Water Quality and Irrigation

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Water is the single most important biological factor affecting plant growth and health. Water is essential for nearly every plant process: photosynthesis, nutrient transport, and cell expansion and development. In fact, 80 to 90 percent of a seedling's weight is made up of water. Therefore, irrigation management is the most critical aspect of nursery operations (figure 11.1). In tropical nurseries, managing water depends on local climate. Finding and storing high-quality water is a challenge in dry climates, whereas controlling high humidity can be a problem in the humid tropics.

Determining how, when, and how much to irrigate is a crucial part of nursery planning and day-to-day operations. One missed irrigation can cause serious injury and even death to plants, especially during the establishment phase. Adequate watering is particularly important with container plants whose roots cannot access water beyond their container and therefore are entirely dependent on receiving enough water through irrigation. Excessive watering and humidity are also problematic; they are a major cause of root diseases and contribute to other problems with seedling growth.

Tropical nurseries typically grow a wide range of species with different water requirements. In addition, the distinct plant growth phases (establishment, rapid growth, and hardening) require different watering regimes. Designing an effective and efficient irrigation system is based on which types of irrigation practices and systems best serve plant needs at each developmental phase. The nursery might have various propagation areas and corresponding irrigation zones that provide for the changing needs of plants during all phases of growth. For example, the same nursery might have a mist chamber for the germination phase, a subirrigation system in the growing area, a selection of rare plants that receive daily hand watering, and some large plants under drip lines. The best design for any irrigation system will come from understanding the needs of the plants, the factors that affect water availability, and the details of how, when, and why to water.

Facing Page: *Water is a precious resource and the most important biological factor for plant health and growth. Pe‘epe‘e Falls, Wailuku River State Park, Hawai‘i. Photo by Douglass F. Jacobs.*

Sources of Irrigation Water

Tropical plant nurseries can use water from several different sources, including rivers, ponds or reservoirs, rainwater, groundwater, and municipal sources. New nurseries need to evaluate the quantity, quality, and seasonal availability of all potential water sources. Surface water, such as rivers and streams, are typically dammed or diverted into ponds that have enough capacity to meet the water demands of the nursery. Groundwater can be pumped for nursery use, but generally the water is stored in a pond or reservoir. For either surface or groundwater, a hydrologic survey and analysis of local water rights needs to be conducted before nursery development. Surface water sources that have flowed through agricultural land need to be tested for waterborne pests or herbicides and may need to be treated. A wide variety of nursery pests have been detected in water supplies including fungi, nematodes, viruses, and bacteria (Zeng and others 2009). The water mold fungi (*Pythium* and *Phytophthora* species) are particularly destructive because they have a mobile stage.

Municipal water can be used for nursery purposes, but it may have been chemically treated with chlorine or fluoride. Low levels of chlorination guard against human pathogens, and studies have shown water with 2 ppm of free chlorine will not injure woody species (Cayanan and others 2008). Fluoride is added to some municipal drinking water at around 1 ppm to prevent cavities in children (Fawell and others 2006). Fluoride phytotoxicity has been documented for some nursery plants. Leaf damage to ti (*Cordyline fruticosa*) plants has been reported in a Hawaiian nursery, and the nursery recommends that irrigation water contain less than 0.25 ppm fluoride (Kaapuni Nursery 2011).

Rainwater is an attractive source of high-quality water for tropical nurseries if enough can be stored to supply all the needs. In high-rainfall areas, water can be collected from the roofs of buildings and then stored in tanks until needed. A special rainwater collection system is being used to supply water for irrigation at the native plant nursery at Volcanoes National Park in Hawai‘i (figure 11.2A). In these ground-level systems, the water must be pumped to generate enough pressure to run sprinklers in the nursery. In mountainous regions, rain water can be collected and stored in ponds or tanks above the nursery. Enough water pressure can be generated by the difference in elevation to run small microsprinklers or drip irrigation systems in a nursery. The water pressure can be calculated (figures 11.2B, 11.2C) or measured directly at the point of use in the nursery. A full discussion of all types of irrigation designs and calculations is available in Stetson and Mecham (2011).

Figure 11.1*—A supply of good-quality water is one of the most critical requirements for a native plant nursery. Photo by Brian F. Daley.*

Advantages of a Well-Designed Irrigation System

- Better plant quality and health
- Lower labor costs
- Improved crop uniformity and reliability
- Reduced runoff and waste of water

Attributes of Good Water Management

- Reliable source of water
- Efficient use of water
- Flexible approach tailored to the changing needs of the species grown and their development phases
- Responsible reuse, recycling, and management of any runoff water

Water Quality

Irrigation water quality is a critical factor in initial site selection and affects all phases of nursery management. Improving poor-quality irrigation water is expensive, often prohibitively so. Therefore, water quality needs to be a primary consideration during nursery site evaluation.

For irrigation purposes, water quality is determined by two factors:

- The types and concentrations of dissolved salts (total salinity and individual toxic ions).
- The presence of pests (pathogenic fungi, weed seeds, algae, and possible pesticide contamination).

Salts

For our purposes, a salt can be defined as a chemical compound that releases charged particles called ions when dissolved in water. Some salts are fertilizers that increase plant growth rates, while other salts can reduce growth or even cause injury or death. For example, sodium chloride (ordinary table salt) dissolves into harmful ions that can damage or even kill plant tissue.

An excess of dissolved salts in nursery irrigation water can clog nozzles (figure 11.3A), accumulate in growing media, and eventually harm plant tissue (figure 11.3B), The most characteristic symptom of high salinity is burn or scorch of leaf margins or tips (figure 11.3C). Symptoms can

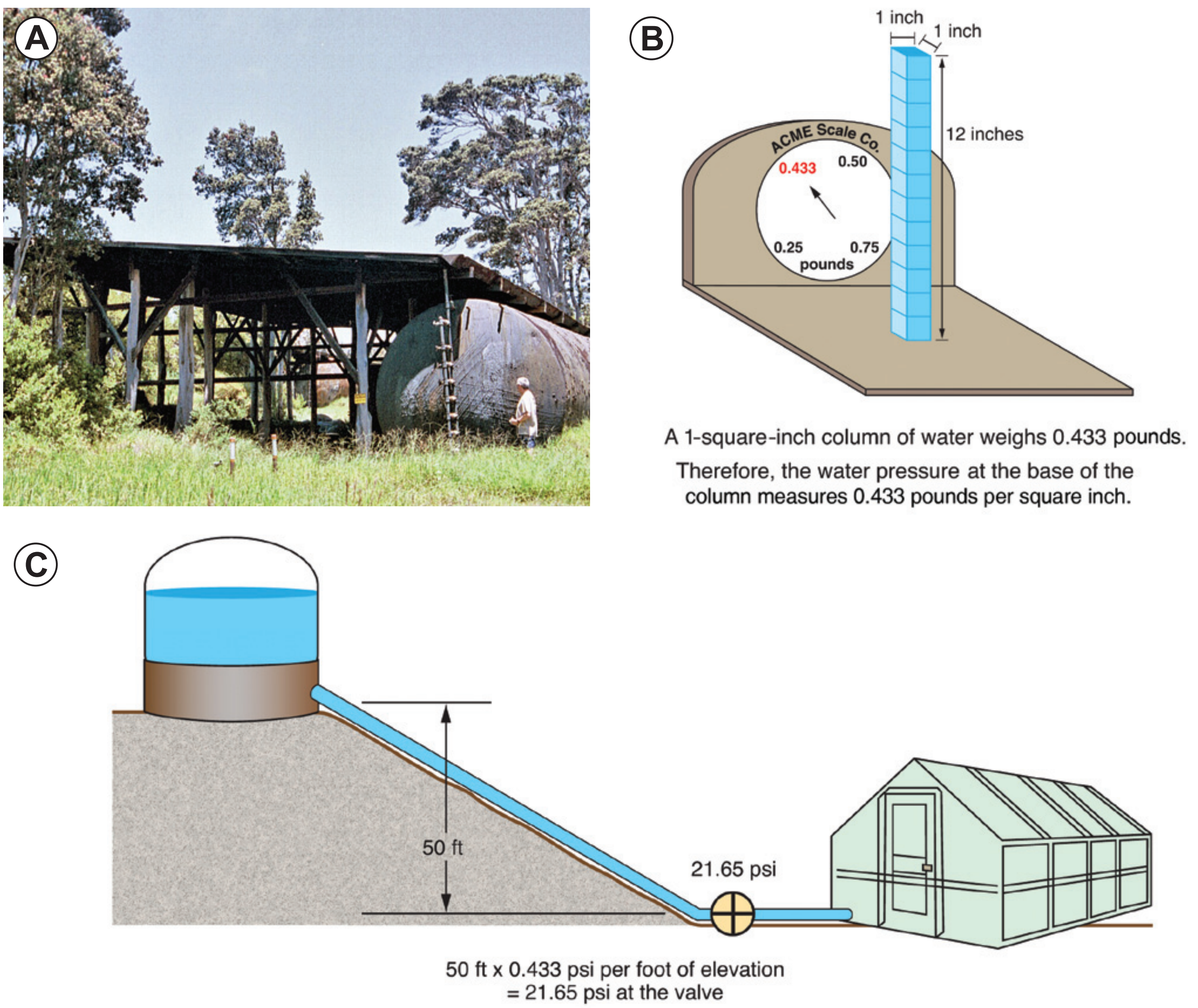

Figure 11.2—Rain collection systems are possible in high-rainfall climates (A). If the storage tanks are located at higher elevations, enough static pressure can be generated (B) to operate drip or microsprinkler systems in the nursery (C). Photo A by Thomas D. Landis, and illustrations B and C modified from Stetson and Mecham (2011) by Jim Marin. [Metric conversions: 1 in = 2.5 cm; 1 ft = 0.91 m; 1 psi = 0.007 MPa; 1 pound = 0.45 kg.]

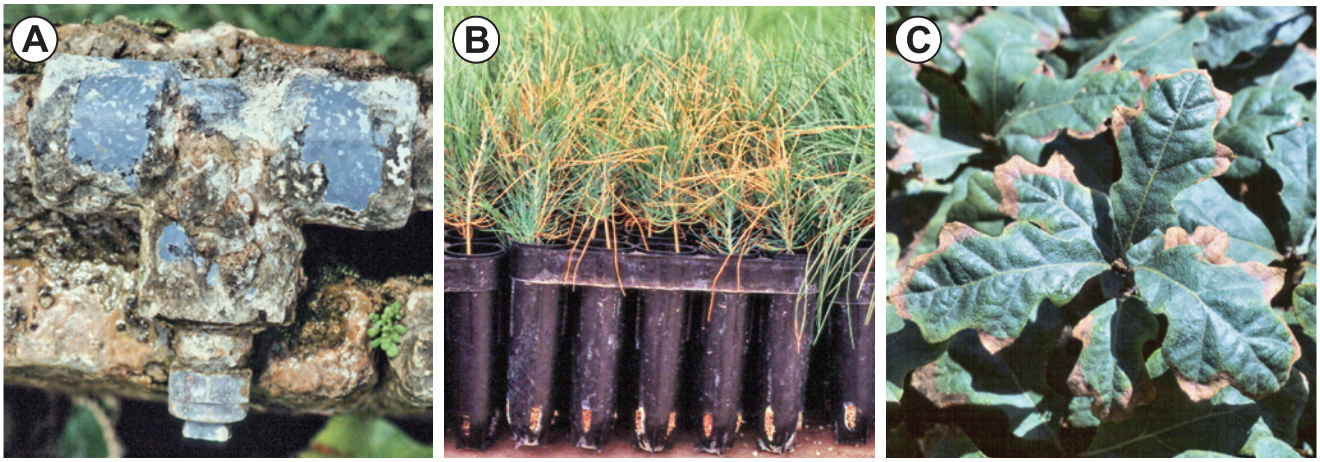

Figure 11.3*—Agricultural water quality is determined by the level of soluble salts because they can build up on irrigation nozzles (A), accumulate in containers, usually around the drainage holes (B), and eventually "burn" seedling foliage (C). Photos by Thomas D. Landis.*

vary with species but can include foliar tip burn, scorching or bluish color on leaves, stunting, patchy growth, and eventual mortality. The principal damage of high salinity is reduced growth rate, which usually develops before more visible symptoms become evident.

