Water Quality and Irrigation

10

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Water is the single most important biological factor affecting plant growth and health. Water is essential for almost 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 10.1).

Determining how, when, and how much to irrigate is a crucial part of nursery planning as well as day-to-day operations. One missed watering session can cause serious injury and even death to plants at any stage in their development. Adequate watering is particularly important with container plants, whose roots cannot access water beyond the container walls and therefore are entirely dependent on receiving enough water through irrigation. Excessive watering is also problematic; it is the major cause of root diseases and contributes to other problems with seedling growth. Therefore, good design and operation of an irrigation system is central to managing a nursery successfully.

Every nursery is unique and native plant nurseries typically grow a wide range of species with differing water requirements. In addition, the distinct phases of growth that plants go through (establishment, rapid growth, and hardening) will require differing watering regimes. Designing an effective and efficient irrigation system is not a matter of deciding on one specific system but rather choosing which types of irrigation systems and practices best serve the needs of the plants. The nursery might have various propagation environments and corresponding irrigation zones that provide for the changing needs

Redosier dogwood after irrigation by Tara Luna.

Figure 10.1—*A supply of good-quality water is one of the most critical requirements for a native plant nursery.* Photo by Thomas D. Landis.

of plants during all phases of growth. For example, one nursery might have a mist chamber for the germination phase, overhead sprinklers in the growing area, a selection of rare plants that receive daily hand watering, and some large plants under driplines. In addition, irrigation may be needed for other horticultural purposes such as cooling or frost protection.

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. The first step in setting up a nursery and its watering system is to ensure that the nursery has a reliable and high-quality source of water for irrigation.

WATER QUALITY

The quality of irrigation water is a critical factor in the site selection for and management of a container nursery. Improving poor-quality irrigation water is expensive, often prohibitively so. Therefore, water quality should be a primary consideration during nursery site evaluation. A water sample should be collected and sent to a laboratory to test its quality—soluble salts in water can clog nozzles (figure 10.2A), accumulate in containers (figure 10.2B), and eventually harm plants (figure 10.2C).

For irrigation purposes, water quality is determined by two factors: (1) the types and concentrations of dissolved salts (total salinity and individual toxic ions) and (2) the presence of pests (pathogenic fungi, weed seeds, algae, and possible pesticide contamination).

Figure 10.2—*Agricultural water quality is determined by the level of soluble salts because they can (A) build up on irrigation nozzles (B) accumulate in containers, usually around the drainage holes, and (C) eventually "burn" seedling foilage (C).* Photos by Thomas D. Landis.

A WELL-DESIGNED IRRIGATION SYSTEM HAS MANY ADVANTAGES

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

Water Quality: 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 can have a beneficial effect, while other salts have a neutral effect. Salts such as sodium chloride (ordinary table salt), however, dissolve into harmful ions that can damage or even kill plant tissue.

An excess of dissolved salts in nursery irrigation water has negative effects, including the following:

- Water availability is reduced resulting in growth loss.
- Some ions (sodium, chloride, and boron) are directly toxic to plants.
- Other ions (calcium) affect mineral nutrient availability.
- Other ions (bicarbonate or iron) cause salt crusts or staining.
- Salt deposits may also accumulate on sprinkler nozzles and reduce their efficiency.

GOOD WATER MANAGEMENT HAS THE FOLLOWING ATTRIBUTES

— Efficient use of water.
— Reliable source of water.
— High uniformity of water distribution.
— An approach that is flexible and tailored to the changing needs of the species grown and their phases of development.

An excess of dissolved salts in the water can be the result of a number of factors. First, the topographic location of a container nursery can have an effect on irrigation water quality because of local climatic or geologic influences. In locations with arid or semiarid climates where evapotranspiration exceeds precipitation, salts naturally accumulate in the soil, and groundwater irrigation sources are often high in salt content. Second, in coastal areas, irrigation water may be contaminated by saltwater intrusion. Third, the high fertilization rates used in container nurseries can lead to a salinity problem. Fourth, improper horticultural practices can compound salt problems: the soluble salt level doubles when the growing medium dries from 50 to 25 percent moisture content.

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

It is expensive to remove salts from irrigation water, so ideally the nursery should 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 reading (table 10.1). The EC can be checked at the nursery using a conductivity meter (see figure 11.12), or by sending water samples to a local laboratory. The most commonly used salinity units in irrigation water quality are micromhos per centimeter (abbreviated as umho/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 10.1.

As already mentioned, irrigation water salinity tests should be tested prior to nursery establishment and retested periodically. It is particularly important to do an initial test in areas with high salinity because the addition of fertilizer could raise salinity to unacceptable levels (figure 10.3). In these cases, a nursery would need to be careful to use very dilute liquid fertilizers or controlled-release fertilizers to keep salinity within acceptable ranges. Horticultural practices such as increasing the porosity of the growing medium and leaching more frequently during waterings can help alleviate the effects of saline water.

Water Quality: Pests

Container 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 should 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 container nurseries. Waterborne pests can be killed with chlorination, and some specialized filtration systems can remove many disease organisms from irrigation water. See the following sections for more information on chlorination and filtration.

Irrigation water, especially in agricultural areas, may have become contaminated with residual pesticides. Herbicides applied to adjacent cropland or to control aquatic weeds in reservoirs can affect irrigation water

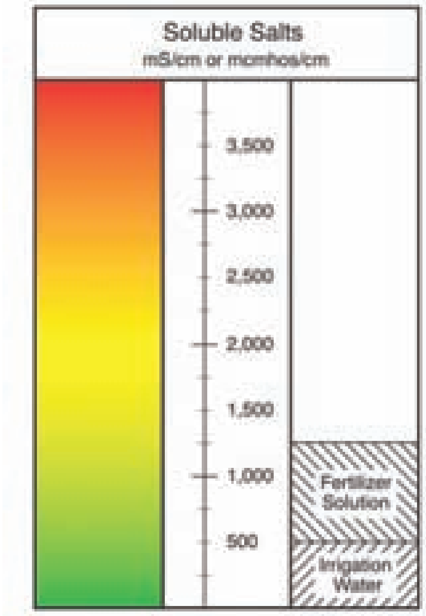


Figure 10.3—*When soluble fertilizers are injected into the irrigation system, salinity levels are cumulative. For example, a nursery with a base irrigation salinity of 500 µS/cm has good quality but, after fertigation is added, the total salinity can reach into the zone of caution.* Illustration by Jim Marin.

Figure 10.4—*Water quality should be tested before nursery establishment, and then yearly to make certain that quality has not changed.* Photo by Thomas D. Landis.

quality. Potential sources of irrigation water should be tested for pesticide contamination when a nursery site is being evaluated.

