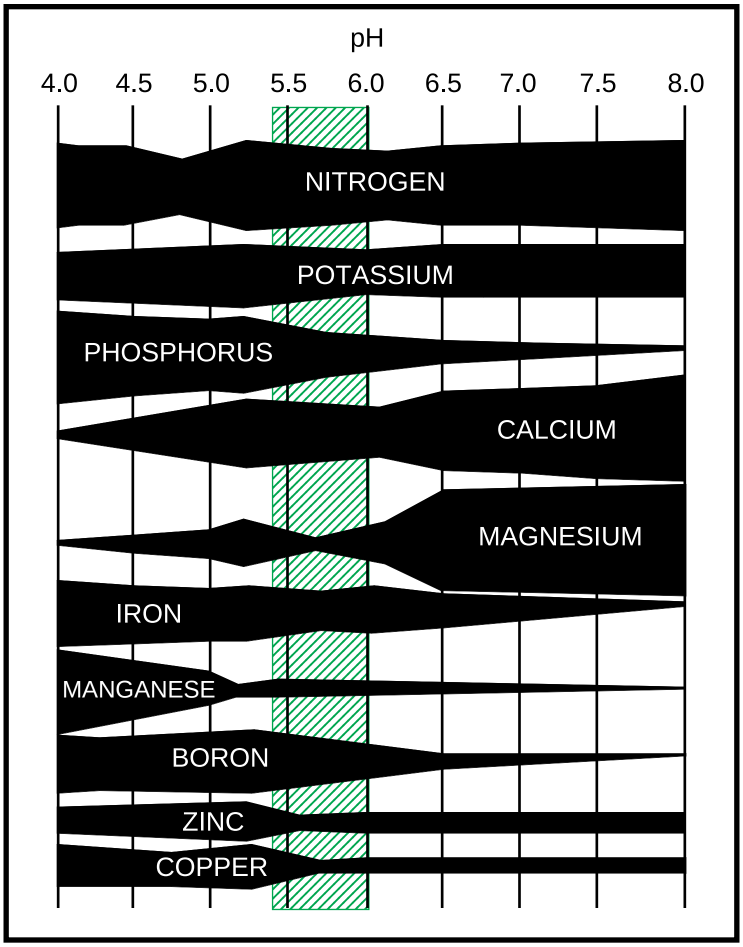

Figure 1. Influence of pH level on the availability of essential nutrients in a soilless substrate containing sphagnum peat moss, composted pine bark, vermiculite, and sand. The pH range recommended for most greenhouse crops is indicated by slashed lines.

an alkalinity of 71 mg/L $CaCO_3$ (TC = 1.42 meq/L). To reduce 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 water with a pH of 8.3 and an alkalinity of 310 mg/L $CaCO_3$ (TC = 6.20 meq/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. Even though Grower B's water is one pH unit lower than Grower A's, it takes *more than four times more acid* to lower the pH to 5.8 due to the differences in alkalinity. Both alkalinity and pH are must be considered when adjusting the pH of water.

Alkalinity can be a major problem in the North Carolina, especially in the coastal plains region. Levels of 2 meq/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 your water has more than 1.5 meq/L . If the alkalinity of your irrigation water is above 2.0 meq/L (or above 1.5 meq/L for a plug producer), you should consider injecting an acid to neutralize the bicarbonates (alkalinity), 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 and nursery use. When selecting a pH meter, look for an accuracy of ±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 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, phone: 800.323.4340; Extech Instruments Corp., 150 Bear Hill Road, Waltham, MA 02154, phone: 617. 890.7440; Myron L Co., 6231 C. Yarrow Drive, Carlsbad, CA 92009, phone: 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 container production will have alkalinity in the range of 0 to 8 meq/L (0 to 400 ppm alkalinity expressed as $CaCO_3$).

When looking for a test kit, this is the range that is needed. The level of accuracy does vary from kit to kit; ± 0.4 meq/L (20 ppm alkalinity expressed as $CaCO_3$) 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) with good results (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 (± 0.2 meq/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:

$$\mathbf{H^+} \text{ (from acid)} + \mathbf{HCO_3^-} \text{ (in the water)} \rightarrow \mathbf{CO_2}\uparrow + \mathbf{H_2O}$$

Sulfuric (H_2SO_4), phosphoric (H_3PO_4), nitric (H_2NO_3), or citric ($H_3C_6H_5O_7$) acid are commonly injected into irrigation water to neutralize water alkalinity (Table 1). When deciding on which acid is best for your situation, evaluate ∂ safety and ease of use; ∑ the relative cost of the acid; ∏ plant nutrient being injected with the acid (how much N, P, or S will be injected into your irrigation water); and π availability.

Safety. Citric acid, 75% phosphoric acid and 35% sulfuric acid are relatively safe to work with as compared to the 67% nitric acid (Table 1). Nitric acid is very caustic and can cause serious injury to exposed tissue, especially eyes. Since nitric acid can also fume during handling, take care to avoid breathing fumes.