Other ways excess dissolved salts may affect nursery crops include the following—

- Water availability to the plant is reduced resulting in growth loss.
- Some ions (sodium, chloride, boron, and fluoride) are directly toxic to plants.
- Other ions (calcium) affect mineral nutrient availability.
- Other ions (bicarbonate or iron) cause salt crusts or staining.

An excess of dissolved salts in the water can be the result of a number of factors. The local climatic or geologic influences at the nursery's location are significant. In arid or semiarid climates where evapotranspiration exceeds precipitation, salts naturally accumulate in the soil, and ground water irrigation sources are often high in salt content. In coastal areas, saltwater intrusion can lower water quality. On Guam, the geology of the northern half of the island is formed from uplifted coral whereas the southern half is volcanic (Gingerich 2003). From a nursery standpoint, this distinction is that the groundwater in the north is very high in pH and calcium and in the south, the water is low in pH and dissolved salts. High fertilization rates or poor irrigation practices can also lead to salinity problems. Studies have shown that soluble salt levels double when the growing medium dries from 50- to 25-percent moisture content.

It is expensive to remove salts from irrigation water, so ideally the nursery needs to be established on a site where water salinity is within acceptable levels. Test results for salinity are traditionally expressed as electrical conductivity (EC); the higher the salt concentration, the higher the EC (table 11.1). The EC can be checked at the nursery using a conductivity meter or by sending water samples to a local laboratory. The most commonly used units in irrigation water quality are micromhos per centimeter (abbreviated as µmho/cm and pronounced "micro-mows") and the International System of Units of microsiemens per centimeter, which are equivalent. Microsiemens per centimeter (abbreviated as µS/cm) will be used as the standard EC unit in this handbook. General guidelines for salinity ranges are in table 11.1.

Irrigation water salinity tests need to be conducted before nursery establishment and retested periodically thereafter.

Table 11.1*—Water-quality standards for nursery irrigation water. Adapted from Landis and others (1989) and Robbins 2011.*

Quality index	Optimal	Unacceptable
pH	5.5 to 6.5	
Salinity (µS/cm)	0 to 500	>1,500
Sodium (ppm)	<50	>50
Chloride (ppm)	<70	>70
Boron (ppm)	<0.75	>0.75
Fluoride (ppm)	<1.00	>1.00**
Iron (ppm)	<1.00	>1.00

** Sensitive species may be damaged at lower levels

Table 11.2—Water-quality test results from Micronesian Islands.

Island	Electrical conductivity (µS/cm)	Quality rating (see table 11.1)
Guam (North)	840	Marginal
Guam (South)	150	Good
Saipan	1,860	Poor
Yap	185	Good
Palau	60	Good
Pohnpei (domestic)	125	Good
Pohnpei (rainwater)	16	Good

EC tests were conducted at native plant nurseries in some of the Micronesian islands and the results reflect local geology (table 11.2). As previously mentioned, the northern part of Guam is limestone and the EC is much higher than the volcanic soils in the southern part. The water in Saipan has very high EC readings because of limestone soils, and this marginal water quality can be seen in the nursery.

Water tests are particularly important in areas with high salinity because the addition of fertilizer could raise salinity to unacceptable levels (figure 11.4). In these cases, a nursery would need to be careful to use very dilute fertilizers, low-nutrient concentrations of organic fertilizers, or controlled-release fertilizers to keep salinity within acceptable ranges. See Chapter 12, Plant Nutrition and Fertilization, for details. Horticultural practices such as increasing the porosity of the growing medium and leaching more frequently when watering can also help alleviate the effects of saline water.

Pests

Tropical nurseries that use irrigation water from surface water sources such as ponds, lakes, or rivers may encounter problems with biotic pests; that is, weeds, pathogenic fungi, moss, algae, or liverworts. Surface water that originates from other nurseries or farmland is particularly likely to be contaminated with water-mold fungi, such as *Pythium* and *Phytophthora*, which cause damping-off. Recycled nursery irrigation water should also be suspect and needs to be analyzed. Many weed seeds and moss and algal spores are small enough to pass through the irrigation system and can cause real problems in nurseries. Chlorination and some specialized filtration systems may remove many disease and pest organisms from irrigation water, as discussed in the following section.

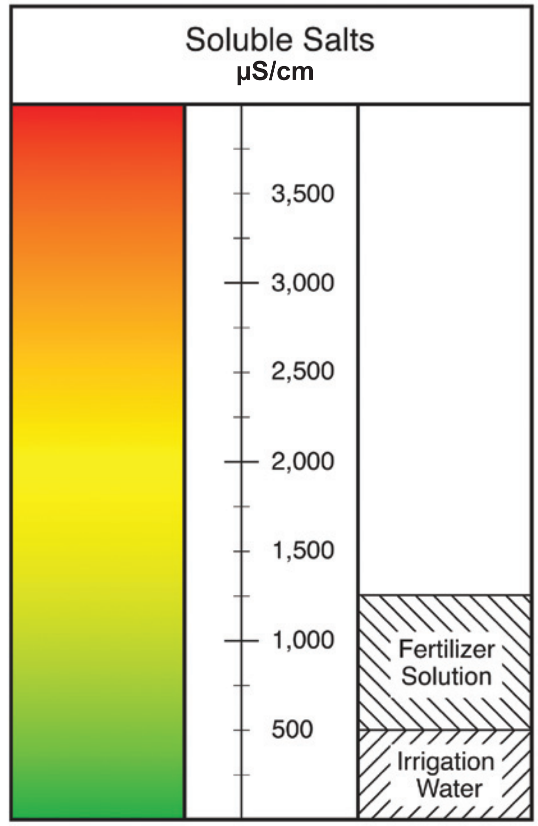

Figure 11.4*—When soluble fertilizers are injected into the irrigation system, salinity levels are cumulative. For example, a nursery with a base irrigation salinity of 500 µS/cm has good quality, but after soluble fertilizer is added, the total salinity can reach into the zone of caution. Illustration from Dumroese and others (2008).*

Irrigation water, especially in agricultural areas, may be contaminated with residual pesticides. Herbicides applied to adjacent cropland or to control aquatic weeds in reservoirs can affect ground water. Potential sources of irrigation water need to be tested for pesticide contamination when a nursery site is being evaluated.

Testing Water Quality

A water-quality test needs to be done before the nursery site selection is finalized to ensure adequate quality and quantity of water will be available before the nursery is established. A water-quality test can be repeated when the nursery is established and again at yearly intervals. A complete analysis of irrigation water quality consists of a salinity evaluation listing the concentrations of sodium, chloride, and boron, which are reported in parts per million (ppm). In addition to the individual ion concentrations, the analysis needs to include three standard water-quality indices: EC, toxic ion concentrations, and pH. Most labs have a standard irrigation water-quality test, which will cover all these concerns.

Irrigation water also needs to be tested for the presence of pathogenic fungi during the site selection process, and again if a problem is observed at a later date. Most plant pathology laboratories can conduct bioassays of irrigation water.

Testing for residual herbicides is also possible but can be expensive because of the sophisticated analytical procedures required. Because of the different chemical structures of various pesticides, a separate analysis for each suspected pesticide is usually required. Therefore, pesticide tests are generally considered only when a specific problem is suspected.

To collect an irrigation water sample, use a clean plastic bottle with a firm, watertight lid. A 16-fluid-ounce (475-ml) container is ideal for most water tests. To begin, let the water run for several minutes (figure 11.5), and then rinse the sample bottle well before collecting the sample. Label the sample bottle properly with a waterproof marker before sending it to the analytical laboratory. The sample needs to be sent away for testing as quickly as possible but can be stored under refrigeration for short periods, if necessary. Most laboratories charge \$25 to \$50 and will provide results within a few weeks.

***Figure 11.5**—Water quality needs to be tested before nursery establishment and then every few years to make certain that the quality has not changed. Photo by Brian F. Daley.*

Water Treatments

Establishing the nursery on a site with tested, good-quality water is the best way to preclude water-related problems. If existing water quality is poor, methods such as deionization and reverse osmosis can treat and improve irrigation water, but they are often prohibitively expensive and not feasible for most tropical plant nurseries. To correct or safeguard against minor problems with otherwise good-quality water, however, some treatments are low cost and highly effective for container nurseries.

Chlorination

Chlorination can be used to kill fungi, bacteria, algae, or liverworts introduced through the irrigation system (Zheng and others 2009). Studies have shown that *Pythium* and *Phytophthora* can be controlled with 2 ppm of free chlorine without injury to woody species (Cayanan and others 2008).

Filtration

Filtration is used to remove suspended or colloidal particles such as very fine sand or silt. Filtration prevents problems such as plugging or damaging irrigation or fertilization equipment. Filters also remove unwanted pests such as weed seeds or algae spores. Two types of filters are commonly used in nurseries: granular medium filters consist of beds of granular particles that trap suspended material in the pores between the particles and surface filters use a porous screen or mesh to strain the suspended material from the irrigation water. Granular medium filters can be used to remove fine sand or organic matter and are constructed so that they can be backflushed for cleaning. Surface filters include screens or cartridges of various mesh sizes to remove suspended material (figure 11.6A); screens must be physically removed and cleaned whereas cartridge filters are not reusable and must be regularly replaced. Jones (1983) recommends cartridge filters because they are easy to change. Backflushing screens or granular medium filters is not practical with many nursery irrigation systems.

Filters need to be installed at a location before the water passes through the nutrient injector to intercept sand particles that can cause excessive wear or plug valves (figure 11.6B). Handreck and Black (1984) recommend using filters small enough to remove particles

Chlorination with Household Bleach To Treat Water for Pests

- Mix household bleach (5.25-percent sodium hypochlorite) at a rate of 2.4 ounces of bleach per 1,000 gal of water (18 ml per 1,000 L).
- This low dose (about 1 ppm chlorine) was not found to be phytotoxic to a wide range of plant species, and it has been successful in controlling moss and liverwort on noncrop surfaces.

greater than 5 microns in diameter, which will take care of most suspended materials (figure 11.6C). Specialized filtration systems, such as those manufactured by Millipore Corporation, can remove particles around 1 micron in diameter; such a system is therefore capable of removing some disease organisms and most suspended solids. More sophisticated filtration systems are relatively expensive and require frequent maintenance (Jones 1983).

Water Quantity

The amount of water necessary to produce a crop of container plants depends on many factors, such as climate, type of growing structures, type of irrigation system, growing medium, plant species, number of plants being grown, and container size. The amount of water to grow a crop will vary tremendously between humid and arid locations. Some examples of water use data from nurseries in the mainland United States are provided in table 11.3.

Remember that a nursery also needs water for operational requirements other than irrigating crops. Mixing growing media, cleaning containers, structures, and equipment, and providing for staff personal water needs all increase water use. Also, a nursery that starts small may choose to expand. Therefore, ensure that an abundance of water is available to meet present and future needs.

Even in cases in which the nursery has access to a steady, reliable, high-quality water source, a backup system is always a good idea in case of emergency. A prudent investment is a backup water storage tank containing sufficient water to meet the nursery's needs for at least 1 week (figure 11.7). Backup systems may be pumped into the normal irrigation system, but it is advantageous to locate the storage tank upslope so that water can be supplied by gravity in case of power failure.

