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PB1617-Irrigation Water Quality for Greenhouse Production

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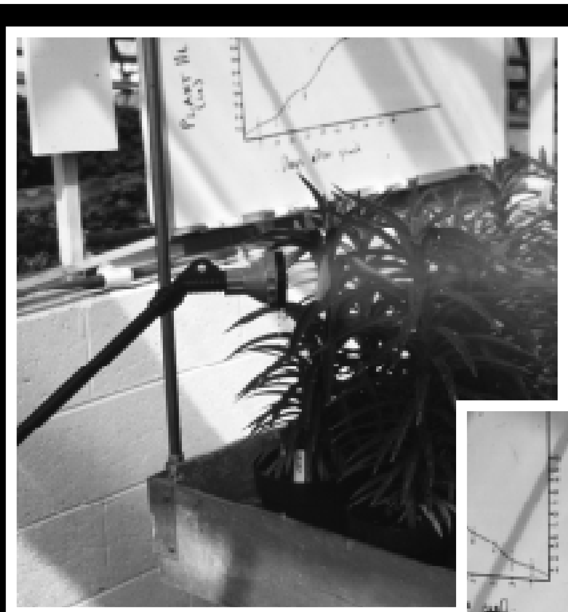

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Irrigation Water Quality For Greenhouse Production

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This publication is one of three in a series that covers the basics of developing a nutritional program for producing container-grown plants in greenhouses. A complete nutrition program encompasses the fertilizers, media and water used. The first publication, **Plant Nutrition and Fertilizers for Greenhouse Production** (PB 1616), develops background information about plant nutrition and discusses the important characteristics of fertilizers used in greenhouse production. This publication examines the effect of water quality on a greenhouse nutritional program. The third publication, **Growing Media for Greenhouse Production** (PB 1618), describes the important physical and chemical properties of growing media, media testing procedures and interpretation of test results. The objective of this series of publications is to provide basic information that will allow greenhouse operators to develop a nutritional program for their specific business.

High-quality crops can be produced only by using high-quality irrigation water. Characteristics of irrigation water that define its quality vary with the source of the water. There are regional differences in water characteristics, based mainly on geology and climate. There may also be great differences in the quality of water available on a local level depending on whether the source is from above ground (rivers and ponds) or from groundwater aquifers with varying geology, and whether the water has been chemically treated.

The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients. To evaluate the quality of irrigation water, we need to identify the characteristics that are important for plant growth, and the acceptable levels or concentrations of these factors. Having the water tested by a reputable laboratory is the first step in this process. A knowledgeable interpretation of the results allows us to correct water quality problems and/or choose fertilizers and irrigation techniques to avoid crop damage.

Factors Affecting Water Quality

Many factors taken together determine the quality of water for irrigation of plants. Individual components most commonly analyzed for in a water test are discussed below. Levels considered desirable in an irrigation water source are summarized in Table 1.

pH

The pH of water is a measure of the acidity or basicity. It is reported as the negative log of the H^+ ion concentration, so acidic water (high concentration of H^+ ions) has a low pH and basic water (low concentration of H+ ions) has a high pH value. Most plants grow best when the media solution pH is 5.6 to 6.2. The main effect of water pH on plant growth is through control of nutrient availability. A low pH may be responsible for excess iron and manganese availability leading to toxicity, or calcium and magnesium deficiencies. A high pH may cause iron and manganese and other minor nutrients to become unavailable to plants, leading to deficiencies.

Table 1. Desirable levels of nutrients and other components of irrigation water. Note: These are desirable levels, while acceptable levels can be broader.

Water Quality Measurements	Desirable Range
pH	5.8 to 6.0
Alkalinity	0.75 - 2.6 meq/l CaCO3
Soluble salts (EC)	<1.5 mmhos/cm
Hardness	100 to 150 mg CaCO3/l
Calcium (Ca)	40 to 100 ppm
Magnesium (Mg)	30 to 50 ppm
Sodium (Na)	< 50 ppm
Sulfate (SO4)	< 50 ppm
Chloride (Cl -)	< 100 - 150 ppm
Boron (B)	< 0.5 ppm
Fluoride (F -)	< 0.75 ppm

Alkalinity/Carbonates and Bicarbonates

The key effect if irrigation water on media pH is not the water pH but the alkalinity of the water. Alkalinity is the concentration of soluble compounds in the water that have the ability to neutralize acids. Alkalinity is related to pH, because water with high alkalinity has a high "buffering capacity" or capacity for neutralizing added acids.

