WATER SUPPLY AND WATER QUALITY FOR NURSERY AND GREENHOUSE CROPS

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A sufficient quantity of high quality water is extremely important for the production of nursery and greenhouse crops. Daily irrigation is required during most of the growing season for container crops that are predominantly grown in bark-based potting substrates, in the case of nurseries, and under protected cover that excludes precipitation, as in greenhouse production. This need for frequent irrigation requires careful planning and management, to ensure that operations have sufficient water to maintain adequate supplies for crop production. In addition, many container nurseries capture and recycle irrigation water, not only to protect the environment but also to provide adequate irrigation supplies for production. High quality water is required for a number of reasons, including the prevention of plugging of nozzles, staining of foliage and containers, excessively high substrate salt levels, and improper substrate pH. Water supplies containing iron and bicarbonates frequently require pre-treatment before use. Sediment must be filtered out of water supplies to prevent wear and clogging of irrigation systems. To improve the quality of recycled water, nurseries may use a variety of landscape features including vegetative buffers, grassed waterways and collection structures to slow velocity, filter and direct movement of runoff to collection basins. Various disinfection practices may be installed at nurseries that recycle irrigation water.

Irrigation Water Supply

Greenhouse production uses large volumes of water for irrigation, estimated at 2 quarts per square foot (20 L/m^2) of covered area per day (Bailey et al., 1996). Therefore, a one-acre (0.4 ha) greenhouse uses approximately 22,000 gallons (83 kL) of water per day for irrigation purposes.

Water used for evaporative cooling during the summer months can dramatically increase the total water use. Under “optimum” evaporative conditions, a greenhouse pad and fan cooling system will use as much as 0.045 gallons (0.17 L) per 1,000 cubic feet per minute (cfm) (472 L/sec) of fan capacity. This equates to a peak demand of approximately 19 gallons per minute (gpm) for an acre (180 L/ha) of greenhouse. Evaporative rates vary drastically with temperature and relative humidity conditions. However, an “average” cooling water requirement will be 11 gpm for an acre (100.0 l/ha) of greenhouse. If pad and fan cooling is used 12 hours per day, cooling water use will be about 8,000 gallons per acre per day (75 kL/ha/day) (Bailey et al.,1999; http://www.ces.ncsu.edu/depts/hort/floriculture/hils/HIL557.pdf)

Most nursery crops grown in 1 to 5 gallon (4 to 14 L) containers are irrigated with overhead sprinklers. A single sprinkler nozzle will require 4 to 7 gallons (15 to 26 L) per minute (gpm) for proper performance. For container nurseries a minimum of a 30 day supply of one acre- inch (27154 gal / acre or 102.8 m$^{3.}$ha) should be planned (Bilderback, 2002 b). . Another common recommendation (Furuta, 1978) is to plan for 5 to 10 acre-feet of irrigation water annually per acre (156000 to 31200 kL/ha) of nursery stock. If container stock is irrigated for 163 days a year at the rate of 1 acre-inch per day, approximately 4.5 million gallons per acre (43088 kL/ha) will be required annually. This is equivalent to 14 acre-feet of water per acre (43680 kL/ha) of nursery stock. Therefore, for site development and water supply planning purposes, 14 acre-feet of water per acre (43680 kL/ha) of nursery production area should provide adequate water supplies. In reality, nurseries may need only one-half this amount, using a square irrigation design which can reduce daily irrigation requirement to one half acre inch (9 kL/ha) compared to an acre inch (18 kL/ha) per day for less efficient systems. Furthermore, recharge from rainfall, runoff, wells or streams can reduce the amount of storage needed.