Testing Water Quality

Ideally, a water-quality test is done when the nursery is established and then at yearly intervals (figure 10.4). Many existing nurseries, however, have never had a detailed water analysis performed. A complete analysis of irrigation water quality should consist of a salinity evaluation listing the concentrations of eight specific ions that should be reported in parts per million (ppm). For a small additional fee, it is possible to test for the other nutrient ions at the same time. In addition to the ion concentrations, the testing laboratory should report three standard water-quality indices: EC, toxic ion concentrations, and pH.

Irrigation water should also be tested for the presence of pathogenic fungi, preferably during the site selection process but also 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, specialized pesticide tests are generally considered only when a definite problem is suspected.

Collecting a sample for irrigation water testing should be done properly. 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, 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 should 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.

Table 10.1—Water-quality standards for nursery irrigation water (modified from Landis and others 1989)

Quality Index	Optimal	Acceptable	Unacceptable
pH	5.5 to 6.5		
Salinity (µS/cm)	0 to 500	500 to 1,500	1,500
Sodium (ppm)			> 50
Chloride (ppm)			> 70
Boron (ppm)			> 0.75

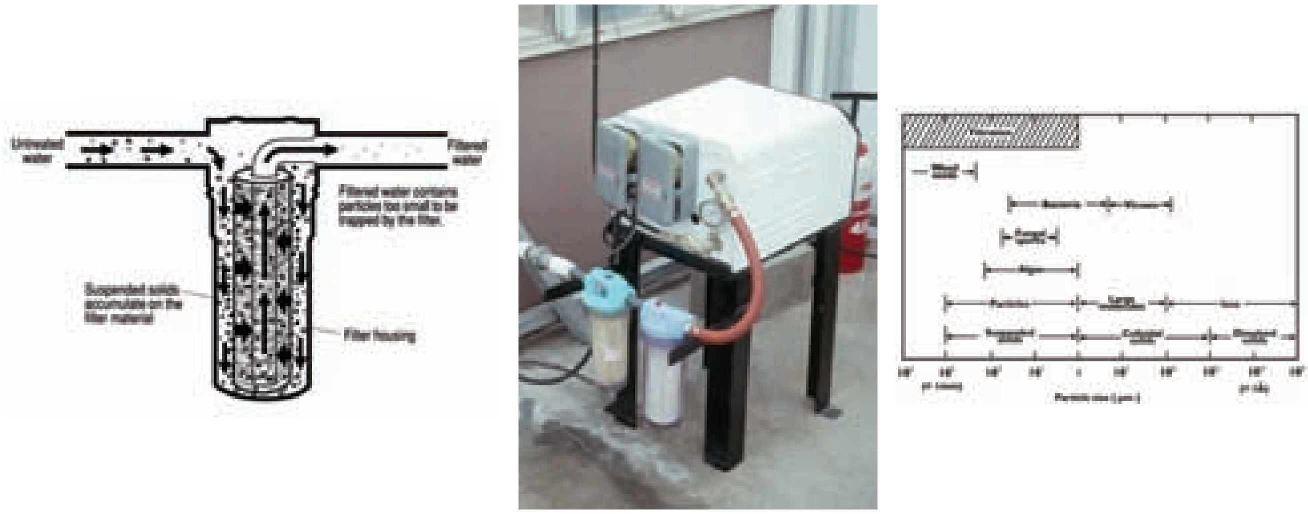


Figure 10.5—*(A) Cartridge filters are an effective and inexpensive way to treat irrigation water: (B) they should be installed before the fertilizer injector, and (C) they can remove sand, silt, fungal and algal spores.* Photo by Thomas D. Landis, illustrations by Jim Marin.

Practical Water Treatments: Filtration, Chlorination, and Temperature Modification

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 native 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. These treatments include filtration, chlorination, and temperature modification.

Filtration is used to remove suspended or colloidal particles such as very fine sand or silt. Filtration is recommended for most container nurseries because it prevents problems such as the plugging of nozzles or damage to the irrigation or fertilization equipment (figure 10.5). Filters also remove unwanted pests such as weed seeds or algae spores. Two types of filters are commonly used in nurseries: granular medium filters and surface filters. A local irrigation supplier may be able to help you select a good-quality filter. Granular medium filters consist of beds of granular particles that trap suspended material in the pores between the particles, whereas 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; screens must be physically removed and cleaned whereas cartridge filters are not reusable and must be regularly replaced.

Filters should be installed before the water passes through the nutrient injector to intercept sand particles that can cause excessive wear of plumbing or plug valves (figure 10.5B). 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. Handreck and Black (1984) recommend using filters small enough to remove particles greater than 5 microns in diameter, which will take care of most suspended materials (figure 10.5C). 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 (figure 10.5C). Unfortunately, more sophisticated filtration systems are relatively expensive and require frequent maintenance (Jones 1983). Chlorination can be used to kill fungi, bacteria, algae, or liverworts introduced through the irrigation system and causing problems.

Another aspect of water quality that can be controlled in container seedling nurseries is the temperature of the irrigation water. Cold irrigation water can significantly lower the temperature of the growing medium and has been shown to reduce plant growth in ornamental container nurseries. Water uptake by plants is minimal below 50 °F (10 °C), so cold soil temperatures can definitely reduce seedling growth. Cold irrigation water is most damaging during seed germi-

CHLORINATION WITH HOUSEHOLD BLEACH

— 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.

nation and could delay seedling emergence. A low-cost way of obtaining warmer water is to store water in black plastic storage tanks that are exposed to the sun or located inside a heated location (figure 10.6).

Figure 10.6—*Black water storage tanks are a low-cost way to warm irrigation water with solar energy before it is applied to crops.* Photo by Thomas D. Landis.

WATER QUANTITY

The amount of water necessary to produce a crop of container plants depends on many factors, such as climate, type of growing structure, type of irrigation system, growing medium, and seedling characteristics. Therefore, it is difficult to estimate the amount of water that a native plant nursery will require, but some water use data from conifer nurseries in the Western United States are provided in table 10.2.

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

Even in cases in which the nursery has access to a very steady, reliable, and high-quality municipal 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 a week (figure 10.6). 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.

FACTORS AFFECTING WATER AVAILABILITY TO PLANTS

After a good site with tested, reliable, high-quality water has been obtained, the next step in irrigation design is to understand the factors that affect water availability. 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 10.7A). After the seedling's roots occupy the container, however, transpiration becomes the primary force for water loss (figure 10.7B).

Several factors unique to container nurseries affect water availability. These factors include the types of containers, especially their volume (table 10.2), and the types of growing media. These factors make water management in a container nursery distinct from water management in a bareroot nursery, a garden, or other agricultural setting.

The type of growing medium has a large impact on 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 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 10.8). See Chapter 5, *Growing Media*, for more details on this topic.

Container type, volume, and shape also affect water availability. Water in a container behaves differently

Table 10.2—Typical irrigation use in forest and conservation nurseries for a crop of 1,000 conifer seedlings

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-tainers™ 4 in^3 (66 ml)	10 (38)	15 (57)
Mt. Sopris, Colorado	Ray Leach Cone-tainers™ 10 in^3 (172 ml)	15 (57)	50 (189)
University of Idaho, Moscow	Styroblock™ 20 in^3 (340 ml)	60 (227)	125 (473)

than water in unconfined soil because it does not drain completely, resulting in a layer of saturated medium at the bottom (figure 10.7B). 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 6.2).