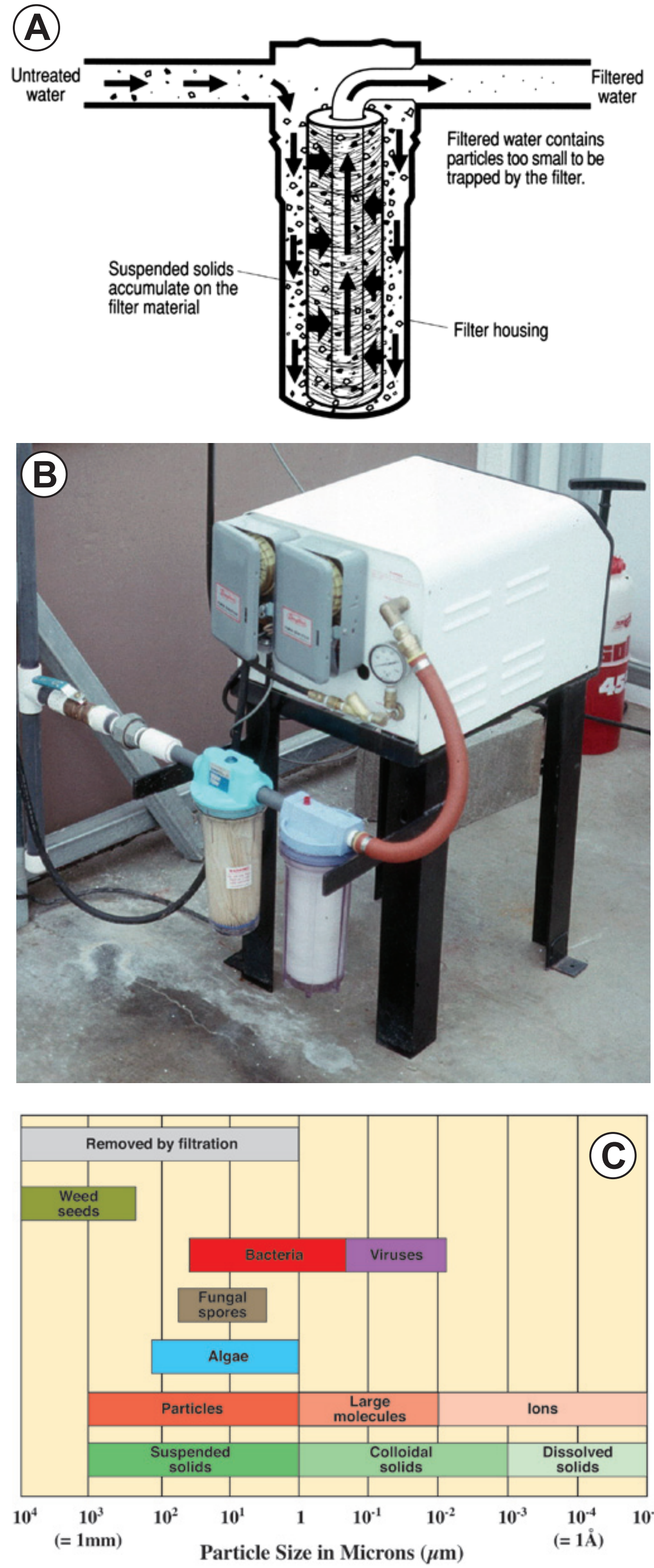

***Figure 11.6**—Cartridge filters (A) are an effective and inexpensive way to treat irrigation water: they need to be installed before the fertilizer injector (B) and can remove sand, silt, and fungal and algal spores (C). Illustration A from Dumroese and others (2008), photo B by Thomas D. Landis, and illustration C adapted from Tchobanoglous and Schroeder (1985) by Jim Marin.*

Factors Affecting Water Availability to Plants

Plant water use is affected by environmental conditions such as humidity, temperature, season, and the amount of sunlight the plants receive. The growth phase of the crop will also affect the rate of evaporation and transpiration. During seedling germination and early emergence, evaporation is the primary cause of water loss (figure 11.8A). After the seedling's roots occupy the container, however, transpiration becomes the primary force for water loss (figure 11.8B).

The type of growing medium also influences water availability and use. Common components of artificial media behave very differently than soil. Peat moss and vermiculite have a high water-holding capacity, whereas perlite and pumice do not. Water infiltration and drainage are much higher with artificial media than with mineral soils. The average pore size of the growing medium is the most significant influence. All things being equal, a finer textured growing medium with a smaller average pore size holds more water than a coarser textured medium does (figure 11.9). See Chapter 6, Growing Media, for more details on this topic.

Container type, volume (table 11.3), and shape also affect water availability. Water in a container behaves differently than water in unconfined soil because it does not drain completely, resulting in a layer of saturated medium at the bottom (figure 11.8B). The height of this saturated medium is a function of the growing medium, but taller containers will have a smaller proportion of saturated medium than shorter ones (see Figure 7.2 in Chapter 7, Containers).

The small top opening of some containers in relation to their volume can make it difficult to get water into the containers with typical sprinkler irrigation, resulting in considerable variation in growing medium water content from one container to another. This distribution problem becomes even more critical when the plants become larger and their foliage begins to intercept water before it can reach the surface of the container. Subirrigation (described later in this chapter) and hand watering are sometimes used to overcome this problem. Because small containers have a correspondingly small volume of growing medium, they have limited moisture reserves and require frequent irrigation, especially in times of high evapotranspirational losses.

Figure 11.7*—A backup water storage tank containing sufficient water to meet the nursery's needs for at least 1 week is a prudent investment. Photo by Thomas D. Landis.*

Determining How Much To Irrigate

When irrigating container nursery crops, it is important to apply enough water during each event to more than saturate the medium so that a small amount of leaching occurs. In other words, apply enough water so

Table 11.3*—Typical irrigation use in forest and conservation nurseries for a crop of 1,000 conifer seedlings on the mainland of the Western United States. Adapted from Dumroese and others (2008).*

Nursery and location	Container type and volume	Irrigation water use per week (gallons [liters])	
		Establishment phase	Rapid growth phase
University of Idaho, Moscow	Ray Leach Cone-tainer™ 4 in^3 (66 ml)	10 (38)	15 (57)
Mt. Sopris, Colorado	Ray Leach Cone-tainer™ 10 in^3 (172 ml)	15 (57)	50 (189)
University of Idaho, Moscow	Styroblock™ 20 in^3 (340 ml)	60 (227)	125 (473)

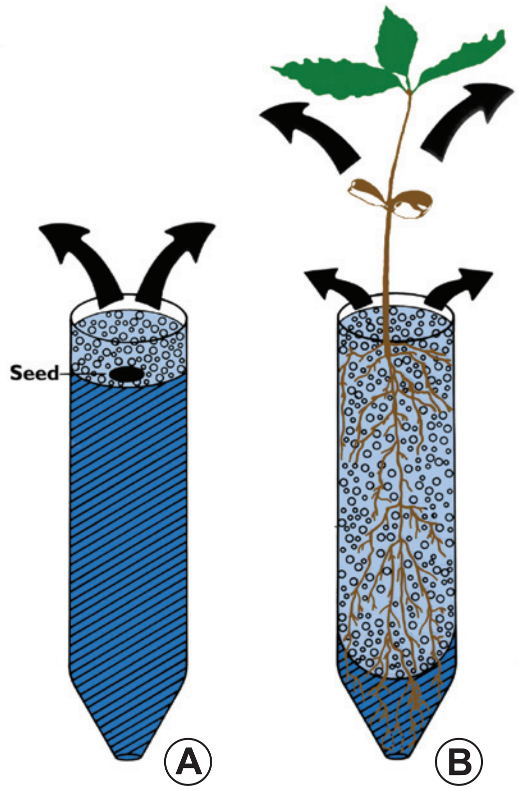

Figure 11.8—The amount and type of water use changes dramatically during the growing season. During the establishment phase, a relatively small amount of water is used by evaporation (A) but, when the seedling fully occupies the container during the rapid growth phase, a much greater amount is used for transpiration with relatively little lost to evaporation (B). Illustration adapted from Landis and others (1989).

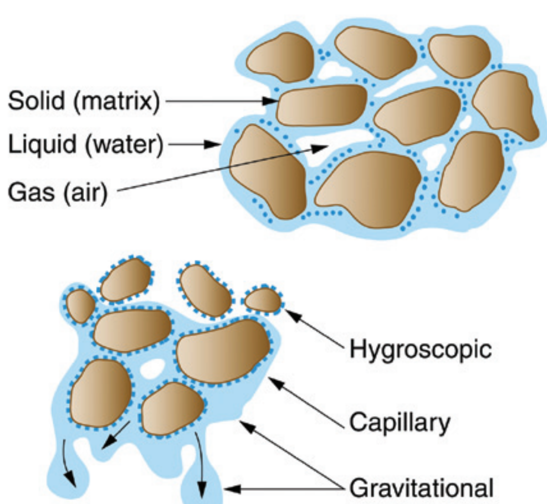

Figure 11.9—Water is held in the pores between particles by capillarity. For any growing medium, the larger the particles, the less water will be held. Plants can only use capillary water; gravitational water drains away, and hydroscopic water is held too tightly for plant use. Illustration from Dumroese and others (2008).

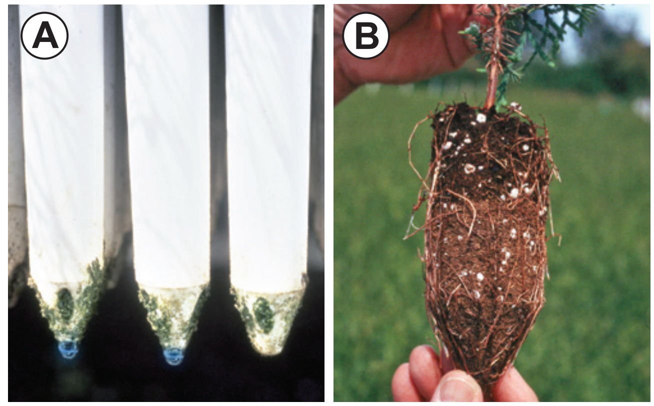

Figure 11.10—Apply enough water during irrigation to fully saturate the growing medium profile and permit some leaching out the bottom of the container. Some water will drip out of the bottom of each container if the plants were watered sufficiently (A). Insufficient irrigation will result in a dry layer within the growing medium (B). Photos by Thomas D. Landis.

that some drips out the bottom of the container (figure 11.10A), but not so much that water streams out the bottom. If the irrigation period is too short, the water will not reach the bottom of the container and a layer of dry growing medium underneath will exist (figure 11.10B). If the growing medium is not completely saturated after irrigation, the seedling will not develop roots in the dry medium at the bottom of the container, resulting in a poorly formed plug. In addition, fertilizer salts will accumulate in the medium and cause salinity damage or "fertilizer burn."

The general rule for sprinkler, overhead, hand-watering, or microirrigation is to apply approximately 10 percent more water than is needed to completely saturate the entire growing medium profile during irrigation. The best procedure to ensure that some water is dripping out of the bottom of the container during or immediately after irrigation is by direct inspection.

The amount of irrigation to apply varies during the growing season because of the stages of seedling development and the horticultural objectives of the nursery manager. As discussed in Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records, plants go through three phases of development: establishment, rapid growth, and hardening. Irrigation is an important strategy for managing plant growth and health as the crop moves through these phases.