Surface water storage structures are the primary source of irrigation water at most container nurseries. Wells are often used to recharge (dilute/freshen) and re-supply water in storage structures. An estimate of the storage basin capacity can be made by multiplying the average width, length, and depth of the basin to determine the approximate volume in cubic feet and multiplying the result by 7.5 (7.5 gallons = 1 cubic foot). If metric is used, 264 gallons = 1 m^3. Assuming 1/2 inch (1.3 cm) of water is applied per acre of nursery production area per day, dividing the storage capacity by 13,500 gallons (129.3 kL)/acre provides the approximate number of irrigation days for 1 acre (0.4 ha) available from the stored supplies. The number of days for 1 acre divided by the production area in acres gives an estimate of the number of days of irrigation available for the entire nursery. This calculation does not account for evaporation and all other losses of water from the basin, but is useful for planning purposes.

Disinfection and Treatment of Recycled Water

Many wholesale nurseries capture and recycle irrigation water runoff to provide enough water for their container crops. However, recycled irrigation supplies can be a source of pathogenic fungal species such as *Pythium* and *Phytophthora* and possibly other diseases. Recycled water also contains nutrients that support the growth of microorganisms. Therefore, many nurseries have installed irrigation water disinfection systems to remove algae, iron bacteria and other organisms that can create problems for the plants or the irrigation system.

The most common disinfection systems are liquid and/or gas chlorination systems. Other types of disinfection systems include bromination (primarily for propagation), Cu ion generators, hydrogen peroxide, ultra-violet light lamps, and ozonation. All of these disinfection techniques require relatively clean water to be effective; thus pretreatment filtration with screen or disk filters is necessary for overhead sprinkler irrigation and sand media filtration is usually necessary for low volume drip irrigation systems. Depending upon the amount of organic materials in the irrigation water supply, you may need a filter both before and after chlorination to remove free floating debris.

Chlorine is typically used as a disinfectant and oxidizing agent. Chlorine oxidizes ferrous iron (Fe^{++}) to ferric (Fe^{+++}). As a disinfectant, chlorine kills algae, bacteria and other organisms in the water supply. Chlorination also eliminates the energy source for iron bacteria. If large amounts of algae are present in the irrigation water, filters are necessary post-treatment to remove the debris to prevent plugging of irrigation nozzles.

Injecting chlorine into existing irrigation lines requires some retrofitting and installation of backflow devices in the irrigation system, normally near the pump discharge. To be effective, chlorine requires adequate contact time in the irrigation water -- about 1 minute at a minimum of 0.5 ppm (mg L^{-1}) active chlorine. This can be accomplished with storage tanks, swirl chambers or extra loops in the irrigation lines. To reduce the amount of chlorine needed, organic residue should be filtered before the chlorine injector. Usually sand media filters are installed. A minimum of two media filters are recommended, allowing one filter to be backwashed while the other filter operates during irrigation.

Chlorine gas is injected from gas cylinders. Gas is more effective than liquid chlorine but is also considerably more dangerous and may require community notification and even evacuation plans for storage of large quantities of chlorine gas. The greatest danger occurs when cylinders have to be changed, particularly if the cylinders are housed in a building. A locked wire cage with a roof covering is preferable to reduce potential human exposure to gas chlorine when changing gas cylinders (Fig.27). Employee training and safety instructions are essential if gas chlorination is used.

Liquid chlorine injection is a safer alternative. Liquid chlorine (16 % sodium hypochlorite) is usually purchased in 50 gallon (190 l) drums. A variable ratio injector should be used because 16% sodium hypochlorite loses strength over time and the injection rate must be increased. Free chlorine is checked using a swimming pool test kit at the end of an irrigation line or riser and if the test sample turns slightly pink, indicating 1 to 3 ppm (mg L^{-1}), sufficient chlorine has been injected.