The small top opening in some types of plant containers is important operationally because it is extremely difficult to distribute irrigation evenly between containers, which leads to considerable variation in growing medium water content. 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. Foliage interception is particularly serious for broad-leaved species.

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. These factors should be kept in mind when designing the irrigation system the plants will depend on to grow and survive.

Figure 10.7—*The amount and type of water use changes dramatically during the growing season. (A) During the establishment phase, a relatively small amount of water is used by evaporation but, (B) 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. In all containers, a layer of saturated media always exists at the bottom.* Illustration by Jim Marin.

Irrigation as a Cultural Treatment: Determining How Much To Irrigate

The next step is to determine how much water will need to be applied per irrigation event. The most important concept in container irrigation is to apply enough water during each event to more than saturate the medium so that a small amount of leaching occurs. This practice simply means applying enough water that some drips out the bottom of the container

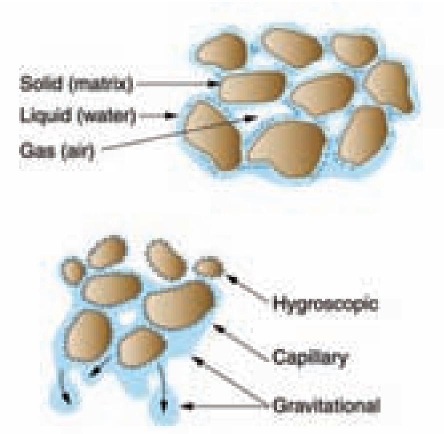


Figure 10.8—*Water is held in the pores between growing media particles by capillarity. For a given type of media, the larger the particles, the less water will be held.* Illustration by Jim Marin.

WATER USE CONSIDERATIONS FOR NATIVE PLANTS 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.
— Native plant containers are relatively small, and 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.

(although not so much that water streams out the bottom). Because of the unique properties of artificial growing media in containers (as discussed in Chapter 5, *Growing Media*), enough water must be applied to the surface to force the air out of the medium pores (figure 10.9A). If the irrigation period is too short, the water will never reach the bottom of the container. The result will be a perched water table with a layer of dry growing medium underneath (figure 10.9B). To avoid this result, it is important to always fully saturate the medium profile; otherwise, only the top part of the medium will be wetted. If the growing medium throughout the container is not completely saturated after irrigation, the seedling will never develop roots in the dry medium at the bottom of the container, resulting in a poorly formed plug. Another hazard is that fertilizer salts will accumulate in the medium and cause salinity damage or "fertilizer burn."

So, the general rule of thumb for sprinkler irrigation is to apply approximately 10 percent more water than is needed to completely saturate the entire growing medium profile during irrigation. The best procedure is to actually check to make sure that drainage is occurring during or immediately after irrigation by direct inspection.

IRRIGATION AND SEEDLING GROWTH PHASES

The amount of irrigation to apply varies during the growing season in a native plant seedling nursery because of the stages of seedling development and the horticultural objectives of the nursery manager. Because water is so essential to plant growth, the irrigation regime can be manipulated to control seedling growth. As discussed in Chapter 3, *Planning Crops and Developing Propagation Protocols*, plants go through three phases of development: establishment, rapid growth, and hardening. Irrigation is an important strategy for both manipulating and supporting 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 should be completely saturated. Thereafter, watering needs during establishment should be monitored carefully and tailored to the needs of the species. Some species such as quaking aspen, willow, and cottonwood require nearly continuous misting and may even benefit from a fog chamber. Other species may 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. Conversely, excessive irrigation may create overly wet conditions around the seeds for some species, promoting damping-off and/or delaying germination. For these reasons, irrigation should be applied on an as-needed basis as determined by the germinant requirements and by observation of the crop (figure 10.10). Remember that until the seeds germinate and begin to grow, the major water loss is from evaporation from the top of the container, not from water use by the germinating plants. 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 mistings or light irrigation as necessary with a very fine spray nozzle, which also protects germinating seeds from being moved or damaged by the force of the

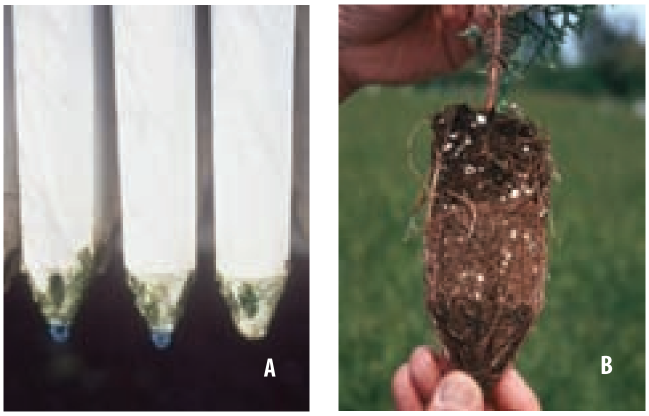


Figure 10.9—*(A) Apply enough water during irrigation to fully saturate the growing medium profile and permit some leaching out the bottom of the container; (B) insufficient irrigation will result in a "perched water table" within the growing media.* Photos by Thomas D. Landis.

water. In some cases, if seeds are mulched, irrigation may not be necessary for the first week or so of the germination phase. The water status of the medium can be checked by scratching through the surface of the mulch or grit and making sure the medium is moist enough.

Irrigation can also be used to control the temperature around germinating seeds. Germinants, particularly those covered by dark-colored mulches, can be injured by high temperatures on the surface of the growing medium. If temperatures exceed 86 °F (30 °C), light mistings will help keep germinants cool. This practice is sometimes called "water shading." These waterings should not add much water to the medium but are merely used to dissipate the heat from the mulch. After plants develop thicker stems, they become more resistant to heat injury. Water shading should not be used in nurseries with saline water or salts can build up in surface layers of the growing medium.

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 10.2, water use will double or even triple during the rapid growth phase. A tremendous amount of variability occurs between different native species. Full saturation is best for some species whereas others might benefit from periods of slight moisture stress between waterings. No plants should ever be allowed to dry out completely (figure 10.11). Nursery managers should be aware of the varying water requirements for the species grown and adjust their irrigation practices accordingly. Grouping species together by their water requirements ("wet," "moderate," or "dry") makes this practice much easier.

Another factor that comes into play during the rapid growth phase is the effect of foliage interception of water. 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. This "umbrella effect" is particularly serious with broad-leaved 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 almost no 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 below will help address this issue for broad-leaved species, particularly through subirrigation and/or 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 be concerned about the accumulation of salts. Remember that fertilizers are salts, too, and that injecting liquid fertilizers adds to the base salinity level of the irrigation water. Increases in salinity are a concern with controlled-release fertilizers as well because their release rate is controlled by water and temperature and salts can accumulate quickly in small containers. Frequent leachings with regular irrigation water ("clearwater flush") are 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 (see figure 10.2B).