Irrigating During the Establishment Phase

Immediately after the sown containers are placed in the growing area, the growing medium needs to be completely saturated. Thereafter, watering needs during establishment should be monitored carefully and tailored to the

> ***Water Use Considerations for Plants Grown in Containers***
>
> - Root volume is proportional to plant size.
> - Plants in containers do not have the ability to "forage" for water outside the root zone of the container.
> - Because containers are relatively small, moisture reserves can be used up quickly in hot weather.
> - Containers have a small top opening relative to volume that makes it challenging to apply equal amounts of water per container.

needs of the species. Some species require nearly continuous misting (figure 11.11) and may even benefit from a fog chamber. Other species require less water, but, nevertheless, inadequate or too-infrequent irrigations will cause the seeds to dry out, which will decrease germination success or even cause total crop loss. On the other hand, excessive irrigation may create overly wet conditions, promoting damping-off and decreasing germination.

To help determine the watering regime for a given species, consider the water availability in the plant's native habitat (such as rainforest, cloudforest, or dryland) at the time of year when this species usually germinates. Remember, until the seeds germinate and begin to grow, water loss is primarily from evaporation from the top of the container. Irrigation during this period, therefore, must be applied with the goal of replenishing the moisture in the thin surface layer of the medium. This practice is usually best accomplished by periodic misting or light irrigation with a very fine spray nozzle, which also protects germinating seeds from being moved or damaged by the force of the water. In some cases, if seeds are mulched, irrigation may not be necessary for the first week or so of the germination phase. Scratch through the surface of the mulch or grit to check the water status of the medium and ensure the medium is moist enough.

Irrigation can also be used to control the temperature around germinating seeds. High temperatures on the surface of the growing medium can injure germinants, particularly those covered by dark-colored mulches. If temperatures exceed 86 °F (30 °C), light misting will help keep germinants cool through evaporative cooling. This practice is sometimes called "water shading." When misting for cooling, do not add too much water to the medium, only enough to dissipate heat around the seedling. After plants develop thicker stems, they become more resistant to heat injury. Do not use water shading in nurseries with saline water because salts can build up in surface layers of the growing medium.

> ***The key to irrigating during the establishment phase: keep the growing medium "moist, but not saturated."***

Irrigating During the Rapid-Growth Phase

After the seedling's roots have expanded throughout the container, the amount of water lost through transpiration increases greatly and so irrigations must be longer and more frequent. As seen in table 11.3, water usage can double or even triple during the rapid-growth phase. Each plant needs to be watered thoroughly (until some water drips out the bottom). Regular saturation is best for some species whereas others might benefit from periods of slight moisture stress between watering. No plants should ever be allowed to dry out completely (figure 11.12). Nursery managers need to be aware of the varying water requirements for different species and adjust irrigation practices accordingly. Grouping species together by their water requirements ("wet," "moderate," or "dry") makes this practice much easier.

During the rapid growth phase, the leaves of plants begin to form a tight canopy that causes a significant reduction in the amount of irrigation that can reach the growing medium surface if delivered from above. This "umbrella effect" is particularly serious with broadleaved species. Water will often drip through the foliage irregularly so that one container is fully saturated whereas the one right next to it may receive

Figure 11.11*—During the establishment phase, watering needs to be tailored to the requirements of each species. For many species, mist nozzles in a special germination chamber generate a fine spray, which provides enough water for germination and also protects young germinants from heat injury. Overwatering must be avoided to prevent disease problems. Photo by Brian F. Daley.*

very little water. To compensate for foliage interception, growers tend to irrigate more frequently and longer. This practice still results in uneven irrigation and wasted water, because the water runs off the leaves and onto the floor. The types of irrigation systems discussed later in this chapter will help address this issue for broadleaved species, particularly through subirrigation and hand watering practices.

The rapid growth phase is also the time when liquid fertilizers are most concentrated and water loss through transpiration is high, so growers must monitor for salt accumulation.

Irrigating During the Hardening Phase

Manipulating irrigation frequency is an effective way to initiate the hardening of plants before shipment and outplanting. Because seedling growth is so critically tied to moisture stress levels, growers can slow shoot growth and increase general resistance to stress by inducing moderate water stress. This "drought stressing" procedure consists of withholding irrigation for short periods of time until the plants can be seen to wilt or until some predetermined moisture stress is reached. After this stress treatment, the crop is returned to a maintenance irrigation schedule.

Implementing moisture stress, however, can be challenging with tropical plants because (1) hardiness is affected by other environmental conditions, (2) considerable variation in growing medium moisture content can exist among containers, and (3) if the growing medium is allowed to dry too far, it can become hydrophobic and difficult to rewet.

Water stressing must be done correctly and conscientiously, and there is no substitute for experience. Most of the water stress research has been done with commercial conifers, and good guidelines have been published for monitoring container weights (for example, Landis and others 1989). It is unfortunate that little is known about the response of most tropical native plants. Inducing moisture stress, therefore, can be risky if the plant's tolerance is unknown. Drought stressing simply does not work for some species and in some environments. Growers need to conduct their own trials of operational moisture stressing to determine the effect on their own species in their respective growing environments. Careful scheduling and communication with other nursery workers is essential (figure 11.13). Be sure to keep detailed records of how the crops respond.

In spite of these caveats, the induction of mild moisture stresses should be considered as a horticultural technique to manipulate seedling physiology and morphology. A further discussion of the hardening process, including moisture stress, is provided in Chapter 15, Hardening.

Figure 11.12*—These seedlings are suffering from severe water stress because of improper irrigation. Seedlings use a lot of water during the rapid growth phase and frequent irrigation is needed to prevent growth loss. Photo by Thomas D. Landis.*

Fertigation

Irrigation is critical to the proper application of fertilizers, especially when injecting liquid fertilizer solution into the irrigation system—a practice called "fertigation." Fertigation can be used with many different types of irrigation systems, from hand watering to automated sprinkler or drip systems. Fertilizer injectors range from simple, low-cost siphons for hand watering to sophisticated pumps for automated sprinklers. Because it can be designed to apply the proper mineral nutrients at the proper concentration and at the proper time, fertigation has several advantages over other types of fertilization. Remember that fertilizers are salts and that injecting liquid fertilizers adds to the base salinity level of the irrigation water. Frequent leaching with regular irrigation water ("clearwater flush") is needed to push excess salts out the bottom of the container. One of the first signs of a salinity problem is salt crust around the drainage holes (figure 11.3B). See Chapter 12, Plant Nutrition and Fertilization, for more information on fertigation and how it can be applied in tropical native plant nurseries.

Determining When to Irrigate

It is absolutely necessary to regularly monitor the moisture status of growing media. In small containers, the limited volume of moisture reserves means that critical moisture stresses can develop quickly.

Visual and tactile assessments are the most common method of monitoring irrigation effectiveness. Monitoring can also include formal or informal assessments of container weight. In addition, various tools such as tensiometers, electrometric instruments, balances, commercial moisture meters (figure 11.14), or pressure chambers can be used to monitor irrigation efficacy (Landis and others 1989). Any equipment-based method must also be supported by actual observation (visual and tactile) and the grower's experience.

Visual and Tactile Assessment of Growing Medium Moisture

Most nurseries successfully monitor irrigation efficacy based on the feel and appearance of the plants and the growing medium (figure 11.15A). The best technique is to observe the relative ease with which water can be squeezed from the medium and attempt to correlate this moisture condition with plant appearance and container weight (figure 11.15B). This process requires a lot of experience and is very subjective but can be very effective when used by a knowledgeable, experienced nursery manager.

Looking at the root systems or the growing media may involve damage to the plants that are examined, especially if they must be pulled from their containers. This practice may be necessary during the learning phase of growing a new crop. With time and experience, nondestructive indicators such as the appearance of the plant, the look and feel of the growing medium, and the weight of the containers will be practiced most of the time, and the need for destructive sampling will be reduced or eliminated.

Monitoring Container Weights

Monitoring container weight is one of the few objective, nondestructive, and repeatable techniques for monitoring irrigation in container nurseries. Container weight is also the best way to determine irrigation needs early in the

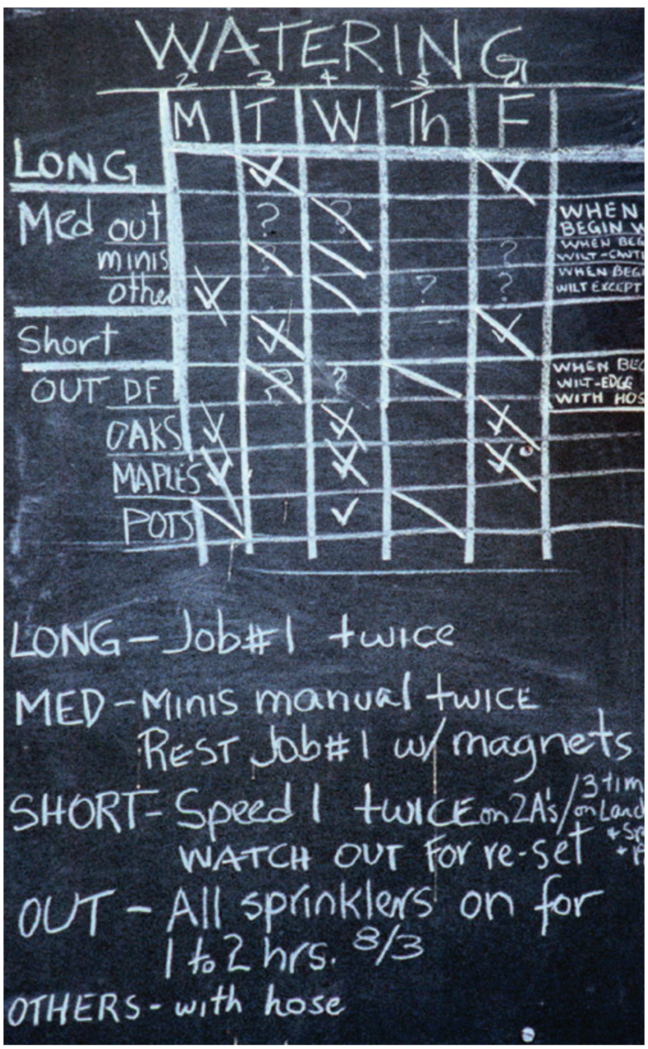

***Figure 11.13**—Because so little is known about the response of most tropical plants to water stress, good scheduling, record-keeping, and communication are critical to determine plant needs. Photo by Thomas D. Landis.*

***Figure 11.14**—Many types of tools can be used to help test and assess the effectiveness of water application, including this moisture meter. Visual and tactile assessments are more prevalent in tropical plant nurseries, however, and can be quite effective when carried out by trained staff. Photo by Thomas D. Landis.*

Figure 11.15—Growers can monitor the need for irrigation by careful observation of plant condition (A) so that water can be applied before plants are seriously wilted (B). Feeling the weight of containers can also be an effective way to determine when to irrigate (C). Monitoring container weights is a standard method to assess irrigation needs in container crops (D). Photos A, B, and C by Tara Luna, and photo D by Thomas D. Landis.

growing season before plants are large enough to show moisture stress or test in a pressure chamber. Container weight decreases between irrigations because the water in the growing medium is lost through evaporation and transpiration. When the container weight reaches some predetermined level, the crop is irrigated. With experience, workers can develop an intuitive sense of this level based on picking up a few randomly spaced trays (figure 11.15C). It can also be done objectively, weighing containers on a simple household scale (figure 11.15D).

The procedure is to completely saturate the growing media in a container or block of containers and let it drain—measured as the "wet weight." The container or block is then sown as usual, marked with a tag or flag stake, and placed out in the nursery. Then, once or twice per week during the growing season, this monitoring block is weighed and the weight is recorded as a percentage of the wet weight. A typical weight chart is shown in table 11.4 with the decision point on when to water at 85 percent of the wet weight during the rapid growth phase or 70 percent during the hardening phase. Decision points will vary between species because of the physiological response of different species to moisture stress.

Visual and Tactile Clues for Monitoring Irrigation

- Leaves should look and feel firm, not wilted.
- Potting medium should be moist throughout the plug; moisture should come out when squeezed.
- Containers should feel relatively heavy when lifted.
- Immediately after watering, some water will drip (but not stream) out of the bottom of each container to indicate plants were irrigated sufficiently.