More recently, chlorine dioxide has been used for water disinfection as well as many other applications approved by the Environmental Protection Agency (EPA) and Food and Drug Administration (FDA). Chlorine dioxide (ClO_2) has been successfully used for taste and odor control, color reduction, and oxidation of inorganic compounds like iron, manganese or sulfur compounds to improve the aesthetic quality of the drinking water. Interest has been growing in its use as an alternative to conventional chlorine disinfection. The greater efficacy of ClO_2 compared with chlorine, notably at higher pH, points to an increase in its use for disinfection purposes. Chlorine dioxide can be generated in a gas or liquid. Acid-chlorite generators continuously generate and inject chlorine dioxide into the water stream. The dosing pumps add chemical into a reaction chamber and this chamber doses directly into the water stream. The advantage of this technology is that there is no intermediate storage of the concentrated chlorine dioxide solution where degradation can occur. Chlorine-chlorite generators operate on a contiguous basis. An intermediate storage tank of approximately 52 to 132 gallon (200 to 500 L) contains the chlorine dioxide solution at a concentration of around 5 g/L. This tank is level controlled and the low level turns on the generation process. The tank then fills up and stops at the high level. Metering pumps dose the chlorine dioxide solution from the storage tank into the water to be treated. The disadvantage of this technology is the presence of a gas space in the storage tank which causes decomposition and loss of chlorine dioxide. Having large amounts of concentrated chlorine dioxide solution on site can also cause safety concerns. For more information about chlorine dioxide see the EPA website.

All users of sodium chlorite/chlorine dioxide should discuss intended applications with their chemical supplier. Manufacturers have a wealth of experience and can provide assistance regarding possible applications.

Water Quality

As mentioned in the introduction, high quality irrigation water is especially important for greenhouse and nursery production because impurities coat leaf surfaces, reduce plant growth and decrease the marketability of crops. Additionally, many soilless substrates lack the buffering capacity of soils, and therefore alkaline water supplies have drastic effects on availability of nutrients in organic potting substrates. Poor water quality may lead to excessively high salts and pH extremes in the substrate, nutritional problems, fouling of irrigation devices and algae growth. Furthermore, high concentrations of sediment, iron and bicarbonates plug low volume nozzle orifices. Therefore, nursery and greenhouse producers should regularly monitor irrigation water sources for electrical conductivity (EC), pH, and nutrient content. Table 1 lists the most important quality factors to consider for irrigation water for nursery crop use. If test results are above the recommended upper limit for a particular factor, it does not necessarily mean the water source is unacceptable, rather water treatment, a change in management or a change in the fertilization program may be required.

pH and Alkalinity in Water Supplies

The recommended range of irrigation water pH and substrate solution pH for container production depends on the crop species being grown. The generally accepted pH range is 5.4 to 6.8 for irrigation water and 5.2 to 6.3 for the substrate solution. Availability of micronutrients such as iron, manganese, zinc, copper, and boron and future plant growth can be severely reduced by high substrate and irrigation water pH above 6.8. High pH water can also cause salts to precipitate out of fertilizer stock tanks and can also reduce the efficacy of pesticides.

Acid treatment of irrigation water may be needed for container production, if water pH and alkalinity are too high. Alkalinity is defined as the sum of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in solution. High alkaline waters can occur throughout the world.

Water that has high carbonate and bicarbonate levels above 2.0 meq (100 ppm) may require acidification treatment. However, the specific amount of water alkalinity that may be a problem will depend on the crop production time, container size, and crop species. The increase in media pH due to alkalinity will not be a problem for many bedding plants due to short crop times; however, the pH increase will be a problem for the long-term production of many container-grown plants and cut flower crops. While plugs are a short-term crop, they are particularly sensitive to high media pH due to the small container volume. High water alkalinity can cause the pH of plugs to rapidly rise to unacceptable levels. Finally, some crop species such as azaleas (*Rhododendron*) or blue hydrangeas (*Hydrangea*), require low media pH and will be difficult to produce with high water alkalinity. Regardless of the level, alkalinity is too high anytime it causes the media pH to rise to an unacceptable level.