Irrigating During the Hardening Phase

The manipulation of irrigation practices is an effective way to initiate the hardening of plants prior to storage or shipment. Because seedling growth is so critically tied to moisture stress levels, growers can

The key concept to irrigating during the establishment phases is to keep the growing medium "moist, but not saturated."

Figure 10.10—*During the establishment phase, watering should be tailored to the requirements of the species during germination and early growth. For many species, light irrigations as needed using a fine spray ("misting") provide enough water for germination and early growth and also protect the young germinants from heat injury. Overwatering must be avoided.* Photo by Thomas D. Landis.

Figure 10.11— *These quaking aspen seedlings are suffering from severe water stress due to 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.

affect shoot growth (slow or stop it by inducing bud set), increase general resistance to stress (especially water stress), and/or initiate the development of cold hardiness in many species of container plants by horticulturally 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 native plants because (1) dormancy and hardiness are affected by other environmental conditions, such as day length, (2) considerable variation in growing medium moisture content can exist between adjacent containers, so it is hard to achieve a uniform level of moisture stress, 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 example, Landis and others 1989) for monitoring container weights. Unfortunately, little is known about the response of most 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 should 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 10.12). Be sure to keep good 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 12, *Hardening*.

Irrigating for Frost Protection

In cold climates, irrigation can also be used for the frost protection of plants in open growing compounds. Container plants that are raised in outdoor growing areas or stored in sheltered storage may require protection against freezing temperatures in autumn or spring. Proper hardening procedures will help protect shoots against frost injury, but unusually cold weather can sometimes occur suddenly before the plants have had time to harden sufficiently. Roots do not achieve a high degree of cold hardiness and should always be insulated if plants are to be stored under exposed conditions.

Sprinkler irrigation protects against cold injury because heat is released when water freezes on the seedling foliage, and the ice layer provides some degree of insulation (figure 10.13). The main protection comes from the heat released from the freezing water, however, so this protective effect lasts only as long as irrigation continues to be applied. Irrigation should begin as soon as the temperature drops below freezing and continue until the ice is melted. Water is not effective in all freezing weather, especially in areas with advective frosts where dry, cold winds can actually drive the temperature down if water is applied. Therefore, growers must carefully monitor conditions before taking action. Some nurseries test their plants for frost hardiness and base their determinations of when frost protection should begin on these tests. Frost protection with sprinkler irrigation cannot protect against severe "hard" freezes, but agricultural crops have been saved in temperatures as low as 17 °F (-8 °C).

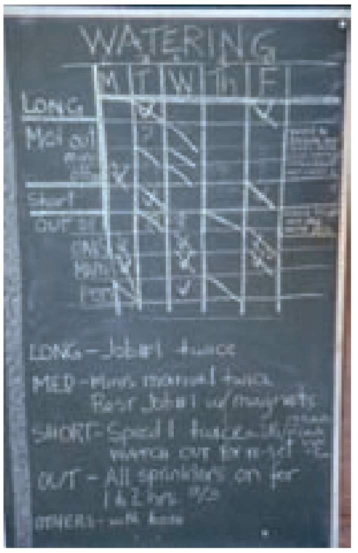


Figure 10.12—*Because so little is known about the response of most native plants to water stress, good scheduling, recordkeeping, and communication is critical in order to determine what the plants need.* Photo by Thomas D. Landis.

Detrimental Results of Irrigation on Plant Growth and Health

When not applied properly, irrigation can cause serious problems. Excessive irrigation leads to root diseases and fungus gnats and during hardening can delay the normal development of frost hardiness. On the other hand, applying a too-severe moisture stress treatment may actually inhibit the development of frost hardiness. The most common mistake is not adjusting irrigation for different growth phases.

Figure 10.13—*Water can be used to protect succulent plant tissue during unseasonal frosts in spring or autumn.* 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 to proper mineral nutrients at the proper concentration and at the proper time, fertigation has several advantages over other types of fertilization. See Chapter 11, *Fertilization*, for more information on fertigation and how it can be applied in native plant nurseries.

TYPES OF IRRIGATION SYSTEMS

The best method of applying irrigation water in container nurseries depends on the size and complexity of the operation and on the water requirements of the plants being grown. Small nurseries and those growing a variety of species may prefer hand-watering for irri-

Figure 10.14—*Hand-watering is often the best way to irrigate small lots of native plants in various types of containers and with different water requirements.* Photo by Tara Luna.

gation, whereas large nurseries growing only a few species of commercial conifers may use some sort of mechanical irrigation system, such as mobile overhead booms. Most native plant nurseries use a combination of systems in different watering zones to fulfill their irrigation needs, and these will be discussed one by one in the following sections.

Hand-Watering

Hand-watering is often the most practical irrigation strategy for small native plant nurseries or for nurseries producing a diversity of species with radically different water requirements (figure 10.14). Often hand-watering is also the best strategy for a nursery in the startup phase. After the different watering requirements are understood for each nursery crop, then, if desired, an investment can be made in appropriate irrigation systems to meet the plant's needs.

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 native plants in a variety of containers and at various growth stages is challenging. Nursery managers should make sure that irrigators have a conscientious attitude and are properly trained to work effectively with water application.

Good hand-watering practices include the following:

- Direct water to the roots of the plants.
- Avoid spraying the foliage to conserve water and preclude foliar diseases.
- Angle the watering nozzle straight down (not sideways) so the water does not wash out seeds, medium, or mulch.
- Use an appropriate nozzle type and water volume for the crops: 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 or washing out root 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 south-facing wall might need more water).
- 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.

Overhead Irrigation Systems

Overhead sprinkler systems are a common type of irrigation system and the kind that most people imagine when they think of irrigation. Many types of overhead irrigation systems exist, ranging from fixed sprinklers to moving boom systems. Fixed irrigation systems consist of a grid of regularly spaced irrigation nozzles and are popular because they are less expensive than mobile systems. Mobile systems have a traveling boom that distributes water to the crops, a system that works well but is too costly for most small-scale nurseries. The following section discusses two types of fixed irrigation systems: fixed overhead sprinklers and fixed basal sprinklers.

Fixed Overhead Sprinklers

Fixed overhead sprinkler systems consist of a series of parallel irrigation lines, usually constructed of plastic polyvinyl chloride 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.

Generally, the propagation environment is divided into irrigation "bays" or "zones" depending on the num-

HAND-WATERING

Advantages

— 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.