Assessing Irrigation Distribution

Irrigation systems need to be checked every few months because nozzles or drippers can become plugged or wear down to the point that they are no longer operating properly. The evenness of overhead irrigation systems can be easily checked by running a simple "cup test," which involves measuring the irrigation water caught in a series of cups laid out on a regular grid system throughout the growing area (figure 11.16). Containers for cup tests should have circular openings that have narrow rims; the shape of the container below the opening is not important as long as the cups are stable and 2 to 4 in (5 to 10 cm) deep to hold water without any splashing out.

Simply distribute empty cups evenly throughout the nursery irrigation station and run the overhead irrigation as usual for a standard time period. Turn off the system and measure the depth of the water in the cups. If water depth is not relatively uniform among cups, check pressure in the line and also check for clogs or problems with individual nozzles.

Types of Irrigation Systems

The best method of applying irrigation water in tropical nurseries depends on the water requirements of the species being grown and on the size and complexity of the operation (table 11.5). Small nurseries and those growing a variety of species may prefer hand watering for irrigation. Large nurseries growing only a few species may use some sort of mechanical irrigation system. Most nurseries use a combination of several systems in different watering zones to fulfill their irrigation needs (figure 11.17).

With the exception of hand-watering, most irrigation systems can be hooked up to automatic controllers based on timers or container weight so that irrigation can be automatically applied. Controllers enable the nursery manager to preprogram periods of irrigation, thereby saving time and labor. The prudent grower, however, will never

Table11.4—*An example of a weekly irrigation-monitoring program using container weights. Adapted from Dumroese and others (2008).*

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Wet weight	26.0	26.0	26.0	26.0	26.0	26.0	26.0
Actual weight	22.0	25.0	23.5	21.0	24.5	21.5	25.0
Wet weight (%)	85	96	90	81	94	83	96
Need to water?	Yes	No	No	Yes	No	Yes	No

Figure 11.16—*Periodic checks of water distribution can easily be done with a "cup test" in which cups are arranged in a grid pattern (A). The depth of water in the cups is measured after a standard watering period (B). Photo A by Kim M. Wilkinson, and photo B by Thomas D. Landis.*

become completely reliant on automatic systems and will continue to directly monitor irrigation efficiency and its effect on plant growth on a regular basis.

Hand Watering

Hand watering is often the most practical irrigation strategy for small tropical plant nurseries, nurseries producing a wide diversity of species with radically different water requirements, or nurseries in the startup phase. Hand watering requires simple and inexpensive equipment; a hose, a couple of different nozzle types, and a long-handled spray wand are all that are absolutely necessary. The watering job will be more pleasant and efficient with a few additional small investments, such as overhead wires to guide the hoses and rubber boots for the staff (Biernbaum 1995). Although the task may appear easy, good technique and the application of the proper amount of water to diverse species of plants in different containers and at different growth stages is very challenging. Nursery managers need to ensure that irrigators have a conscientious attitude and are properly trained to work effectively with water application.

Figure 11.17—*Most native plant nurseries use a combination of irrigation types to meet the needs of diverse species. This growing area of a nursery has both overhead sprinklers and access to a hose for hand watering. Photo by Thomas D. Landis.*

Table 11.5—Types of irrigation systems for container nurseries.

Advantages	Disadvantages
Hand watering	
• Requires inexpensive equipment that is simple to install • Is flexible and can adjust for different species and container sizes • Irrigators have a daily connection to the crop and can scout out diseases or other potential problems • Allows water to be directed under plant foliage, reducing risk of diseases	• Is time consuming and labor intensive • Involves a daily responsibility including weekends and holidays • Requires skill, experience, and presence of mind to do properly • Presents a risk of washing out or compacting growing medium
Microirrigation	
• Water is delivered directly to the root zone of plants (not to foliage, where it may cause disease) • Use of water is very efficient; less than 10 percent of applied water is wasted • Delivery is uniform; an even amount of water is applied to each container • Infiltration rate is good (because of slow delivery). • The amount of leachate is low	• Designing the system and installing individual emitters for each plant is difficult and time consuming • It is not generally efficient to install for plants grown in containers smaller than 1 gallon in size • Each irrigation station must run a long time because of slow water delivery • Emitters can plug easily (water filtration and frequent irrigation system maintenance is required) • With drippers, it is difficult to verify water delivery visually; often, problems are not detected until it is too late
Sprinkler irrigation	
• Relatively simple and inexpensive to design and install • A variety of nozzle patterns and application rates are available • Water distribution patterns can be measured with a cup test	• Foliar interception makes overhead watering ineffective for large-leaved crops • Irrigation water can be wasted because of inefficient circular patterns • An increased risk of foliar diseases is possible from excessive water on leaves • For overhead sprinklers, nozzle drip from residual water in lines can harm germinants and young plants • For basal sprinklers, irrigation lines must run along the floor, creating obstacles for workers and equipment
Subirrigation	
• Although commercial products are available, subirrigation systems can be constructed from affordable, local materials • Foliage remains dry, reducing the risk of foliar diseases • Water use is efficient (up to 80 percent less water use than overhead watering systems) • Application among plants is uniform • Lower fertilizer rates are possible • Reduced leaching of mineral nutrients is possible • Drainage water can be captured for reuse or recycling • No splashing disrupts or displaces mulch, germinants, or medium • Provides the ability to irrigate different size containers and different age plants concurrently • Is efficient in terms of time and labor requirements following installation	• Overhead or hand watering may be required to ensure sufficient surface moisture until seeds germinate • It cannot be used with poor-quality water because salt buildup would occur • Less air pruning of roots occurs • Risk of spreading waterborne diseases is greater • High humidity within plant canopy is possible

Figure 11.18—*Nursery plants on the outside of a bench or table always dry faster, especially in windy weather. Photo by Thomas D. Landis.*

Good hand-watering practices include the following—

- Direct water to the base of the plants.
- Avoid spraying the foliage to conserve water and preclude foliar diseases.
- Angle the watering nozzle down (not sideways) and keep pressure low to avoid washing out seeds, medium, or mulch.
- Use an appropriate nozzle type and water volume for each crop: a very fine, gentle spray for young germinants and a larger volume nozzle for larger plants.
- Adjust the flow, volume, and pace of watering to irrigate efficiently without wasting water or compacting medium (Biernbaum 1995).
- Achieve uniformity of water distribution so all plants are well irrigated; account for microclimate differences in nursery. For example, plants on the outer edge of a bench or in direct sun will need more water (figure 11.18).
- Attend to the individual needs of each crop and its development phase so none are overwatered or underwatered; develop a feel for the watering needs of crops over time.

Microirrigation

For nurseries that grow plants in 1-gal (4-L) or larger containers, microirrigation can be a very efficient method for water delivery. Microirrigation usually involves polyethylene pipe fitted with microsprayers (sometimes called "spitters" or "spray stakes") (figure 11.19A), drippers inserted individually into each container (figure 11.19B), or smaller lateral tubing to reach all areas on the bench (figure 11.19C). Microsprayers are often preferred to drippers because they wet more surface area and distribute water more evenly throughout the container. It is also easier to visually verify the operation of a sprayer than a dripper. Filtration is a necessity for microirrigation systems to prevent emitters from clogging. Because of the slow infiltration rate of microirrigation systems, each irrigation station will need to run a long time to deliver adequate water to plants. Also, if containers are allowed to dry

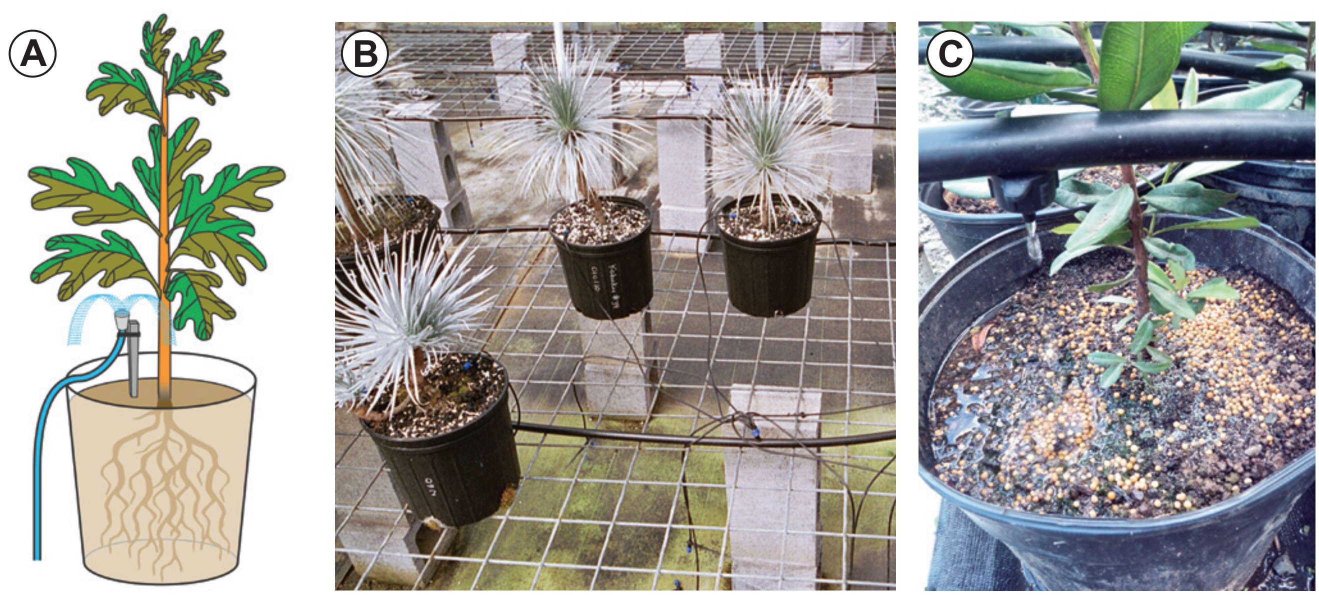

Figure 11.19—*Spray stakes are effective only for larger containers and work well because you can see them functioning and they have more even distribution (A). Drip emitters can also be used for larger containers (B, C). Illustration A from Dumroese and others (2008), photo B by Thomas D. Landis, and photo C by Brian F. Daley.*

out, hand watering may be necessary to rewet the growing medium before drip irrigation will work.

Fixed Irrigation Systems

Overhead sprinkler systems are a common type of irrigation system and the kind that many people imagine when they think of irrigation. Many types of overhead irrigation systems exist, ranging from fixed sprinklers to moving boom systems.

Fixed Overhead Sprinklers

Fixed overhead sprinkler systems consist of a series of parallel irrigation lines, usually constructed of plastic polyvinyl chloride (PVC) pipe, with sprinklers spaced at uniform intervals to form a regular grid pattern. Overhead sprinklers apply water at a fairly rapid rate and will do an acceptable job if properly designed and maintained.

Several types of spray nozzles are used for fixed overhead irrigation systems. Spinner sprinklers, which have offset nozzles at the end of a rotating arm, spin in a circle when water pressure is applied (figure 11.20A). Stationary nozzles (figures 11.20B, 11.20C) have no moving parts but distribute water in a circular pattern; these nozzles also come in one-half and one-fourth of a circle patterns (figure 11.20D) so that full overlap coverage can be obtained by placing irrigation lines around the perimeter of the area to be irrigated. Mist nozzles are also sometimes installed on overhead irrigation lines and are primarily used during the germination period and for cooling and humidity control.