Alkalinity is reported as milligrams per liter (or parts per million, ppm) of calcium carbonate equivalents (mg/l $CaCO_3$) or milliequivalents per liter of calcium carbonate equivalents (meq/l CaCO3). One meq/l $CaCO_3$ = 50 mg/l $CaCO_3$ (Note: 1 mg/l = 1 ppm).

The major chemicals responsible for alkalinity in water are the dissolved carbonates and bicarbonates from the geologic materials of the aquifer from which the water is drawn, such as limestone and dolomite. The dissolved carbonates and bicarbonates increase the media pH over time by neutralizing H^+ ions in the media solution. Rainwater, on the other hand, has no alkalinity.

There are no established optimum or toxic levels for alkalinity. A concentration of 1 meq/l in irrigation water has been reported to be high enough to cause a rise in media solution pH over time. Typical recommendations range from 1 to 1.6 meq/l for plugs, to 2.6 to 3.6 meq/l for plants in 6-inch pots. There are cases where the alkalinity of the irrigation water is low enough to provide no buffering capacity against pH changes. When this happens, media solution pH may decline rapidly when acid-residue fertilizers are used.

Table 2 gives recommended irrigation water alkalinity upper limits for different production systems. In general, the larger the rooting volume, the higher the allowable alkalinity. This is because the media has at least a limited ability to supply H^+ ions to neutralize the alkalinity of the water applied.

Soluble Salts

Soluble salts in water are measured by electrical conductivity (EC_w) expressed as millimhos per centimeter (mmhos/cm), which is equivalent to milliSiemens per centimeter (mS/cm). Electrical conductivity is also referred to as specific conductance or salinity. The irrigation water EC should be taken into account when determining total salts load to a fertilized crop and amount of leaching required to maintain proper media salts levels. EC_w values of less than about 1.5 are acceptable for use with a normal fertilizer program, although values of less than 1 are recommended for plugs. Excess soluble salts impair roots to function properly, which can lead to reduced water uptake and nutrient deficiencies.

Table 2. Recommended irrigation water alkalinity upper limits.

Container	Minimum alkalinity (meq/l)	Maximum alkalinity (meq/l)
Plugs or seedlings	0.75	1.3
Small pots / shallow flats	0.75	1.7
4 - 5 inches pots / deep flats	0.75	2.1
6 inches pots / long term crops	0.75	2.6

Hardness

Hardness is an indication of the amount of calcium and magnesium in the water and is expressed as mg $CaCO_3$/l, or parts per million $CaCO_3$. The amounts of these two elements in irrigation water are variable. For example, ground water from a limestone aquifer may contain more than 100 ppm calcium, while water from a granite or sandstone aquifer may contain less than 10 ppm calcium. Water with hardness in the range of 100 to 150 mg $CaCO_3$/l is considered desirable for plant growth. Plants tolerate high levels of these elements, so toxicity is not normally a problem. However, excessive hardness may cause foliar deposits of calcium or magnesium carbonate under overhead irrigation. Soft water ($<$50 mg $CaCO_3$/l) may need additional calcium and or magnesium over and above that supplied by typical fertilizers to achieve good plant growth.

Major Nutrients

Calcium and Magnesium: These essential elements for plant growth are reported in parts of element per million parts water (ppm) on a weight basis. Calcium in the range of 40 - 100 ppm, and magnesium in the range of 30 - 50 ppm are considered desirable for irrigation water.

Sodium: Wells and municipal water sources may contain high sodium levels. High sodium acts to inhibit plant uptake of calcium, and may result in excess leaching of calcium and magnesium from the media. There is the possibility of foliar absorption of sodium, resulting in leaf burn. Sodium levels of about 50 ppm or less are considered acceptable for overhead irrigation. Because of its effects on calcium and magnesium availability, the amount of sodium in irrigation water should be evaluated when you consider whether you have adequate calcium and magnesium. The effect of sodium is calculated as the sodium adsorption ratio (SAR). If the SAR is less than 2 and sodium is less than 40 ppm, then sodium should not limit calcium and magnesium availability.