Disadvantages

—Is time consuming and labor intensive.
—Involves a daily responsibility; weekends and holidays do not exist for plants.
—Requires skill, experience, and presence of mind to do properly (the task should not be assigned to inexperienced staff).
—Presents a risk of washing out or compacting medium from the containers.
—Presents a risk of runoff and waste.

ber 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 from the manufacturer. Some sprinklers come in different coverages such as full-circle, half-circle, and quarter-circle, so that full overlap coverage can be obtained by placing irrigation lines around the perimeter of the irrigation bay. Each bay should be able to be separately controlled with a solenoid valve, which 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 so that species with differing water requirements can be grown 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 is balanced in terms of coverage and water pressure.

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 10.15A). Stationary nozzles (figure 10.15B) have no moving parts but distribute water in a circular pattern; these nozzles also come in half-circle and quarter-circle patterns (figure 10.15C). Mist nozzles are also sometimes installed on overhead irrigation lines and are primarily used during the germination period and for cooling and humidity control.

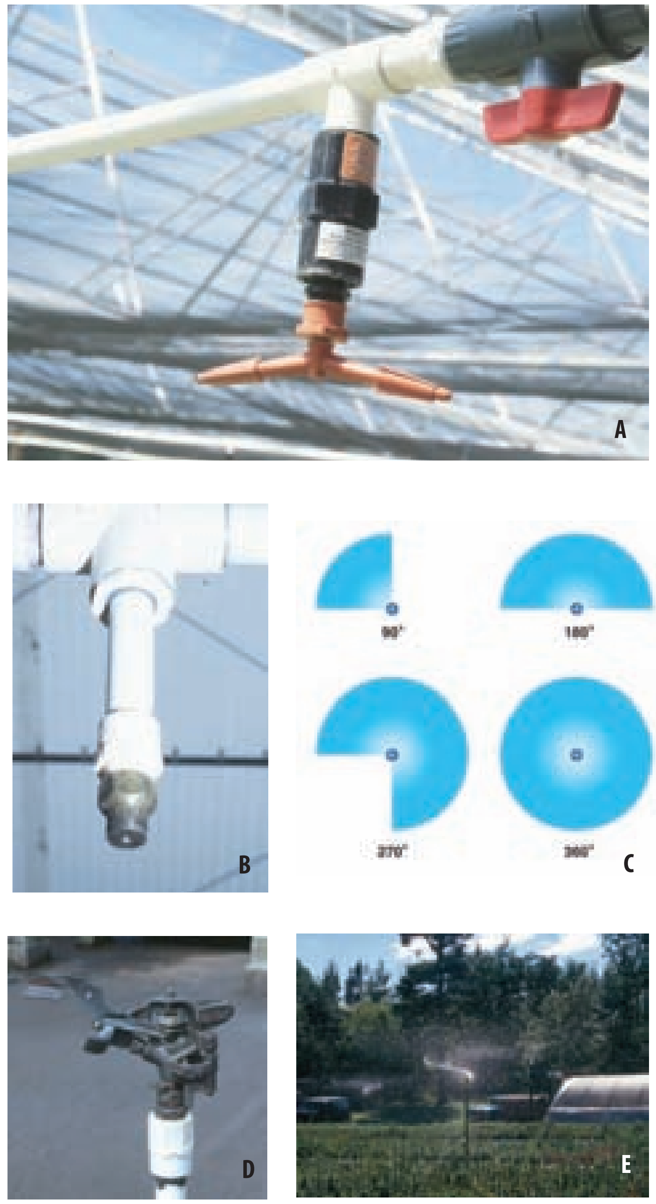


Figure 10.15—*(A) Both overhead and basal sprinkler systems feature rotating "spinners" or (B) stationary nozzles which, in addition to full circles, are (C) available in quarter, half, and three-quarters coverage. (D) Because of their greater coverage, rotating-impact (Rain Bird®-type) sprinklers (E) are commonly used in outdoor growing areas.* Photos by Thomas D. Landis, illustration by Jim Marin.

Fixed Basal Sprinklers

Basal irrigation systems are commonly used in large outdoor growing or holding areas. 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 (figures 10.15A and B) and rotating-impact nozzles (figure 10.15D) are commonly used. These sprinklers rotate slowly due to the impact of a spring-loaded arm that moves in and out of the nozzle stream (figure 10.15E). Rotating-impact sprinklers are available from several manufacturers in a variety of nozzle sizes and coverages. Because the impact arm is driven by the water pressure out of the nozzle jet, 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 that fewer nozzles and less irrigation pipe are required.

Moveable Boom Irrigation Systems

The most efficient but most expensive type of sprinkler irrigation is the moveable boom (figure 10.16A), which applies water in a linear pattern (figure 10.16B) and only to the crop. Moveable booms are generally considered too expensive for most small native plant nurseries but should be considered whenever possible. For more information, see Landis and others (1989).

Designing and Monitoring Fixed Sprinkler Systems

The efficiency of an irrigation system is primarily dependent on its original design. Uniform irrigation 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) effects 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 spacing and pattern of the sprinklers in fixed irrigation systems are related to sprinkler function and the effect of wind. The size of the sprinkler nozzle and its resultant coverage pattern can be determined by consulting the performance specifications provided by the sprinkler manufacturer. Container nursery managers should 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.

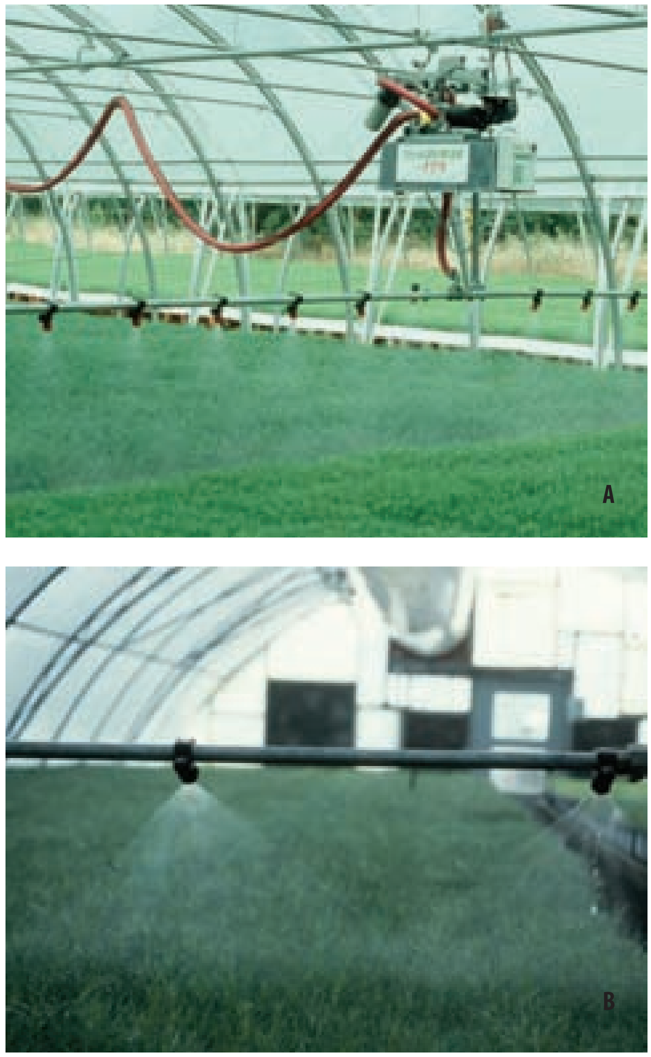


Figure 10.16—*(A) Moveable boom irrigation systems (B) apply water in a very efficient linear pattern but may be considered too expensive for many small native plant nurseries.* Photos by Thomas D. Landis

All types of stationary sprinklers throw water in a circular distribution pattern (figure 10.17A), so irrigation systems should be designed to provide adequate overlap between sprinklers. This consideration is especially important in shadehouses or outdoor growing areas where wind drift can be a problem (figure 10.17B). Too often, sprinklers are spaced at greater intervals in a cost-saving effort, but this practice is economically shortsighted considering the profound effect of water and injected nutrients on plant growth.