In general, the propagation environment is divided into irrigation "bays" or "zones" depending on the number of nozzles that the pump can operate at one time at the desired water pressure. Ideal operating pressures vary with the type of sprinkler, and specifications are available

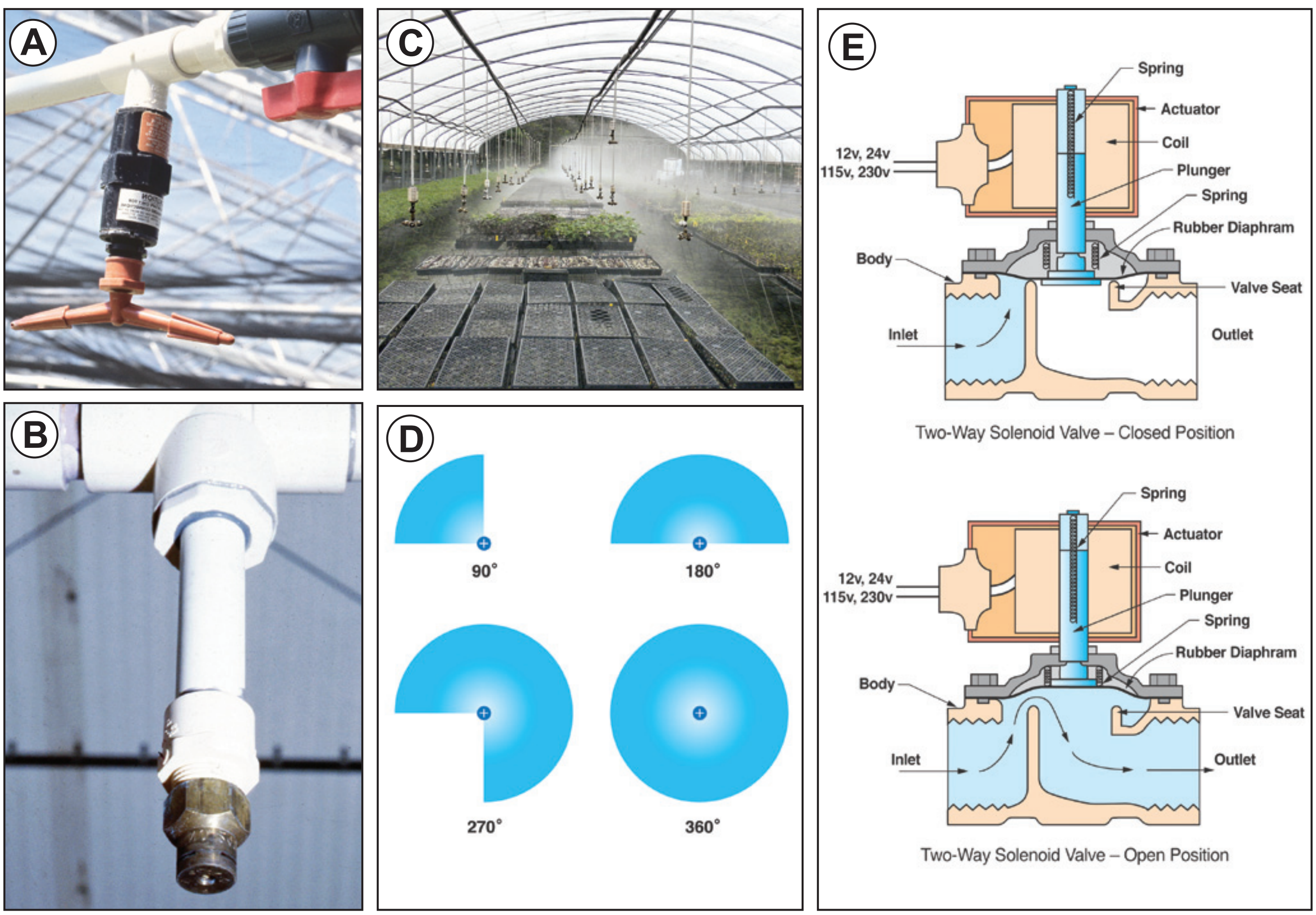

***Figure 11.20**—Either rotating spinners (A) or stationary nozzles (B) can be used with overhead (C) or basal sprinkler systems. In addition to the full-circle version, stationary nozzles are available in one-fourth, one-half, and three-fourths circle versions (D). Irrigation can be controlled with solenoid valves (E) connected to timers. Photos A and B by Thomas D. Landis, photo C by Diane L. Haase, illustration D by Jim Marin, and illustration E by John W. Bartok, Jr.*

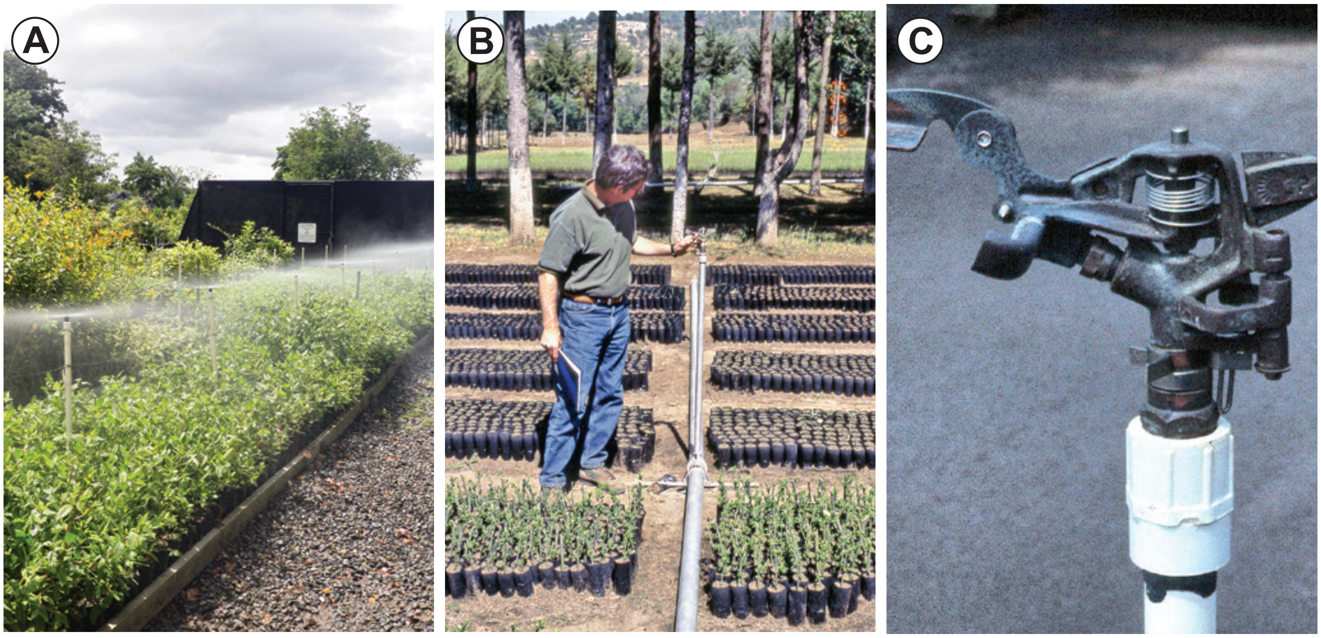

Figure 11.21*—Fixed basal irrigation systems (A) are often used in outdoor growing areas. Rotating-impact sprinklers (B, C) are commonly used because of their greater coverage. Photo A by Brian F. Daley, and photos B and C by Thomas D. Landis.*

from the manufacturer. A solenoid valve control (figure 11.20E) in each bay can be connected to an irrigation timer so that the duration and sequence of irrigation can be programmed. The size of each irrigation bay can be designed to accommodate plants with differing water requirements within a larger growing structure. When designing a new irrigation system, it is a good idea to obtain the help of an irrigation specialist to ensure that the system has balanced coverage and water pressure.

Fixed Basal Sprinklers

Basal irrigation systems are commonly used in large outdoor growing or holding areas (figures 11.21A, 11.21B). They are similar to overhead systems in design and operation in that they use a regular grid of permanent or movable irrigation lines with regularly spaced sprinklers. Both stationary sprinklers and rotating-impact nozzles (figures 11.21B, 11.21C) are commonly used. These sprinklers rotate slowly because of the impact of a spring-loaded arm that moves in and out of the nozzle stream. Rotating-impact sprinklers are available from several manufacturers in a variety of nozzle sizes and coverage capabilities. Because the water pressure out of the nozzle jet drives the impact arm, the water distribution pattern of these sprinklers is particularly dependent on proper water pressure. One advantage of basal irrigation systems is that impact sprinklers have relatively large coverage areas, which means fewer nozzles and less irrigation pipe are required.

Designing and Monitoring Fixed Sprinkler Systems

The efficiency and uniformity of an irrigation system is a function of five factors: (1) nozzle design, (2) size of the nozzle orifice, (3) water pressure and application rate at the nozzle, (4) spacing and pattern of the nozzles, and (5) amount of wind. Few operational procedures can improve a poorly designed system. Therefore, it is important to consult an irrigation engineer during the planning stages. Basic engineering considerations, such as friction loss in pipes or fittings and the effect of water pressure on sprinkler function, must be incorporated into the irrigation system design.

The size of the sprinkler nozzle and its resultant coverage pattern can be determined by consulting the performance specifications provided by the sprinkler manufacturer. Nursery managers need to select a nozzle size that is coarse enough to penetrate the plant's foliage and minimize wind drift but not large enough to create splash problems. Most stationary sprinklers throw water in a circular distribution pattern (figure 11.22A), so irrigation systems need to be designed to provide adequate overlap between sprinklers (figure 11.22B). This consideration is especially important in shadehouses or outdoor growing areas where wind drift can be a problem. Too often, sprinklers are spaced at greater intervals in a cost-saving effort, but this practice is false economy considering the profound effect of water and injected nutrients on plant growth.

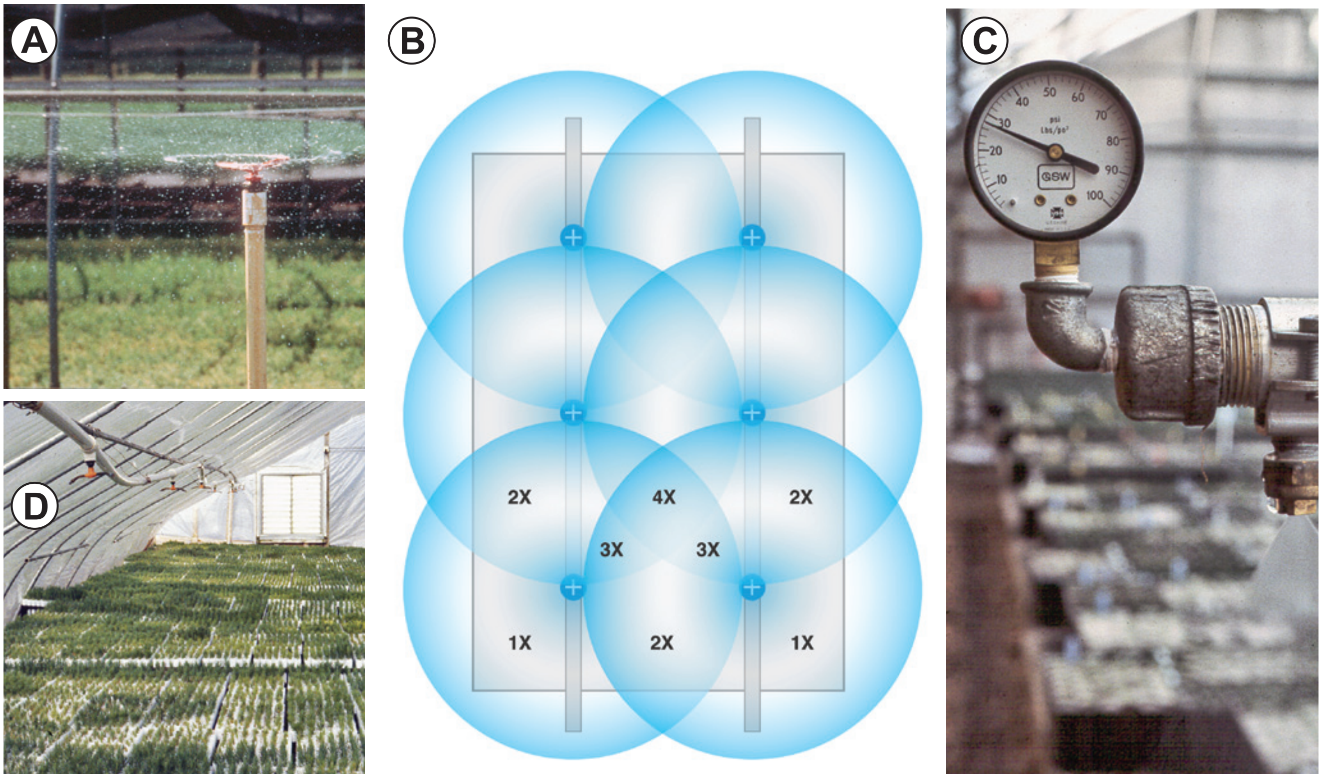

Figure 11.22*—Because sprinklers produce a circular irrigation pattern (A), proper spacing is critical to produce enough overlap (B). Check the water pressure of irrigation systems annually to ensure efficient nozzle operation (C) before irrigation problems become apparent (D). Photos A, C, and D by Thomas D. Landis, and illustration B by Jim Marin.*