Acidification reduces the amount of these ions in water, resulting in the formation of carbon dioxide and water. Sulfuric (H_2SO_4), phosphoric (H_3PO_4), nitric (H_2NO_3), or citric ($H_3C_6H_5O_7$) acids are commonly injected. In addition to cost, ease of use and plant nutrients, safety is a factor in deciding which acid to use. Citric acid, 75% phosphoric acid and 35% sulfuric acid are relatively safe to work with, compared to the 67% nitric acid. Nitric acid is very corrosive and can cause serious injury to exposed tissue, especially eyes. Nitric acid can also fume during handling, requiring precaution to avoid breathing fumes. (For detailed guidelines on acid treatment of irrigation supplies see information leaflets available at http://www.ces.ncsu.edu/depts/hort/floriculture/crop/crop_water.htm).

Several options are available to control low to moderate alkalinity through cultural practices. Producers that mix their own media can add less lime to the media. For growers who use basic fertilizers such as calcium nitrate and potassium nitrate the water pH and alkalinity can be on the low end of the recommended range to prevent the media pH from increasing to unacceptable levels during production. Growers who use acidic fertilizers, especially in warm climates, can readily use water with the pH and alkalinity in the center or upper part of the recommended range for an individual species.

Producers can rotate among acidic and basic fertilizers. While many premixed fertilizers have relatively high ammonium levels and are acidic, basic nitrate-based fertilizers are available. In addition, growers can combine potassium nitrate and calcium nitrate to make their own basic fertilizer. Unfortunately, high ammonium fertilizers are not feasible in some situations which limits the ability of growers to control media pH through fertilizer choice. High ammonium fertilizers should not be used when the media temperature is below 55^{o}F (13^{o}C) due to slow conversion of ammonium to nitrates by nitrifying bacteria in the media. Ammonium can also produce excessive growth which can counteract height control measures for some crops.

Electrical Conductivity

Electrical conductivity (EC) is a measure of the total dissolved salts (TDS) in any solution. A high concentration of salts provides an osmotic potential that reduces water uptake and increases the uptake of unwanted ions by plants. This results in various symptoms such as wilting, stunting, and the necrosis of leaf margins. Younger seedlings tend to be more sensitive to high salt levels than other crops, so EC monitoring is especially important for plug production of seedlings and in propagation houses.

Water's ability to conduct an electrical current is directly related to the concentration of dissolved salts. Pure water is a relatively poor conductor of electricity, whereas salty water is a good conductor. The greater the EC, the more dissolved salts are present in solution. EC is commonly expressed in units of millimhos per centimeter (mmohs/cm) or deciSemens per meter (dS/m), which are numerically equivalent. The soluble salt level in the irrigation water should

Table 1. Nutrient and Chemical Ranges Occuring for Water, Substrates and Plant Tissue Parameters in Woody Ornamental Crop Production

Quality Factor	Irrigation Water[1] (BMP's)	Substrate Leachate[2] (PourThru)	Plant Tissue[3]
pH	5.4-6.8	5.2-6.3	-
Conductivity	0.2-2.0 mmhos/cm (dS/m)	0.5-2.0 mmhos/cm (dS/m)	-
Total dissolved salts	<1000 ppm	<1400 ppm	-
Bicarbonate	<100 ppm or <2 meq/l	-	-
Alkalinity	<2 meq/l	-	-
(carb. + bicarb.) [1 meq = 50 ppm]	<100 ppm$CaCO_3$	-	-
TC	<2 meq/l	-	-
Hardness	150 ppm or <3 meq/l (Ca + Mg)	-	-
SAR	<10 meq/l		
Na	<3 meq/l or <50 ppm	<50 ppm	0.01-0.1%
Chlorides	<70 ppm	<70 ppm	50-200 ppm
N		25-150 ppm	2.0-3.5%
NO_3-N	<10 ppm	50 ppm	-
NH_4-N	1-2 ppm	50 ppm	-
P	<1 ppm	1-5 ppm	0.2-0.5%
K	<10 ppm	<100 ppm	1.1-2.0%
Ca	<60 ppm	40-200 ppm	1.0-2.0%
Mg	<6-24 ppm	10-50 ppm	0.3-0.8%
S	<24 ppm	75-125 ppm	0.2-0.7%
Fe	0.2-4.0 ppm	0.3-3.0 ppm	35-250 ppm
Mn	<0.5-2.0 ppm	0.02-3.0 ppm	50-200 ppm
Zn	<0.3 ppm	0.3-3.0 ppm	20-200 ppm
Cu	<0.2 ppm	0.01-0.5 ppm	6-25 ppm
B	<0.5 ppm	0.5-3.0 ppm	6-75 ppm
Mo	<0.1 ppm	0.0-1.0 ppm	0.1-2.0 ppm
Al	0.05-0.5 ppm	0.0-3.0 ppm	<300.0 ppb
Fl	<1.0 ppm		