Because water pressure has such an effect on sprinkler function and efficiency, it should be checked regularly. Performance specifications for sprinklers at standard water pressures can be obtained from the manufacturer. The water pressure should be regularly monitored with a gauge permanently mounted near the nozzles (figure 10.17C) or with a pressure gauge equipped with a pitot tube directly from the sprinkler nozzle orifice. The pressure should 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. Water pressure that is either too high or too low can cause erratic stripe or doughnut-shaped distribution patterns (figure 10.17D).

Subirrigation

Overhead irrigation systems have always 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 native plants, especially those with broad leaves. Wide leaf blades combined with the close spacing of most containers create a canopy that intercepts most of the water applied through overhead irrigation systems, reducing water use efficiency and creating variable water distribution among individual containers (figure 10.18A). These problems can be precluded by subirrigation systems, which offer a promising alternative for native plant nurseries.

Subirrigation is a relatively new irrigation option. Subirrigation has been used to grow several species of wetland plants, but its applications are being expanded for many types of plants, including forbs (Pinto and others 2008), conifers (Dumroese and others 2006), and hardwood trees (Davis and others 2008). In subirrigation systems, the bottoms of containers are temporarily immersed in water on a periodic basis (for example, for a few minutes once a day). The water then drains away, leaving the growing medium thoroughly wet while the leaves remain dry. Subirrigation thereby bypasses the problem of large leaves intercepting overhead water and precludes other problems inherent in overhead irrigation.

All 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. Once the subirrigation tray is flooded, water will move up through the growing medium in the containers (figure 10.18B), with the extent of this movement dependent on the characteristics of the container and the growing medium, mainly the latter. The smaller the pores between the growing medium particles, the higher water will climb. Once the root systems are saturated (usually a few minutes), the water drains away. Thus, subirrigation is the practice of periodically recharging the moisture in the growing medium by providing water from the bottom.

Several different subirrigation systems have been developed but some, such as capillary beds and mats, will not work with the narrow-bottomed containers often used in native plant nurseries. A couple of others, however, have promise. For example, with ebb-and-flow or ebb-and-flood systems, containers sit on the floor in a shallow structure constructed from pond liner material surrounded by a raised border of wood or masonry.

Subirrigation trays, troughs, and bench liners are filled with water and drained after the growing medium in the containers has been saturated (figure 10.18B).

Either of these subirrigation systems should work for a variety of native plants. Although prefabricated subirrigation systems are available commercially, nurseries on a limited budget may consider designing their own systems using available materials. A trough system can be made out of concrete blocks and pond liner or out of prefabricated drainable plastic ponds.

SPRINKLER IRRIGATION SYSTEMS

Advantages

— They are 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."

Disadvantages

— Foliar interception makes overhead watering ineffective for large-leaved crops.
— Irrigation water can be wasted due to 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.

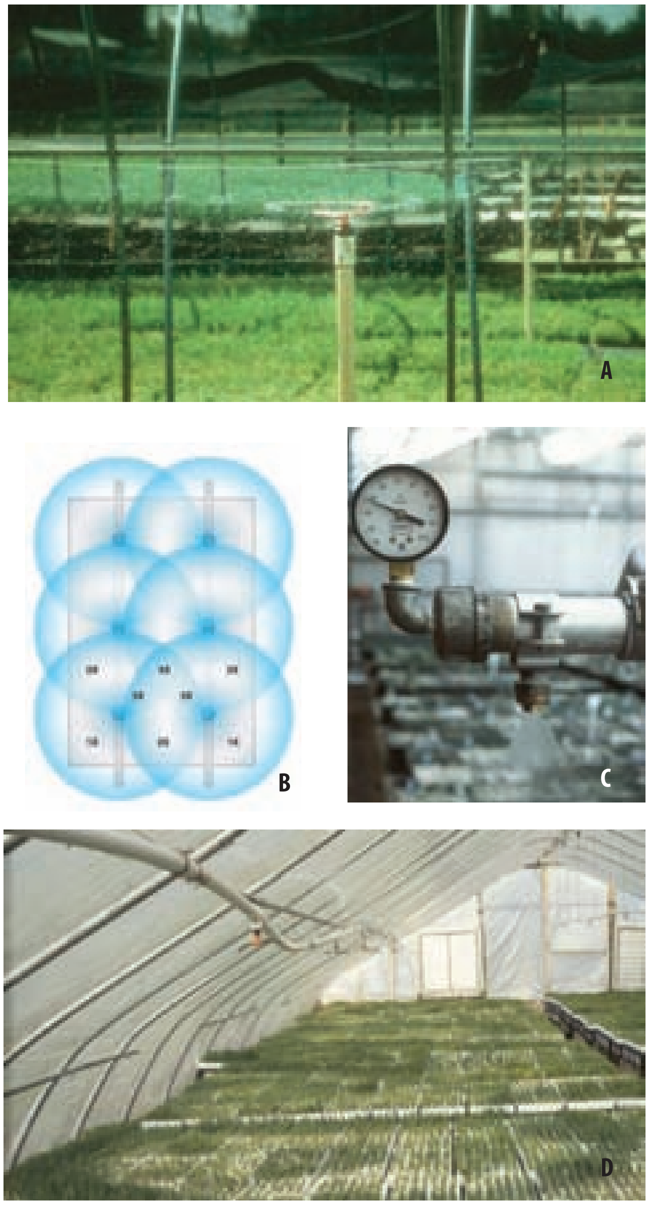


Figure 10.17—*(A) Because sprinklers produce a circular irrigation pattern, (B) proper spacing is critical to produce enough overlap. (C) The water pressure of irrigation systems should also be checked annually to make sure that nozzles are operating efficiently (D) before irrigation problems become apparent.* Photos by Thomas D. Landis, illustration by Jim Marin.