Because water pressure has such an effect on sprinkler function and efficiency, it needs to be monitored regularly with a gauge permanently mounted near the nozzles (figure 11.22C) or with a pressure gauge equipped with a pitot tube directly from the sprinkler nozzle orifice. The pressure needs to be checked at several different nozzles including the nozzle farthest from the pump. The importance of regular water pressure checks cannot be overemphasized because many factors can cause a change in nozzle pressure. When water pressure is either too high or too low, it can cause erratic stripe or doughnut-shaped distribution patterns (figure 11.22D). Performance specifications for sprinklers at standard water pressures can be obtained from the manufacturer.

Moveable Boom Irrigation Systems

The most expensive but efficient type of overhead sprinkler irrigation is the moveable boom (figure 11.23A), which applies water in a linear pattern (figure 11.23B). Moveable booms are generally considered too expensive for smaller plant nurseries but need to be considered if appropriate to your scale. For more information, see Landis and others (1989).

Subirrigation

Overhead irrigation systems have often been the choice of container nurseries because the systems are relatively cheap and easy to install. The inherent inefficiency of overhead systems, however, becomes a very serious problem with many tropical species, especially those with broad leaves. Wide leaves combined with the close spacing of plants in a nursery create a canopy that intercepts most of the water applied through overhead irrigation systems, reducing water use efficiency and creating variable water distribution among plants (figures 11.24A, 11.24B). These problems can be precluded by subirrigation systems, which offer a promising alternative for tropical plant nurseries (Schmal and others 2011).

Subirrigation is a relatively new irrigation option but has been successfully used to grow many native plants, from forbs (Pinto and others 2008) to trees (Dumroese and others 2006, Davis and others 2008). Studies taking place with native tropical trees and other native species are demonstrating that subirrigated plants can grow as well as plants irrigated with overhead irrigation systems, but with less water use, less water wasted, and less run-

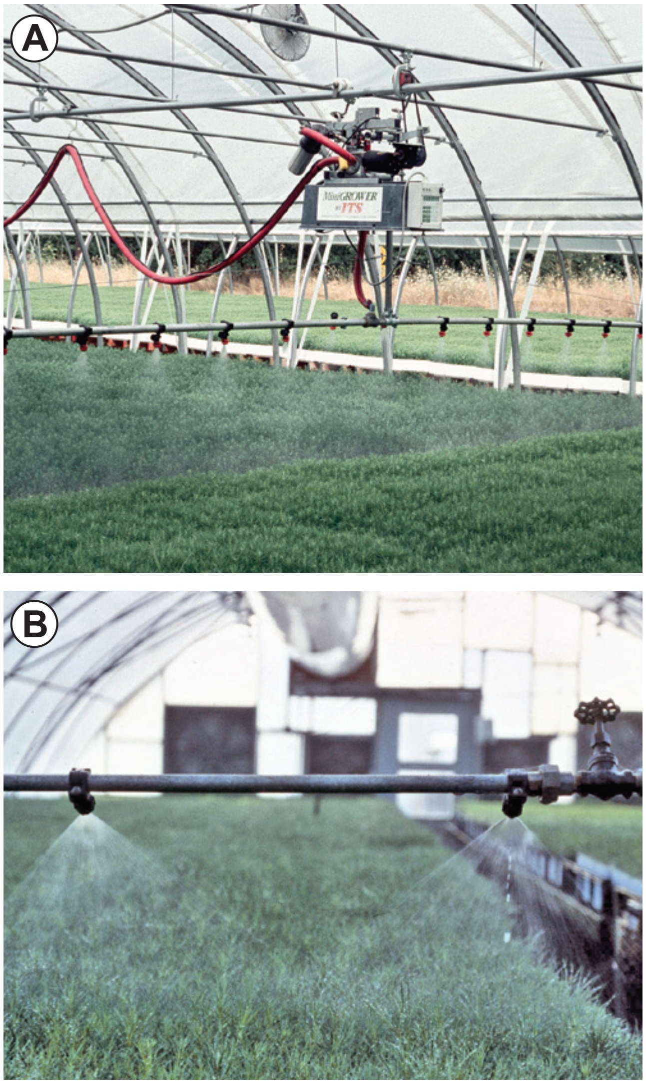

Figure 11.23—Moveable boom irrigation systems (A) apply water in a very efficient linear pattern (B) but may be considered too expensive for many tropical nurseries. Photos by Thomas D. Landis.

off of nitrogen fertilizers (Dumroese and others 2007). In subirrigation systems, the bottoms of containers are temporarily immersed in water on a periodic basis (for example, for several minutes once a day). The water is then drained away, leaving the growing medium thoroughly wet while the leaves remain dry.

Subirrigation systems rely on capillary action to move water up through the growing medium against gravity. Capillarity is the result of the attraction of water molecules for each other and other surfaces. After the subirrigation tray is flooded, water will move up through the growing medium in the containers (figure 11.24C). The height to which water will move will depend on the characteristics of the container and the growing medium. The smaller the pores between the growing medium particles, the higher the water will move.

Several different subirrigation systems have been developed. Some, such as capillary beds and mats, will not work with the narrow-bottomed containers often used in tropical nurseries. With ebb-and-flow (or ebb-and-flood) subirrigation systems, containers sit in enclosures mounted on benches or on the floor. The enclosure may be a bench (figures 11.24D, 11.24E) or tray (figure 11.24 F) designed for subirrigation or may be constructed from pond liner material surrounded by a raised border of wood or masonry. Another type of subirrigation is the flooded floor type, where special concrete flooring is flooded and then water is drained. In trough subirrigation systems, enclosures are mounted on benches at a slight slope, and water is flowed through the enclosures. The drained water can be captured in a holding tank and reused on the crops or directed to landscaping, stooling beds, or other parts of the nursery, or drained to the ground (use caution with this step to ensure fertilizer salts do not affect groundwater quality). If water is recycled, be sure to monitor water quality periodically to avoid possible problems with accumulated salts or disease transfer.

Subirrigation systems are ideal for many topical native plants. Although prefabricated subirrigation systems are available commercially, nurseries on a limited budget may consider designing their own systems using available materials. For example, systems can be made out of concrete blocks and pond liner or out of prefabricated drainable plastic ponds, even plastic "kiddie pools" (figure 11.24 G) (Schmal and others 2007). (Note: Some materials, such as galvanized metal, are inappropriate because of zinc toxicity.)

Some important design considerations exist for subirrigation systems. The drainage holes at the bottom of the containers must have good contact with the water for the water to enter the container. Subirrigation may be less effective during the establishment phase, when growing medium in the upper portions of containers needs to be moist to promote germination and early growth; therefore, supplemental hand watering or sprinkler irrigation may be necessary initially. Air root pruning may be reduced with subirrigation, resulting in a need for hand pruning; making this system inadvisable for use with plants that are very sensitive to root pruning.

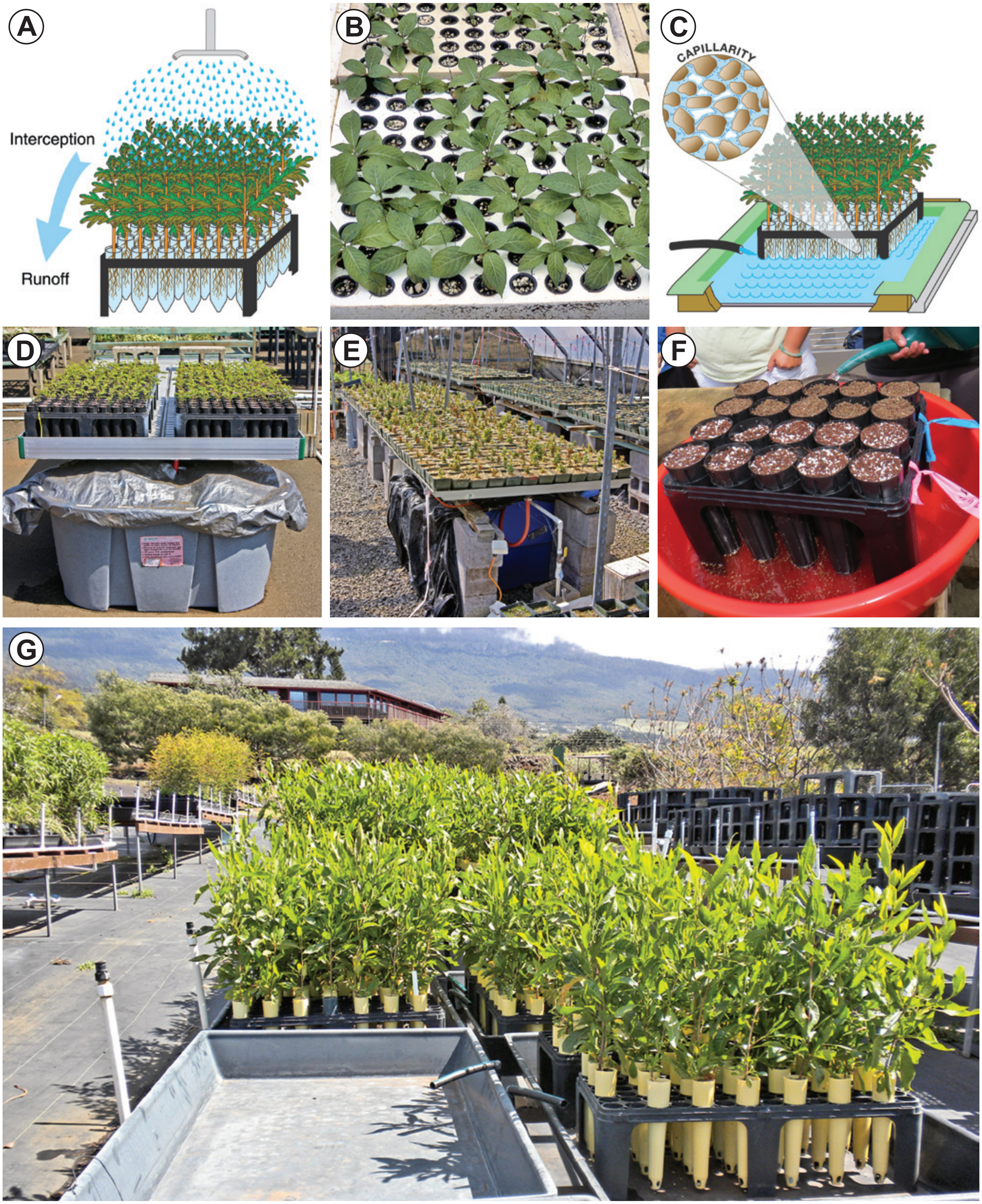

Figure 11.24—Overhead irrigation is ineffective for broadleaved plants because so much water is intercepted by the foliage, called "the umbrella effect" (A), which can begin even when seedlings are young (B). Subirrigation works because water is drawn upward into the containers by capillarity (C). Subirrigation has been used effectively in a number of tropical nurseries and can be accomplished via benches (D, E), trays (F) or other enclosures (G). Illustrations A and C from Dumroese and others (2008), photos B, D, and E by Thomas D. Landis, and photos F and G by Diane L. Haase

Water Conservation and Managing Nursery Wastewater

Depending on the efficiency of the irrigation system, nursery runoff and wastewater may be important factors to consider. Overhead sprinkler irrigation is less efficient than a boom system. Microirrigation or subirrigation systems are much more efficient but are impractical for some types of containers and plants.