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1. Ranges that generally do not require water treatment.
2. Recommended concentration in leachate collected from substrate. See the following section "Monitoring Container Leachates For EC And pH"
3. Desired concentration in leaf tissue samples

ideally be under 0.75 dS/m for seedlings, less than 1.5 dS/m for greenhouse crops, and less than 2.0 dS/m for nursery crops. Although EC is an indicator of total dissolved salts, it offers little information on what ions are present, and no information on the concentrations of each element. Moderately high EC (0.75 dS/m) during summer months in water supplies might suggest the presence of nitrogen or other nutrients. Under drought conditions, sulfates and chlorides become concentrated in water supplies, rather than essential nutrients. Only laboratory analysis can confirm what management strategies need to be employed.

Monitoring container leachate for EC and pH

Monitoring container leachates can help growers take preventive steps to reduce possible damage to roots due to high electrical conductivity before visible symptoms occur. Some nurseries and greenhouses monitor EC's on a weekly basis, to determine how they will irrigate or fertigate each zone the following week. If the leachate EC is elevated during nursery crop production, more water will be applied the following week to leach out salts. If EC's are low, the irrigation volume will be decreased in those zones the following week. The Southern Nursery Association BMP manual (Yeager et al., 1997) recommends that growers monitor EC at least once a month. For greenhouse production, growers can leach out the salts or fertilizer rates can be reduced, if the EC is too high. If the EC is too low, fertilizer rates can be increased. Data from monitoring EC's can provide valuable insight into the fertilization program, and pre-empt plant growth problems that may arise from excess (or deficient) salts. Monitoring on a frequent basis allows for sound management decisions – the more frequent the monitoring, the better the quality of the data and the more likely that production problems will be caught in a timely fashion.

Nutrient concentrations, pH and electrical conductivity levels can be monitored by using the pour through extraction procedure (Wright et al. 1986). The procedure requires pouring enough water over the surface of the substrate to collect approximately 2 fl. oz. (50 ml) leachate solution from containers about 30 minutes to 2 hours after irrigation, and collecting the effluent that comes out of the bottom of the container (Fig.28). Alternatively growers can collect solution that drips out of the container 30 minutes to 2 hours after irrigating. The BMP manual for nurseries suggests minimal levels for EC should range from 0.2 to 0.5 dS/m for controlled release fertilizers (CRF's) and 0.5 to 1.0 dS/m for liquid feed or combinations of CRF's and liquid. Maximum EC levels for most plant species grown in pine-bark based substrates should not exceed 2.0 dS/m. For greenhouse, less than 2.6 dS/m is considered low for most crops, 2.6 to 4.6 dS/m is normal, and greater than 4.6 dS/m is high. Levels greater than 7.8 dS/m will generally result in rapid crop injury and immediate leaching is required.