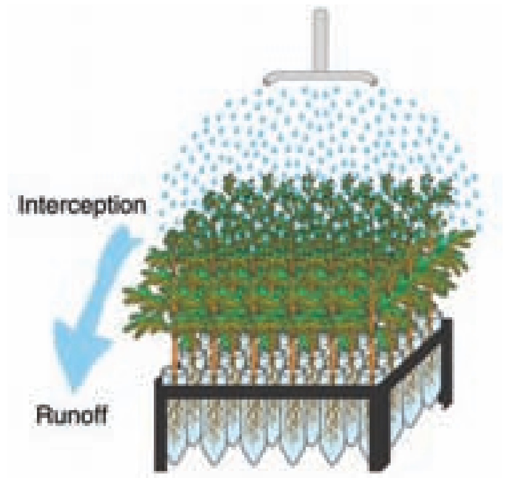
(Note: some materials, such as galvanized metal, are inappropriate due to zinc toxicity.) There are some important design considerations for subirrigation systems. The holes of the containers must have good contact with the water in order for the water to enter the container. Subirrigation may be less effective during the establishment phase, when 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 at first. Air root pruning is usually reduced with this system, resulting in a need for hand-pruning of roots and making this system inadvisable for use with very sensitive plants. Of the four irrigation systems mentioned in this chapter, subirrigation may require the most upfront planning and design work. Nevertheless, we think that it has very good potential for native plant nurseries.

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 poly pipe fitted with microsprayers (sometimes called "spitters" or "spray stakes") (figure 10.19A) or drippers (figure 10.19B) inserted individually into each container, sometimes with the use of small tubing to extend the emitters beyond the poly tube. 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 in order to prevent emitters from clogging. Because of the slow infiltration rate of microirrigation systems, each irrigation station will need to run a long time in order to deliver adequate water to plants. Also, if containers are allowed to dry out, hand-watering may be necessary to rewet the growing medium before drip irrigation will work.

Automating Irrigation Systems

Several types of automatic controllers are available, some using time clocks and one using container weight, so that irrigation can be automatically applied. This equipment allows the nursery manager to preprogram periods of irrigation and saves time and labor. The prudent grower, however, will never become com-



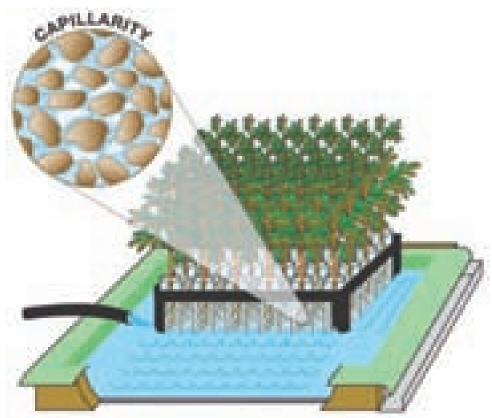


Figure 10.18—*(A) Overhead irrigation is ineffective for broad-leaved plants because so much water is intercepted by the foliage, called "the umbrella effect." (B) Subirrigation works because water is drawn upward into the containers by capillarity.* Illustrations by Jim Marin.

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

SUBIRRIGATION SYSTEMS

Periodic saturation with water supplied from below the containers followed by drainage of growing medium.

Advantages

—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 (up to 80 percent less than overhead watering systems) is efficient.
—Application among plants is very uniform.
—Lower fertilizer rates are possible.
—Reduced leaching of mineral nutrients is possible.
—Drainage water can be recycled or reused.
—No soil 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.

Disadvantages

—Overhead or hand watering may be required to ensure sufficient surface moisture until seeds germinate.
—No leaching occurs, so 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.
—Almost nothing is known about the response of most native plant crops to subirrigation practices.

Monitoring Water in Containers: Determining When To Irrigate

Determining the moisture status of the growing medium in most of the containers used in native plant nurseries is a challenge because it is difficult to observe or sample the medium in small containers. Some containers, such as the "book" type, can be opened up to allow direct observation of the moisture content of the medium. In other cases, it is difficult to ascertain whether plants are getting adequate water saturating throughout the root system. In spite of these difficulties, it is absolutely necessary to regularly monitor the moisture status of container growing media. The limited volume of moisture reserves in small containers means that critical moisture stresses can develop quickly.

Many types of equipment can be used to test and assess the effectiveness of water application. These tools include tensiometers, electrometric instruments, balances for measuring container weight, commercial moisture meters, or pressure chambers. Some of these tools are described in Landis and others (1989). Currently, no inexpensive yet accurate instrument is available to measure growing media moisture content in containers. Any method must be supported by actual observation

CHARACTERISTICS OF MICROIRRIGATION SYSTEMS

Advantages

—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 (due to slow delivery).
—The amount of leachate is also reduced.

Disadvantages

—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 due to slow water delivery.
—Emitters can plug easily (water filtration and frequent irrigation system maintenance is required).
—It is difficult to verify water delivery visually; often, problems are not detected until it is too late.

Figure 10.19—*(A) Spray stakes are effective only for larger containers and work well because you can see them functioning and they have more even distribution. (B) Drip emitters can also be used for larger containers such as these quaking aspen.* Photo by Thomas D. Landis, illustration by Jim Marin.

and the grower's experience; indeed, visual and tactile assessments are the most common method of monitoring irrigation effectiveness. This monitoring sometimes includes formal or informal assessments of container weight. Visual and tactile monitoring and monitoring with container weights are discussed in the following sections.

Visual and Tactile Assessment

Most nurseries successfully monitor the effectiveness of irrigation based on the feel and appearance of the plants and the growing medium (figure 10.20A). 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 10.20B). This process requires a lot of experience and is very subjective. In spite of its obvious limitations, the visual and tactile technique is still widely used and 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, however, 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 is reduced or eliminated.

Monitoring Irrigation with Container Weights

Developing a container weight scale requires a significant amount of effort and recordkeeping, but container weight is one of the few objective, non- destructive, and repeatable techniques for monitoring irrigation in container nurseries. Container weight is also the best way to determine irrigation needs early in the growing season before plants are large enough to show moisture stress or use in the pressure chamber. The weight of the container decreases between irrigations because the water in the growing medium is lost through evaporation and transpiration, and the crop is irrigated when the container weight reaches some predetermined level. Workers can develop an intuitive sense of this level based on picking up a few randomly spaced trays (figure 10.20). It

Figure 10.20—*(A) Joanne Bigcrane monitors the need for irrigation by careful observation of plant condition so that (B) water can be applied before plants are seriously wilted. (C) Feeling the weight of containers can also be an effective way to determine when to irrigate. (D) Monitoring container weights is a standard method to induce moisture stress in conifer crops..* Photos A-C by Tara Luna, D by Thomas D. Landis.

can also be done objectively, weighing containers on a simple household bathroom scale (figure 10.20D). Container irrigation weights will vary significantly between species due to the physiological response of different species to moisture stress.