The problem of poor irrigation efficiency involves more than simply wasted water, although that alone is a concern both environmentally and economically. In addition, many container nurseries apply some or all of their fertilizer and pesticides through the irrigation system. Liquid fertilizer is usually applied in excess of the actual amount needed to saturate the growing medium and to leach excess salts. Most pesticides are applied in a water-based carrier. Some of these chemicals inevitably end up in the nursery's wastewater runoff.

Until recently, it was thought that the soil beneath the nursery filtered out or decomposed fertilizer salts and pesticides, but this belief has been refuted. Leaching tests in conifer nurseries have shown that excess fertilizer nutrients and pesticides leach downward and may contaminate groundwater. Maximizing the efficiency of irrigation systems and implementing water conservation strategies (table 11.6, figure 11.25) is the most effective way to reduce runoff.

The direct recycling of used nursery water is generally not done except in subirrigation systems. Otherwise, on a small scale, the expense of water treatment and the risks of reintroducing excess salts or pests make the practice unpopular. Recycle systems for nursery runoff water may be economically viable in very water-limited areas, however. Less high-tech options for water reuse can make use of an impermeable nursery floor (such as pond liner) to collect water runoff from the nursery. This water can be stored in a pond or tank or run directly to other crops. Crops that are more tolerant of salts, such as rushes, may benefit from using runoff water, and these crops will even clean and filter the water. Nurseries growing aquatic or semiaquatic plants may be able to direct runoff to these plants and thereby increase the water-use efficiency of the nursery operation. Crops in the field, such as seed orchards, wetland crops, surrounding landscaping, or banana, palm, or tree crops, can all benefit from being irrigated with nursery runoff water. If the crops are located downhill from the nursery itself, the system can be gravity fed. Otherwise, a pump will be necessary to apply the water to the crops.

Table 11.6*—Nurseries can incorporate a variety of horticultural practices to use irrigation water effectively and efficiently.*

Nursery practice	Conservation effect
Mulches (figure 11.25A)	Reduces evaporation from the surface of the growing medium; the larger the container, the greater the savings
Windbreaks (chapter 2, figure 2.13A)	Reduces water loss and seedling stress because of wind
Remove cull plants and minimize space between containers, including aisles	Reduces unnecessary use of water and resultant runoff
Shadecloth and shadehouses (figure 11.25B)	Reduces water use for species that do not require full sunlight
Catch runoff and recycle water for use on landscaping and other crops	Saves considerable amounts of water and reduce fertilizer use
Treat runoff water via filtration or bioswales	Reduces contaminants in recycled water

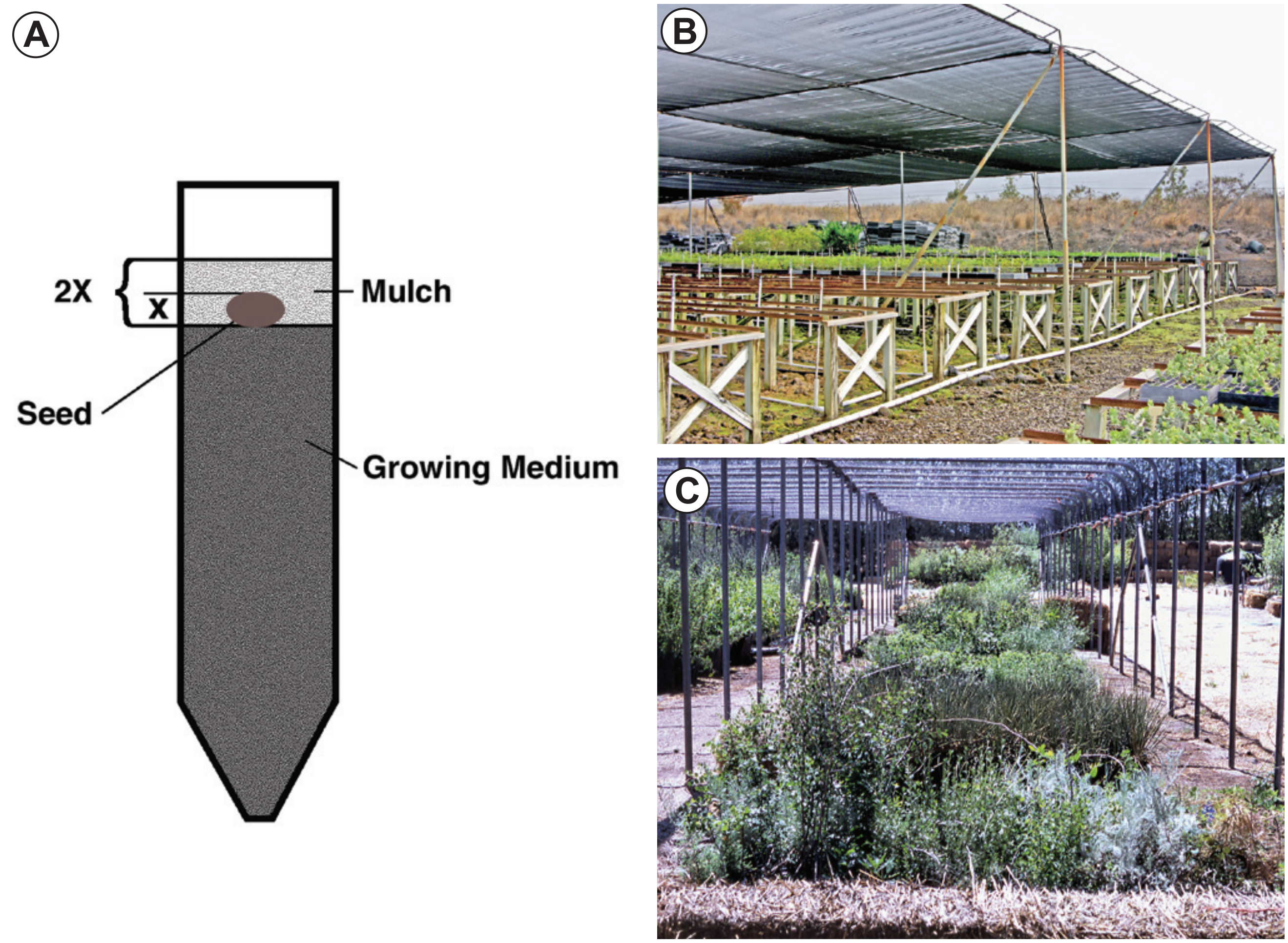

Figure 11.25*—Water can be conserved by many practices, such as covering sown containers with a mulch (A); reducing transpiration and evaporation water loss with shade (B); and insulating crop areas, such as with straw bale insulation around the perimeter of the growing area (C). Illustration A from Dumroese and others (2008), photo B by Thomas D. Landis, and photo C by Tara Luna.*

References

Biernbaum, J. 1995. How to hand water. Greenhouse Grower. 13(14): 39, 24, 44.

Cayanan, D.F.; Zheng, Y.; Zhang, P.; Graham, T. 2008. Sensitivity of five container-grown nursery species to chlorine in overhead irrigation water. HortScience. 43: 1882–1887.

Davis, A.S.; Jacobs, D.F.; Overton, R.P.; Dumroese, R.K. 2008. Influence of irrigation method and container type on growth of *Quercus rubra* seedlings and media electrical conductivity. Native Plants Journal. 9: 4–12.

Dumroese, R.K.; Jacobs, D.F.; Davis, A.S.; Pinto, J.R.; Landis, T.D. 2007. An introduction to subirrigation in forest and conservation nurseries and some preliminary results of demonstrations. In: Riley, L.E.; Dumroese, R.K.; Landis, T.D., eds. national proceedings: forest and conservation nursery associations—2006. Proceedings RMRS-P-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 20–26.

Dumroese, R.K.; Pinto, J.R.; Jacobs, D.F.; Davis, A.S.; Horiuchi, B. 2006. Subirrigation reduces water use, nitrogen loss, and moss growth in a container nursery. Native Plants Journal. 7(3): 253–261.

Dumroese, R.K.; Luna, T.; Landis, T.D. 2008. Nursery manual for native plants: volume 1, a guide for tribal nurseries. Agriculture Handbook 730. Washington, DC: U.S. Department of Agriculture, Forest Service. 302 p.

Fawell, J.; Bailey, K.; Chilton, J.; Dahi, E.; Fewtrell, L.; Magara, Y. 2006. Fluoride in drinking water. World Health Organization. London, United Kingdom: International Water Association (IWA) Publishing. 134 p.

Gingerich, S.B. 2003. Hydrologic resources of Guam. Water-Resources Investigation Report 03-4126. Honolulu, HI: U.S. Department of the Interior, Geological Survey. 3 p.

Handreck, K.A.; Black, N.D. 1984. Growing media for ornamental plants and turf. Kensington, Australia: New South Wales University Press. 401 p.

Jones, J.B., Jr. 1983. A guide for the hydroponic and soilless culture grower. Portland, OR: Timber Press. 124 p.

Kaapuni Nursery. 2011. *Cordyline terminalis* 'Ti' plant. Kapahi, Kaua'i, HI: Kaapuni Nursery. http://www.kaapuninursery.com/Nursery.html. (December 2011).

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1989. The container tree nursery manual: volume 4, seedling nutrition and irrigation. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 119 p.

Pinto, J.R.; Chandler, R.; Dumroese, R.K. 2008. Growth, nitrogen use efficiency, and leachate comparison of subirrigated and overhead irrigated pale purple coneflower seedlings. HortScience. 43: 897–901.

Robbins, J. 2011. Irrigation water for greenhouses and nurseries. Publication FSA6061. Little Rock, AR: University of Arkansas, Horticulture Department. 6 p.

Schmal, J.L.; Wollery, P.O.; Sloan, J.P.; Clark, D.F. 2007. A low-tech, inexpensive subirrigation system for production of broadleaved species in large containers. Native Plants Journal. 8: 267–269.

Schmal, J.L.; Dumroese, R.K.; Davis, A.S.; Pinto, J.R.; Jacobs, D.F. 2011. Subirrigation for production of native plants in nurseries – concepts, current knowledge, and implementation. Native Plants Journal. 12:81-93.

Stetson, L.E.; Mecham, B.Q. 2011. Irrigation. 6th ed. Falls Church, VA: Irrigation Association. 1,089 p.

Tchobanoglous, G.; Schroeder, E.D. 1985. Water quality: characteristics, modeling, modification. Melo Park, CA: Addison-Wesley Publishing Co. 768 p.

Zheng, Y.; Cayanan, D.F.; Dixon, M. 2009. Control of pathogens in irrigation water using chlorine without injury to plants. International Plant Propagators' Society, Combined Proceedings. 58: 248–249.