Potassium and Phosphate: These plant nutrients generally occur in water at very low levels. Presence in irrigation water at levels higher than a few parts per million may indicate the presence of pollution from fertilizers or other contaminants.

Sulfate: Sulfur is an essential element for plant growth that is not commonly incorporated in fertilizers. It is measured in irrigation water to give an indication of possible deficiency problems. If the concentration is less than about 50 ppm, supplemental sulfate may need to be applied for good plant growth.

Chloride: Wells and municipal water sources may contain high chloride levels in association with sodium. The concern with chloride is the possibility of excessive foliar absorption under overhead irrigation or leaf edge burn caused by excessive root uptake in sensitive plants. If concentrations are less than about 100 ppm, there is no concern from excessive foliar absorption. If concentrations are less than about 150 ppm, there is no concern about toxicity resulting from root uptake.

Ammonium and Nitrate: These nutrients are tested to give an indication of possible contamination of the water source. If present in significant amounts (e.g., >5 ppm nitrate), they should be taken into account in the fertility program.

Micronutrients and Trace Minerals

The most important micronutrients are copper, zinc, manganese, iron and boron. They can occur in excessive or deficient quantities. Excess iron and manganese compounds may result in unsightly residues on foliage under overhead irrigation. Poinsettias are particularly sensitive to boron toxicity and concentrations in irrigation water should be less than 0.5 ppm. Fluoride may also be present in levels high enough to damage foliage plants and Easter lilies. Concentrations in irrigation water should be less than 0.75 ppm. There may be a problem with the use of some fluoride-treated municipal water supplies.

On-Site Water Testing

Electrical conductivity and pH are two characteristics of water quality that can be tested periodically at the growing facility. This helps the grower get an indication of the consistency of the water supply and check the results of treatments to reduce pH or soluble

Table 3. Water purification methods and their applications.

	Total Dissolved Solids	Bicarbonate & Carbonate	Calcium & Magnesium	Dissolved Iron & Manganese	Oxidized Iron & Manganese	Borate	Fluoride
Reverse Osmosis	X	X	X	X		X	X
Deionization	X	X	X	X		X	X
Anion Exchange		X				X	X
Water Softening (Cation Exchange)			X	X			
Activated Carbon							X
Activated Alumina							X
Oxidation/ Filtration				X			
Chelation				X			
Filtration					X		
Acid Injection		X					

salts. pH meters range from inexpensive pen types to more sophisticated units. It is recommended to purchase one that can be calibrated using calibration solutions. This assures that the meter is giving correct readings. Electrical conductivity meters are generally more expensive than pH meters. However, they are very useful for testing water quality and media fertilizer levels during crop growth.

Correcting Water Quality Problems

There are three major categories of water quality problems that can be corrected by chemical or physical treatment systems. Alkalinity can be neutralized by addition of acids. Total dissolved solids, the soluble salts measured together as ECw and individually in ppm of the element, can be removed by several water purification systems. Individual elements can be removed from the water if total dissolved solids are not high enough to warrant total salts removal. Before investing in any treatment system, however, it may be advisable to investigate the possibility of switching to an alternate water source, or mixing water sources, if it is an economical alternative for solving a water quality problem. Water purification methods and their applications are summarized in Table 3.

Neutralizing Alkalinity/pH Adjustment

The ability to correct water pH problems and maintain the proper media pH through the crop cycle depends on the alkalinity of the irrigation water. It takes more acid to decrease the pH of water with high alkalinity than water with low alkalinity.

The only economical way to eliminate alkalinity and lower the pH of water is to neutralize with acid. To calculate the amount of acid required, we need to know the starting pH and alkalinity of the irrigation water. You can either target a pH level or an endpoint alkalinity level during treatment. Targeting a pH of 5.8 should be adequate to prevent slow changes in pH of the media solution over the cropping period. A grower can then monitor the irrigation water and acidification process with a pH meter.