To test the leachate solution, a grower needs to purchase a pH and conductivity meter. Inexpensive glass electrode pH pens and conductivity pens provide accurate results and can save thousands of dollars in crop losses. Sending the leachate solution for laboratory analysis at least once during the growing season is a good practice to determine actual nutrient levels in the container and correct them if needed . Leachate analysis and plant tissue analysis are the best diagnostic steps to determine nutritional disorders. Other methods such as 1:2 substrate:water dilution, press test, and saturated media extract can also be used, especially in greenhouse production, to determine substrate EC, pH, and nutrient conditions.

Sodium Absorption Ratio (SAR)

Greenhouse and nursery crops have minimal sodium requirements. The SAR is a calculated value that indicates the concentration of sodium relative to that of calcium and magnesium. Irrigation water having an SAR above 4 can result in root uptake of toxic levels of Na (sodium). Water containing greater than 3 meq/L sodium should not be used for overhead irrigation of ornamentals and greenhouse plants as foliar absorption of sodium can lead to sodium toxicity with sensitive species. Sodium toxicity, whether due to root absorption or foliar absorption of Na, is expressed as marginal leaf burn on older foliage.

Damage from high sodium concentration in irrigation supplies can be partially prevented by the addition of calcium. Dilution of sodium using an alternative water supply is another method to reduce high sodium problems in water supplies. To calculate the approximate SAR of water, sodium (Na), calcium (Ca) and magnesium (Mg) concentrations are entered as meq/L in the following formula:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

In the nursery, the SAR should be less than 10 and in the greenhouse, the SAR should be less than 4 with a maximum of 8.

Macro Elements

The macro elements nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) are essential for plant growth. At moderate levels, these elements do not cause production problems. The concentration of N, P, and K should be evaluated as an indicator of potential contamination and alternatively sources of these nutrients in irrigation water. For example, concentrations of N or K greater than 10 ppm (mg L^{-1}), or concentrations of P greater than 1 ppm (mg L^{-1}) in ground water suggests that the water has been contaminated with a fertilizer or nutrients from other sources, such as septic systems, or from organic sources such as manures.

Concentrations of Ca, Mg, and S in irrigation water should be analyzed for fertilizer requirements. Calcium and magnesium are normally found in irrigation water in the ranges given in Table 1. It is acceptable to use water containing the highest levels of Ca and Mg listed, if the amount of calcium and magnesium supplied in the fertilizer program is reduced and if the ratio of calcium to magnesium in the water source is within acceptable limits. Ideally the calcium to magnesium ratio in the substrate solution (and in the irrigation water) should be 3 Ca to 1 Mg if expressed as meq/L or about 5 Ca to 1 Mg if expressed as ppm. If the ratio is significantly different, a deficiency may occur in the nutrient that is undesirably low. The most common problem is a low level of magnesium relative to calcium (i.e. high ratio). In this case it is necessary to supplement occasionally with a Mg source such as magnesium sulfate (epsom salts). Examine the ratio of calcium to magnesium (Ca:Mg) in the water to anticipate whether the substrate Ca : Mg will tend to shift out of the desired range.

Sulfur concentrations in irrigation water are usually less than 25 ppm (mg L^{-1}), and excessive sulfur is not normally a problem, except where acidification poses problems. Table 1 lists recommended levels of sulfur for best plant growth. It is not usually necessary to add sulfur to reach these recommended levels, as sulfur is a common contaminant of many fertilizer sources. Tissue tests will confirm whether your fertilization program has sufficient sulfur.

Micro Elements

Irrigation water can contain small concentrations of aluminum (Al), boron (B), copper (Cu), fluoride (Fl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). With the exception of Al and Fl, these elements are essential to plant growth and are required in small quantities. Aluminum in irrigation water is rarely found in concentrations high enough to lead to toxicities, and should not be a major concern for most growers. Fluoride is often added to municipal water at a concentration of 1 ppm (mg L^{-1}) to prevent tooth decay. This level is safe for most crops but not for members of the lily family and a few other plants. Toxic levels of fluoride cause tip scorch of the older leaves.