In general, however, container weight will be used subjectively, based on experience. The person in charge of irrigation will develop a feel for the proper weight of containers or trays based on experience. As the person is learning this technique, he or she will need to verify his or her conclusions by examining the appearance of the plant's root system, growing medium, and leaves. Eventually, the visual and tactile method of directly observing the amount of moisture in the growing medium can be used to estimate available moisture levels, and the wilting point can be established by observing the turgidity of the leaves.

Assessing the Evenness of Irrigation Systems

A simple test called a "cup test" can be carried out periodically to evaluate the evenness of irrigation distribution. Both new and existing irrigation systems should be assessed periodically to see if they are performing properly. Existing irrigation systems need to be checked every few months because nozzles can become plugged or wear down to the point that they are no longer operating properly. The cup test measures the irrigation water caught in a series of cups laid out on a regular grid system throughout the growing

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.

Figure 10.21—*Periodic checks of water distribution can easily be done with a "cup test" in which cups are arranged in a grid pattern. The depth of water in them is measured after a standard watering period.* Photo by Kim M. Wilkinson.

Figure 10.22—*(A and B) Water can be conserved by many horticultural practices such as covering sown containers with a mulch or (C) reducing water loss with shade and straw bale insulation around the perimeter of the growing area. (D) Recycled runoff water can be used to propagate riparian and wetland plants or to irrigate surrounding landscaping or orchards.*
Photos A and D by Thomas D. Landis, C by Tara Luna, illustration by Jim Marin.

area (figure 10.21). 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.

Distribute empty cups evenly throughout the nursery irrigation station and run the irrigation as usual for a standard time period. Turn off the system and measure the depth of the water in the cups, which should be relatively even. If not, check pressure in the line and also check for clogs or problems with individual nozzles. If the test is done in a hand-watering system, the person applying the water can learn where the application is uneven.

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 very inefficient. 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 because 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 to stimulate the leaching of excess salts. Most pesticides are applied in a water-based carrier through the irrigation system, and some of these chemicals inevitably end up in the wastewater runoff; growing medium drenches are particularly serious in this regard.

Originally, it was thought that the soil filtered out or absorbed fertilizer salts and pesticides, but this belief has recently been refuted. Leaching tests in conifer nurseries have shown that excess fertilizer nutrients and pesticides drain out of containers and may contaminate groundwater. Maximizing the efficiency of irrigation systems and implementing water conservation strategies, such as the use of mulch, is the most effective way to handle the problem. When runoff is created, it can be collected for treatment and/or redirected to landscaping or other crops for absorption by other plants.

Table 10.3—Native plant nurseries should incorporate a variety of horticultural practices to use irrigation water effectively and efficiently

Nursery Practice	Conservation Effect
Mulches (figure 10.22A and B)	Reduce evaporation from the surface of the growing medium; the larger the container the greater the savings
Windbreaks (see figure 1.12)	Reduce water loss and seedling stress due to wind
Remove cull plants and minimize space between containers, including aisles	Reduce wasted water and resultant runoff
Shadecloth and shadehouses (figure 10.22C)	Reduce water use for species that don't require full sunlight
Catch runoff and recycle water (figure 10.22D)	Can save considerable amounts of water, and reduce fertilizer use as well

Good irrigation design and application minimizes the amount of water used while providing for the needs of the plants. Several horticultural practices can help conserve water and reduce water use and runoff in the nursery (table 10.3).

The direct recycling of used nursery water is generally not done on a small scale because of the expense of water treatment and the risks of reintroducing excess salts or pests. However, these kinds of capture-and-recycle systems for nursery runoff water may be economically viable in very water-limited areas. Less high-tech options for water reuse can make use of an impermeable nursery floor (pond liner, for example) to collect water runoff from the nursery. This water can be stored in a 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 tree crops, can all benefit from receiving nursery runoff water for irrigation. Generally, in these cases, an additional sandbed or filter is used to strain the particulates out of the water before running it through an irrigation system to these crops. 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.

SUMMARY

Because of the overriding importance of water to plant growth, managing irrigation is the most critical cultural operation in native plant nurseries. Water must be managed differently in container nurseries growing systems (in comparison with agricultural crops, gardens, or bareroot nurseries) because of the restrictive effects of the containers. Growing media composed of materials such as peat moss and vermiculite have different properties than soil, including a higher water-holding capacity. The container also has an effect on the water properties of the growing medium because water does not drain completely out of the container, which results in a layer of saturated media at the bottom. The depth of this layer is a function of container height and the properties of the growing medium.

The quantity and quality of the irrigation water is probably the most important consideration in site selection for a nursery. Sufficient quantities of water must be available throughout the year to supply all the various uses at the nursery. The quality of the nursery irrigation water is primarily a function of the concentration and composition of dissolved salts, although the presence of pathogenic fungi, weed seeds, algae, and pesticides must also be considered. Because water treatment is impractical and costly in most instances, irrigation water sources should be thoroughly tested during nursery site selection. Most plants are very sensitive to soluble salts, so water should be tested at all stages of the irrigation process at regular intervals during the growing season.

In general, four types of irrigation systems are appropriate for native plant nurseries: hand-watering, overhead sprinklers, subirrigation, and microirrigation. Optimal irrigation system design usually creates several irrigation zones to meet the unique needs of the diverse species of plants and to cater to their changing needs as they pass through each phase in their growth and development. Each type of irrigation system has advantages and disadvantages as well as important design considerations. For new native plant nurseries, hand-watering may be the most practical strategy during the start-up phase until the plant's needs are thoroughly understood. Every irrigation system must be tested periodically to ensure that it is working properly.

Determining both when and how much to irrigate is one of the most important day-to-day decisions of the nursery manager. Because of the physical limitations of small containers used in nurseries, there is currently no way to directly monitor the water potential of the growing medium within the container. Experienced growers develop an intuitive skill for determining when irrigation is required, using the appearance and feel of the growing medium and the relative weight of the container. Because of the restrictive drainage characteristics of containers, growers must apply enough water during each irrigation event to completely saturate the entire volume of growing medium and flush excess salts out the bottom of the container. The amount of water supplied at each irrigation period is a function of the growth stage of the plants and the environmental conditions. In addition to promoting rapid germination and growth, water can be used as a cultural tool to help harden the plants and induce dormancy. In cold climates, irrigation can be used for frost protection of plants in open growing compounds.

Because of the excess amounts of irrigation required and the poor efficiency of some irrigation systems, the disposal of wastewater is an important consideration in nursery management. Injected fertilizer nutrients, such as nitrate nitrogen and phosphorus, and pesticides applied through the irrigation system may affect groundwater quality and could become a serious problem. In addition to the importance of collecting and managing runoff, practices to conserve water, such as mulching and efficient nursery design, are important for ecologically sound nursery management.

LITERATURE CITED

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

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(1):4–13.

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.

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.

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 42:897–901.

APPENDIX 10.A. PLANTS MENTIONED IN THIS CHAPTER

cottonwood, *Populus* species
quaking aspen, *Populus tremuloides*
redosier dogwood, *Cornus sericea*
rushes, *Juncus* species
willow, *Salix* species