Table 4 gives the approximate amount of acid required to reach an endpoint pH of 5.8 and neutralize about 80 percent of the alkalinity present in the irrigation water. Because it does not take into account the beginning pH of the water, the amount of acid will need to be adjusted. As an example, we can estimate the amount of sulfuric acid (35 percent) needed to neutralize 80 percent of the alkalinity (ending pH of 5.8) if we start with irrigation water that has 4 meq/l alkalinity. At 11 fl. oz for each milliequivalent of alkalinity, it would take approximately 44 fl oz. of 35 percent sulfuric acid to neutralize 1,000 gallons of the water.

You can determine the approximate amount of acid required to neutralize the alkalinity and decrease the pH of your irrigation water by a simple test using a beaker, baby medicine syringe from a pharmacy, phosphoric acid and a pH pen. Put a quart of

Table 4. Approximate acid requirements to reduce alkalinity to an endpoint pH of 5.8.

Acid type	Fluid oz. of acid added to 1,000 gal. water for each meq/l* alkalinity neutralized	Nutrients provided by 1 fluid oz. of acid per 1,000 gal. water
Nitric (67%)	6.6	1.6 ppm N
Phosphoric (75%)	8.1	2.9 ppm P
Sulfuric (35%)	11.0	1.1 ppm S

* One meq/l $CaCO_3$ = 50 ppm $CaCO_3$.

irrigation source water in a glass or plastic beaker. Add the acid a drop at a time using the syringe and keeping track of the amount added. After each addition, stir the water and take a pH reading. When your target pH is reached, note the number of fluid ounces of acid added to the quart of water. Using these numbers, you can calculate the number of ounces needed to adjust the pH of 1,000 gallons of water.

There are merits to setting a target alkalinity endpoint, rather than pH. Setting a target of around 2 meq/l will result in a water pH of 6 to 6.2. This method takes into account seasonal variations in alkalinity that occur in wells, and limits potential problems with plants that naturally change the pH of the root zone (e.g., geranium, dianthus, celosia, begonia).

One can also determine the amount of alkalinity to be neutralized to achieve a desirable level. For example, if your alkalinity is 225 ppm, and you want to reduce it to 100 ppm, then 125 ppm alkalinity must be neutralized. In Table 4, look up 125 in the left column, then just move over to the appropriate column for the type of acid that will be used. If you are using 93 percent sulfuric acid, then 9.3 ounces of acid will need to be added to 1,000 gallons of water to reduce the alkalinity to 100 ppm. An injector will be used to add the acid to the irrigation water.

A computer spread sheet is available to that calculate how much acid is needed to neutralize alkalinity in irrigation water based on beginning soluble salts, pH, and alkalinity. It allows the user to target a pH or alkalinity level to be achieved by acid treatment. The program calculates the ending alkalinity and pH, amounts of the various acids required, nutrients added by each alternative and cost of the alternative acid treatments. If you are interested in the

Table 5. The amount (fluid ounces) of acid to add per 1,000 gallons of water to neutralize a specific amount of alkalinity.

	Fluid ounces of acid to add per 1,000 gallons of water				
Alkalinity ($ppm\ CaCO_3$) to neutralize	**Sulfuric acid 93%**	**Sulfuric acid 33% (Battery acid)**	**Phosphoric acid 85%**	**Phosphoric acid 75%**	**Nitric acid 61%**
10	0.74	2.10	1.75	2.12	3.12
25	1.86	5.24	4.37	5.30	7.80
50	3.72	10.48	8.74	10.60	15.60
75	5.58	15.72	13.11	15.90	23.40
100	7.44	20.96	17.48	21.20	31.20
125	9.3	26.2	21.85	***	39.00
150	11.16	31.44	***	***	46.80
175	13.02	36.68	***	***	54.60
200	14.88	41.92	***	***	62.40
225	16.74	47.16	***	***	70.20
250	18.60	52.40	***	***	78.00
275	20.46	57.64	***	***	85.80
300	22.32	62.88	***	***	93.60

*** Phosphoric acid is relatively ineffective at these higher rates.

computer program, contact the Agricultural Extension office in the Ornamental Horticulture and Landscape Design department at The University of Tennessee.