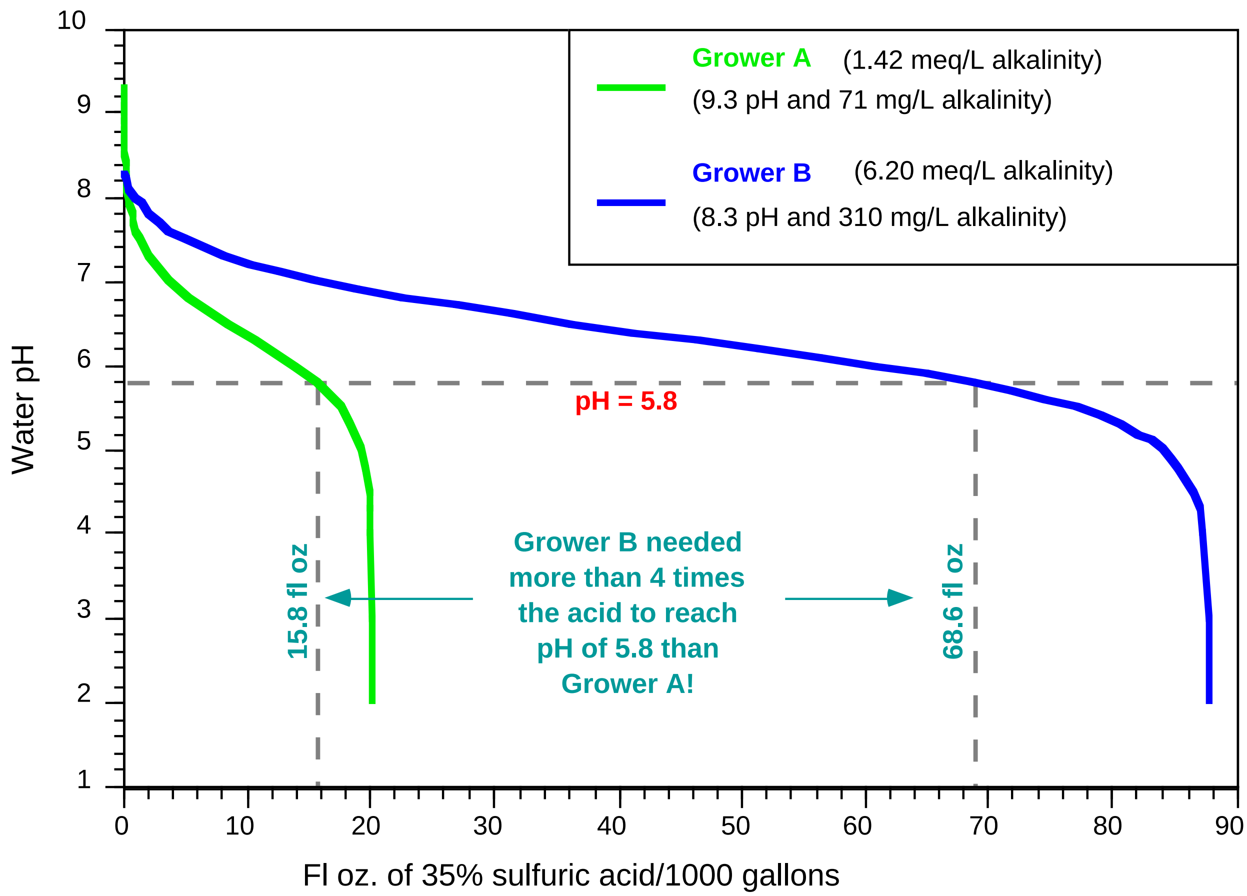

Figure 2. Titrations of two different waters with sulfuric acid. Notice that although the beginning pH of Grower A water is a full unit higher than Grower B water, it takes more than 4 times the acid to drop Grower B water to pH 5.8, due to the greater alkalinity in Grower B water.

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. You may need to recalculate acidification costs using the cost of your acid.

Nutrients from acids. With the exception of citric acid, acids used for water acidification also supply a plant nutrient in conjunction with supplying 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 (Table 1). For example, if using phosphoric acid, make sure to reduce your P 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 meq/L of alkalinity and you used phosphoric acid to neutralize the alkalinity, over 126 ppm P (280 ppm P_2O_5) are supplied at each irrigation. This is an extremely high level of P considering a maximum of 55 ppm P (125 ppm P_2O_5) is recommended. Use another acid if more than this amount of P is being injected with 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 meq/L of alkalinity would supply 67 ppm N at each irrigation, a significant

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-1,2,3-propanetricarboxylic acid) $H_3C_6H_5O_7$	99.5% (w:w) granular FW = 192.1	9.1 oz/1000 gals	none	\$0.59	can cause minor skin and eye irritation
	50% (w:w) liquid d = 1.21	14.5 fl. oz/1000 gals	none	\$0.96	can cause minor skin and eye irritation
Nitric acid H_2NO_3	67% (w:w) liquid d = 1.42	6.6 fl 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 H_3PO_4	75% (w:w) liquid d = 1.58	8.1 fl oz/1000 gals	2.88 ppm P	\$0.44	slightly caustic; can cause skin and eye irritation as well as damage clothing
Sulfuric acid H_2SO_4	35% (w:w) liquid d = 1.26	11.0 fl 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 fl oz/meq/L × 3 meq/L = 33 fl oz). Calculations based on the following dissociation values: 2.07 meq H^+ per 3 meq $H_3C_6H_5O_7$, 1 meq H^+ per 1 meq H_2NO_3, 1.02 meq H^+ per 3 meq H_3PO_4, and 1 meq H^+ per 1 meq H_2SO_4.

**In the above example, the acid would supply 38 ppm S at each irrigation (33 fl oz × 1.14 ppm S/fl oz. = 33 ppm S).

***Acid cost to neutralize 1 meq/L alkalinity per 1000 gallons of water. Based on the following costs: \$1.04/lb of 99.5% citric acid; \$8.45/gal of 50% citric acid; \$5.00/gal of 67% nitric acid; \$7.00/gal of 75% phosphoric acid; \$1.90/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.

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. 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 its 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® and can be purchased from most auto supply stores for about $10 per 5 gallons.

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 initial amounts of acid to inject to lower 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), so 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.

Researchers from NC State University and Purdue University developed an Excel® 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 Doug Bailey 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 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.