Among the plant micronutrients found in water, boron can be particularly troublesome. A concentration less than 0.5 ppm (mg L^{-1}) is safe for any irrigation use. A level greater than 0.5 ppm (mg L^{-1}) could lead to toxicity symptoms in boron-sensitive crops. Boron toxicity can first show up as orange-brown necrosis along the margins of older leaves. Flecking can also occur on the underside of leaves. Boron deficiency can also be a problem, particularly when soilless substrates have been overamended with lime to correct for seemingly low pH's. In such cases, boron is complexed by Ca and therefore not available for plant growth. Excessive bud proliferation with small stunted (chlorotic) young leaves is a striking symptom often associated with B deficiency.

Other micronutrients that can be excessive in irrigation water are iron, manganese, zinc, and copper. Assure that concentrations of these elements are below the levels listed in Table 1 prior to using water. Micronutrient toxicities are more likely to occur when the substrate pH is low, rendering the micronutrients more available for plant uptake. Low pH induced iron or manganese toxicity is a common occurrence in greenhouse production of a geraniums, marigold (*Tagetes*), and New Guinea impatiens (*Impatiens*). If the water contains high micronutrient concentrations, the fertilization program should be adjusted to prevent an overabundance of the elements.

Chloride

Though not usually considered an essential micronutrient, chlorine (as chloride) is needed in small quantities by plants. However, chloride levels greater than 2 meq/L can become a production problem. The principal effect of too much chloride (Cl_-) is to increase the osmotic potential of the substrate solution, which reduces the availability of water to plants and can lead to wilting. High chloride levels can also lead to Cl toxicity symptoms in container production. When Cl is taken up by plant roots, it is transported to leaves, where Cl accumulates. Some species, such as roses, azaleas, camellias, and rhododendrons develop leaf edge burn, leaf necrosis, and leaf abscission when too much chloride is accumulated. Dilution using an alternative water source is the best method to reduce high chloride levels problems in water. Reverse osmosis can also be used, especially for propagation and salt sensitive crops.

Iron and Iron Bacteria

A high iron concentration in irrigation water can lead to aesthetic and nuisance problems (Fig. 16). Overhead irrigation with water containing 0.5 ppm (mg L^{-1}) or more of iron frequently results in a red-brown stain on leaves and containers, making the plants more difficult to sell. Iron concentrations above 0.3 ppm (mg L^{-1}), and the resulting oxidation of iron by bacteria can plug small orifice emitters used for drip irrigation. Well-water containing iron can be pumped into irrigation basins and some of the iron will settle out.

However, the presence of iron-fixing-bacteria can confound iron related problems. Iron bacteria occur naturally in the soil and can be a problem in well and surface irrigation sources. In wells, iron bacteria often plug submersible pumps and cause them to fail. In surface irrigation basins, an oily sheen over the surface of the water is frequently due to iron bacteria (Fig. 17). Iron bacteria keeps the iron in the water from settling out. Plants show both a reddish brown and a bluish-bronze coating when overhead irrigated (Figs.29 and Fig. 30).

Growers can avoid or reduce the problem of iron deposits by making sure that pump intakes are 18 to 30 inches (45 to 75 cm) below the surface of the water but well above the bottom of the water basin. Pump intakes too close to the bottom of the basin pull iron sediment off the bottom. If adjusting the intake is not possible, the other choices are more expensive. The first step is to have the water analyzed at a laboratory. A foliar sample from coated plants is also useful in determining how much iron residue is deposited on the plants. If the iron content is high enough to cause problems, an aeration pump can be placed within approximately 50 ft (15 m) of the pump intake. The aeration pump will directly aerate iron, reducing the amounts available for reduction by iron bacteria. The wave action of the pump also helps keep algae and iron bacteria pushed away from the irrigation pump intake. If aeration is ineffective, iron can be removed through chemical injection and subsequent filtration.