Alkalinity of acidified water should be retested after one day, and two to three weeks later to be sure the alkalinity is on target and pH is acceptable.

Types of Acids

The common acids used for reduction of alkalinity in irrigation water are: phosphoric (75 and 85 percent), sulfuric (35 and 93 percent) and nitric (61.4 and 67 percent). All acids are dangerous because of their caustic nature. Phosphoric acid is the safest, and nitric the least safe of the listed acids. The most commonly used is sulfuric acid. It is inexpensive, moderately safe and provides sulfur for plant growth. Phosphoric acid is suitable when only 1 or 2 meq/l of alkalinity needs to be neutralized. The amount of acid required to neutralize higher alkalinity levels provides phosphorus in concentrations far above those needed by plants. Nitric acid may be used for reducing alkalinity and supplying nitrogen for plant growth at the same time. Growers who acidify their water should adjust their fertilizer program to take into account the nutrients added in the acid.

All acids should be handled as safely as possible. Droplets of splashed acid are very small and can enter the eyes before you see them. It is very important to wear long sleeves and pants, shoes and goggles when handling any acids. Always add small amounts of acids to large volumes of water.

Water Purification to Remove Total Dissolved Solids

Two commonly used systems to remove of total dissolved solids are reverse osmosis and deionization. Distillation and electrodialysis are water purification processes that can produce very high quality water, but at a prohibitive cost. The reader is referred to the chapter on water purification systems in Reed (1996) for information on these systems.

Reverse Osmosis (RO): This type of system is usually the most cost-effective and commonly used for container crop production. It removes 95 to 99 percent of the total dissolved salts at a cost of approximately $0.02 per gallon. The system works by osmosis, which is the passage of a solvent (water) through a semi-permeable membrane separating two solutions of different salts concentrations. A semi-permeable membrane is one through which the solvent can pass but the solutes (salts) can not. If pressure is applied on the solution with a high salt content (the irrigation source water), the solvent (water) is forced to move through the membrane leaving behind the salts. Relatively pure water accumulates on the other side of the membrane. The process is also sometimes called hyperfiltration. An RO unit capable of delivering 6,000 gallons per day is compact and made up of several long (6 feet) 4-inch diameter tubes that contain the membranes.

The pressure required to force the water through the membrane [150 - 400 pounds per square inch (psi)] requires energy. Two types of membranes are used: cellulose acetate (thin film composite) and polyamide (hollow fiber). Maintenance and replacement of membranes are a significant part of the cost of reverse osmosis systems. Less efficient (50 - 70 percent purification) and less costly membranes are available that require less energy because of their lower operating pressures (100 - 300 psi).

The amount of purified water delivered in a given time and the degree of salts removed depends on the pressure of the system, membrane type, total dissolved solids of the water being purified and temperature. Efficiency is strongly dependent on the integrity and cleanliness of the membranes. Chlorine can cause rapid degradation of the membranes and sediments cause clogging. For this reason, water to be purified by RO is usually pretreated to remove suspended solids, calcium carbonates and chlorine, and the pH is adjusted down if it is above 7.

Although total salts removal can be 95 to 99 percent, individual salts are removed with varying efficiency. In general, calcium, magnesium and sulfate are removed more efficiently than potassium, sodium, lithium, nitrate, chloride and borate.

A disadvantage of reverse osmosis systems is that brine (salty) wastewater is produced. Disposal of this waste may fall under government regulation.

Deionization: The soluble salts in water carry a charge that is either positive (cations) or negative (anions). Examples of cations are: sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}), iron (Fe^{++}) and potassium (K^+). Examples of anions are: chloride (Cl^-), sulfate ($SO_4^=$), bicarbonate (HCO_3^-), and fluoride (F^-).

Deionization is a process that removes ions from water using exchange resins. These are usually solid beads that are covered with fixed negative or positive charges. A cation exchange resin has fixed negative charges that are neutralized by H^+. When the irrigation water is passed over the resin, cations in the water replace the H^+ ions and are held on the resin. Likewise, an anion exchange resin has fixed positive charges that are neutralized by hydroxide ions (OH^-). When the irrigation water is passed over the resin, anions in the water replace the OH- ions and are held on the resin. The H^+ and OH^- ions released from the resins combine to form water. A deionization unit will contain both anion and cation resins so that all salts are removed.

Deionization is very effective and produces a higher quality water than is generally needed in crop production. The cost increases with the amount of salts in the water to be removed. The higher the salts content, the more frequently the resins need to be regenerated or replaced. Cost of deionized water is generally five to six times higher than that of water purified by RO. If high-quality water is required (as for holding cut flowers) and the initial salts content of the water is high, RO can be used as an initial purification step and final quality be achieved by deionization. Final costs may actually be lower than with deionization alone.

Removing Individual Salts

Iron and Manganese: Iron and manganese in water become oxidized to insoluble forms that are responsible for black or brown stains on foliage of plants that are overhead irrigated. Iron concentrations of less than 0.3 ppm are required for micro-irrigation systems. There are several ways to remove these elements. If enough space is available, the least expensive approach is to pump the source water into a pond or tank where the insoluble iron and manganese compounds can precipitate and settle out. The water is often pumped in as a spray for rapid oxidation of the iron and manganese to insoluble forms. Enough time must be allowed for the iron and manganese to settle out, and the holding pond or tank must be large enough to accommodate the irrigation volume needs of the facility without disturbing the bottom layer of sediment containing the iron and manganese.

Oxidation filters also oxidize the iron and manganese to insoluble forms using air, potassium permanganate or chlorine. The sediments are removed by filters that must be periodically cleaned, usually by backflushing. Sand may also be used as a filter. If a chemical oxidant is used, this must be renewed as it is used up. Manganese is slower to oxidize and settle out of the water. For efficient removal of manganese, chemical coagulation before sedimentation and filtering may be required. If iron and manganese bacteria are present, oxidizing filters should not be used. The oxidizing filters will be quickly blinded by the bacteria. In Tennessee aquifers, iron and manganese bacteria are commonly encountered; therefore, chlorination and sand filtration should be used in the presence of bacteria.

Another approach to eliminating problems of precipitates is to keep the iron and manganese in soluble form. Polyphosphate chelates added to water attach to the soluble iron and manganese and keep them from becoming oxidized. The chelate-iron (-manganese) complex then passes through the irrigation system and is not precipitated on plants. Chelation generally works if the soluble iron and manganese concentration in the water is low (less than 1 - 2 mg/l). Furthermore, iron and manganese in the water that has already been oxidized by exposure to air cannot be chelated. Water to which chelates have been added cannot be heated, because heating causes the polyphosphates to break down and release the iron and manganese.

Calcium and Magnesium: Calcium and magnesium may need to removed from hard water to eliminate salt deposits left on foliage by overhead irrigation. This can be achieved by water softening; that is, replacing the calcium and magnesium with potassium. Note that the usual water softening unit uses sodium, not potassium. High levels of sodium may be harmful to plants and a softening unit that uses potassium should be used instead. Total salts content of the water is not changed and the potassium is used by the plants. Overfertilization with potassium may occur if the water is very hard. The potassium chloride in the softening unit must be recharged.

Fluoride: Fluoride can be removed from irrigation water by adsorption using activated alumina or activated carbon. When using activated alumina, the pH of the water is first adjusted to 5.5 The activated alumina unit can be regenerated with a strong base, such as sodium hydroxide, and reused. Water pH does not have to be adjusted before treatment with an activated carbon unit and the carbon is usually replaced when its adsorption capacity is used up. Fluoride is not soluble above pH 6 so maintaining a media solution pH above this level will prevent most fluoride toxicity problems.

Boron: Boron occurs in many irrigation water sources in the anionic borate form. Anion exchange resins similar to those described for deionization systems can be used, but at considerable expense. To increase the boron-removal efficiency of a reverse osmosis system, the pH of the water needs to be adjusted to be slightly alkaline (pH 7.5). Thin-film composite type membranes that are more tolerant of the higher pH should be used.

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